HEALTHY FLOODPLAINS

Building the river system model for the Gwydir Valley regulated river system

Model conceptualisation, construction and calibration

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Executive summary

Water management in NSW (and globally) relies on (numerical simulation) models to provide robust and reliable estimates of what water is available, how much is needed, and how the resource can be equitably shared. The Department of Planning and Environment Water (the department) manages the river system models that have been developed for this purpose. A model exists for each of the regulated Valleys in NSW. These models are being extended (or rebuilt) to determine volumetric entitlements for floodplain harvesting consistent with the NSW Floodplain Harvesting Policy.

This report describes the rebuild of the Gwydir Valley river system model – its conceptualisation, construction and calibration. It includes sections that describe the valley (Section 3), and how it has been represented in the model. This extends beyond the physical components of the river system (Section 4) to water licensing (Section 5), water users (Section 6) and water management (Section 7). The model developers describe their approach to the modelling, following, and adapting, contemporary, industry-standard modelling practices (Section 2).

Model results that report the performance of the model are presented in Section 8. In all cases, the model developers provide comment on the results including implications for overall model performance. Where uncertainty in the result has been assessed as being of significance, sensitivity tests have been developed and run, and the results of these tests are reported in Section 9. Section 10 concludes the report by summarising (a) how the model has addressed (and met) the design criteria (established in Section 1) required to meet the modelling objective of being able to determine floodplain harvesting entitlements using an extended river system model; and (b) recommendations for further data collection to reduce residual uncertainty in the model. Extensive supporting material is provided in 7 appendices. Key findings and messages from the model build process are now described in some more detail.

Modelling approach

The Gwydir Valley river system model is designed to support contemporary water management decisions in the Gwydir Valley, whether it is a rule change in the water sharing plan, or estimating long term average water balances for components such as diversions for compliance purposes. It has 2 overarching objectives: (1) to support traditional water policy, planning and compliance uses, such as implementing the Basin Plan and estimating plan limits, and (2) to determine volumetric entitlements for floodplain harvesting. Six design criteria were established to realise these objectives (in Section 1): represent key processes affecting water availability and sharing; use a sufficiently long period of climate data to capture the climate variability; have detailed spatial resolution to allow system analysis and reporting at multiple spatial scales; use a daily time step to enable flow variability assessment and reporting at multiple time scales; represent historical usage on a seasonal basis at sufficient spatial representation to allow for equitable sharing; and provide a pathway to update and improve accuracy (i.e. be update-able and extensible).

Building the model in the IQQM software provided sufficient functionality to simulate the process of water moving out onto floodplains and meet the design criteria. The model was built by connecting IQQM node and link components (in-built or coded by the model developers) to represent a full river system, including its floodplains. These components were then populated (parameterised) with data, in most cases specific to the Gwydir Valley, but where local data were not available, from other parts of NSW and/or the literature. The model enables a water balance assessment accounting for inflows and outflows at multiple scales (daily, seasonal, annual; property, river reach, whole-of-valley).

Simulating a perfect water balance at individual property scale is only possible with fine temporal and spatial data on water movements to and from floodplains and property management practices, and how these might change in response to licensing of harvesting of floodplain water. These data are not yet available – to compensate, we undertook a multiple lines of evidence approach to assessing floodplain harvesting. We used a **capability assessment** to consider the physical infrastructure used for floodplain harvesting and also the opportunity irrigators may have to access floodplain flows based on their location and climatic variability. We also used a water balance assessment given historical crops grown and the estimated water requirements. This assessment focuses on the reach and valley scale to ensure that the total volume of water including historical metered use and estimated floodplain harvesting is representative of the estimated historical water use.

Modelling flows

Rainfall–runoff models have been used to simulate the conversion of rainfall into streamflow. The Gwydir Valley has an extensive network of climate and river gauge stations and 31 models (one for every reach in the model) were built and calibrated to reproduce historical flows. **Effluents** (i.e. rivers/streams that flow out of a river, often only at high flows) and **breakouts** (i.e. the points where the river spills over onto its floodplains) provide the water for properties to access floodplain harvesting. Breakouts and effluents are modelled explicitly using relationships estimated from multiples lines of evidence including surveys, hydraulic modelling, remote sensing and gauged flows. Modelling of the major **water storage** (Copeton Dam) and re-regulating weirs simulate physical processes (e.g. effect of evaporation on the storage volume) and operating rules.

Modelling water sources and licensing

The main licence categories of high security, general security, and supplementary access licences are configured for relevant water users, and regulate access to the water sources in the Valley. Water sources are then labelled as regulated, supplementary, floodplain harvesting, unregulated and ground water. Modelling of these components is very complex and involves the sharing of water between consumptive and environmental requirements, the allocation of water to licences, staged flow threshold rules, together with the ordering and delivery of water through the system. The water available for **floodplain harvesting** for water users is simulated through the breakouts and rainfall–runoff. Harvesting of **rainfall–runoff** water is embedded in the crop water model included for each property which calculates runoff based on soil moisture and rainfall. **Unregulated diversions** are mostly recognised inherently in the gauged inflow data and/or flow–loss relationships. **Groundwater** is included in the Gwydir Valley model where use of groundwater has been identified for floodplain harvesting properties on the regulated river system.

Modelling water users

Water users include urban areas, irrigators, the environment, and water for stock and domestic supply. **Town water supply** volumes are represented using fixed monthly patterns. The volumes are very small in relation to other water users and are not included in the results.

The largest water users are (mainly cotton growing) **irrigation properties** in the floodplain areas along the Gwydir River, Mehi River, Moomin Creek, and Carole-Gil Gil Creek system. Those properties, or groups of properties where they are jointly operated, assessed as eligible for floodplain harvesting entitlements are represented as an individual Irrigator water users in the model. The remaining, generally smaller, properties are aggregated within the river reach where they are located. The most contemporary and detailed sources of information were used to parameterise each irrigation water user. These included information on farm infrastructure such as historical and current river pump capacities, areas developed for irrigation, area planning decisions and irrigated crops for the period 2003/04 to 2012/13 made available through the Floodplain Harvesting Property farm surveys and from the Natural Resource Access Regulator (NRAR); and LIDAR data to derive on-farm storage volumes and surface areas. The modelling can be split into 5 components: a) modelling of on-farm storages and their use for irrigation, simulated based on demand; b) modelling of crop area planting, simulated based on a relationship with water availability; c) modelling of crop water use using embedded crop models that order water based on crop growth and soil moisture balance; d) harvesting of rainfall–runoff simulated from fallow, irrigated crop and undeveloped areas, using the same soil water balance component of the crop model; e) overbank flow harvesting into the on farm storage.

Until more information is available on how **Held Environmental Water** is to be used, it has been modelled as a consumptive use that assumes an irrigation demand pattern. **Stock and domestic** replenishment flows are represented as a demand at the pump site where water is transferred to Thalaba Creek. The model orders water to meet this demand from Copeton dam where it cannot be met by supplementary flows.

Modelling water management rules

IQQM has functionality to assign and track the ownership of water throughout the model network. The **continuous accounting system** used in the Gwydir Valley is modelled to represent operational practice as closely as possible.

The effects of **water trading** are explicitly represented in the model for permanent trade, and in some instances for temporary trade where it has been observed to occur consistently. Where water trading is not able to be represented in the model, it is taken into account when assessing model results. **Environmental flow** rules to represent environmental releases are configured in the model.

The operations of major storages, including re-regulating weirs, are represented in the model.

Model performance

Results have been selected to report on the calibration of the model, and the performance of the overall model. For flow calibration, this focussed on being able to replicate important parts of the flow regime. Overall performance is measured by comparing to recorded data such as flows, metered diversions and irrigated areas.

Statistics and plots for key model components under conditions as at 2008/09 and as configured to meet Plan Limit give confidence that the structure and parameterisation of the model are sufficiently capturing the physical and management processes necessary to meet modelling objectives.

Mean annual and inter-annual variability of flows are well reproduced for headwater inflows and main river flows.

Simulation of irrigation water use was tested against other models or data sources (e.g. Australian Bureau of Statistics). These sources all provided estimates similar to the model, providing confidence in the model.

Simulation of **rainfall–runoff harvesting** for the individual irrigation water users represented in the Gwydir Valley model is based on a relatively simple daily soil moisture model. Long-term averages and annual depths show a clear (and expected) relationship between runoff depth and rainfall. Further data collection is required at farm scale to confirm assumptions used in the modelling, and address what is an area of significant uncertainty in the model.

Overbank flow (for harvesting) depends in part on modelling of frequency and volume of events. Simulation of the number of moderate flood events and events above the commence-to-break flows reasonably match observed.

Farm water balance (i.e. total irrigation water use) was checked at 3 spatial scales. At valley scale, metered diversion results closely match observed. Reach scale indicates that the distribution between reaches is reasonable – again the results match well. At property scale, there can be many variations in water use and efficiency so water balance assessment at this scale was used with caution. We undertook sensitivity testing to understand whether farm scale assumptions caused a significant impact on floodplain harvesting results and generally found low sensitivity.

Seasonal variability of **planted areas** agreed well with those observed by remote sensing and reported in the farm surveys, although there were significant differences in some years.

The model closely simulates **metered diversions** over the validation period with differences on an annual basis attributable to the variations between observed and simulated crop areas.

Total **storages volume** patterns over time match reasonably well with observed. Differences could be due to variation in planted areas, varying crop watering practices, or simulated floodplain harvesting.

Summary

This report captures the considerable body of intellectual effort and modelling expertise that sits behind the construction of the Gwydir Valley river system model. It reports on the modelling approach adopted, how the component parts were put together, and reports outcomes. Significant effort went into understanding how sensitive model results were to uncertainties in climate and flow data, diversion data, model assumptions and simplifications, and model parameters; with the aim of reducing these uncertainties where possible, either through access to better data, improved parameterisation, or re-configuration of the model.

The results show that the most significant diversions in terms of long-term averages in the regulated Gwydir Valley river system are general security, followed by overbank flow harvesting (which is now slightly higher than supplementary access), and lastly on-farm rainfall–runoff harvesting.

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1 Introduction

The Department of Planning Industry and Environment – Water (the department) has developed a new river system model of the Gwydir Valley (the Gwydir Valley model). The model is a complete rebuild in IQQM of an earlier departmental IQQM model and takes advantage of additional data and improved methods.

We use river system models for many policy, planning and compliance uses. One key use for the new model is to determine floodplain harvesting entitlements[1] consistent with the 2013 NSW Floodplain Harvesting Policy (the policy) as revised September 2018.

1.1 Report objectives

Gwydir communities and regulators need to be confident that the modelling underpinning the determination of floodplain harvesting entitlements has been undertaken using best available information and modelling practices. They also need confidence that the model is the best available for other intended purposes such as assessing compliance to water use limits set by the Water Sharing Plan for the Gwydir regulated river water source (Gwydir WSP). This report has been written to underpin that confidence.

The Gwydir Valley model provides support to more than floodplain harvesting. Floodplain harvesting takes place within the context of all other processes operating within the Gwydir valley; including climate conditions, streamflow generation, water storage, water sharing rules, diversions, accounting. The report describes how, and how well, the model represents all these processes.

The following sections of the report describe relevant physical water-related processes and their management in the valley, the information available and its use, modelling approach, and how well the various components, as well as the complete model, perform.

1.2 Report structure

The report structure follows the modelling steps. It provides detail on how the model was built, starting with a description of the Gwydir Valley, the information available to inform the model, our design approach to building these river system models, and model results relevant to assessing model performance (Figure 1).

[1] An access licence entitles its holder to specified shares in the available water within a specified water source, known as the share component. The shares specified in an access licence can also be referred to as an entitlement and are expressed as share components or megalitres per year. You will see both 'licence' and 'entitlement' used in this report.

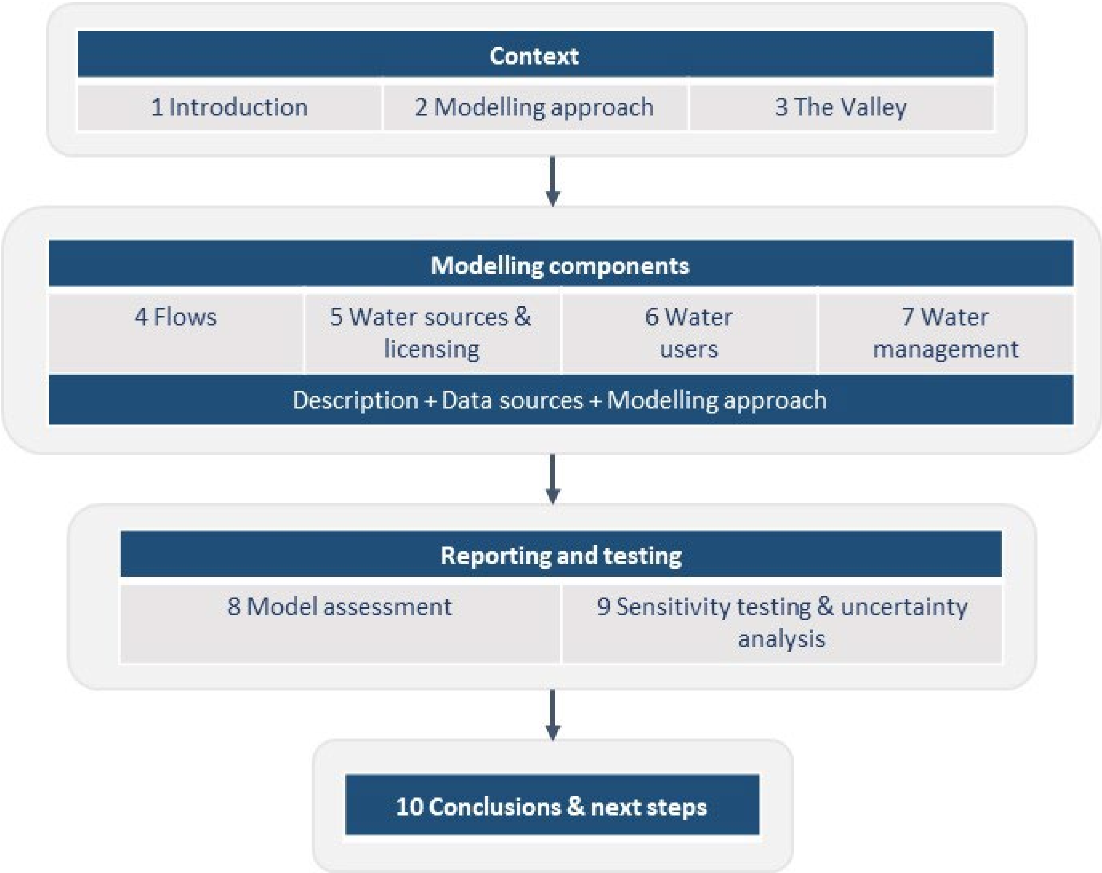

Figure 1 Report structure

Section 2 describes the modelling approach that we have adopted – the objectives for the modelling, the software that we have used, and overviews the modelling phases.

Section 3 introduces the Valley to provide the context for how we have characterised the Valley for modelling.

Sections 4 to 7 contain the details of the modelling, grouped to make for consistent navigation through the valley's:

- physical environment affecting flows
- water sources and licensing
- water users
- water management.

These sections detail the data available to describe the key components of the Valley, how we assessed what data to use and how it was used in the modelling.

In Section 8, we present the results of the modelling, focussed on simulation of headwater inflow and main river flow, water use, and modelling of the water use limit permitted under the *Gwydir WSP*.

Uncertainty analysis and sensitivity testing of key parameters, input data and modelling assumptions are important steps in modelling practice. These are discussed in Section 9.

Section 10 concludes with an assessment of the model suitability against its specific objective of floodplain harvesting entitlements determination. The section includes recommendations for further work to improve the accuracy and capability of the model, particularly the need for more suitable data.

The report contains a large set of appendices to support the report content. These include descriptive information (e.g. identification of rainfall and gauging stations used for the modelling) through to detailed modelling results. They provide extensive documentation and demonstrate the complexity and extent of work involved in building the model.

It is our intention that this report demonstrates our understanding of the river system being modelled, that we have collected the best, readily available and suitable data to build a model that meets the specified objectives, and that our approach to develop the model was sound. Our goal is to provide full transparency. We welcome further enquiries on this work, allowing our stakeholders to have confidence in our work and results.

1.3 Companion reports

This report describes the building of a baseline model for the Gwydir Valley.

How the model has been used to update the long-term average annual extraction limit (Long Term Average Annual Extraction Limit or *Plan Limit*) set by the *Gwydir WSP*, and calculate floodplain harvesting entitlements to bring total diversions back within that limit is described in companion report *Floodplain Harvesting entitlements for Gwydir Valley regulated river system: model scenarios* (DPEDPE Water 2021a).

The use of the model results for predicting potential environmental outcomes is described in companion report *Environmental outcomes of implementing the Floodplain Harvesting Policy in the Gwydir Valley* (DPEDPE Water 2021b).

The three reports together serve to describe how the modelling meets the objectives of the NSW Floodplain Harvesting Policy.

2 Modelling approach

This section describes the modelling approach used to construct a Gwydir Valley model.

While the modelling steps are set out here sequentially, some of the steps can run in parallel, and they are of course iterative as insights or limitations encountered in a step can result in re-working previous steps. The overarching goal is to ensure the model is only as complex as it needs to be to meet its purpose. The modelling described in this report needed to provide information at both a valley scale and irrigation property scale. Assumptions and presumptions are made in this process and we have attempted to document them to the best of our ability in this report.

The model has been developed using department standards and guidelines for good modelling practice. These are constantly refined over time and we also contribute to broader modelling guidelines[2]. Our practice, particularly in regard to assessing data quality, is described in Appendix A.

2.1 Modelling objectives

River system models have been used for several decades to determine water availability, flows and diversions under varying climate conditions, as a critical step in informing the development of water sharing arrangements. The Gwydir Valley model is designed to support contemporary water management decisions in the Gwydir, whether it is a rule change in the *Gwydir WSP*, or estimating long term average water balances for components such as diversions for compliance purposes. It has two overarching objectives, being to:

- support traditional water policy, planning and compliance uses, such as implementing the Basin Plan and estimating plan limits
- determine volumetric entitlements for floodplain harvesting.

Six (6) criteria were established for the design of the model to enable it to meet these objectives. How well these are met is reported in Section 10.1.

Table 1 Model design criteria to meet modelling objectives

	The model must:
1	**Represent the key physical and management processes that affect water availability and sharing within the river system, at a sufficient spatial scale to estimate floodplain harvesting volumes and entitlements at irrigation property level** • Essential to enable the conceptualisation and model execution to meet the other design criteria

[2] https://wiki.ewater.org.au/display/SC/Australian+Modelling+Practice

The model must:

2 **Run over years that capture the climate variability (wet and dry periods)**

- This is required to be able to understand how the water balance varies in wet and dry periods, and so demonstrate that the Valley meets statutory diversion limits (SDLs) as set out in the Basin Plan. Modelling using long periods of climate records that capture a wide range of wet and dry periods is an important way of understanding the effects of Australia's particularly variable climate on river flows and water management arrangements. The Basin Plan requires the assessment of diversions over the period 1895–2009 for calculating SDLs and Baseline Diversion Limits.
- (NOTE: The Gwydir Valley model has been built in a way that enables consideration of impacts from climate change scenarios, however this was not needed for this project, nor for current statutory requirements.)

3 **Report at multiple spatial scales (farm to whole-of-valley)**

- Simulate processes at a suitable spatial resolution to allow **checking of performance** and behaviour of individual components, to allow **aggregation** to report on up to whole-of-valley outcomes, and to support equitable sharing of floodplain harvesting volumes and entitlements at **farm scale**

4 **Report at multiple time scales (daily to annual)**

- Simulate model processes on a **daily** basis so as to properly represent flow variability at a resolution important for ecosystem processes, water management rules, water access (e.g. to high flows for irrigated farms) and other statutory reporting requirements; and to allow **aggregation** to report on up to **annual** outcomes

5 **Capture historical usage on a seasonal basis, at reach and valley scale**

- Simulate **annual water use** under a range of climatic conditions to support statutory requirements. This is required for Annual Permitted Take assessment as part of *Basin Plan* reporting requirements

6 **Be update-able and extensible**

- that is the model can be updated and new functionality added as and if new and better data and methods become available

In the case of the Gwydir Valley river system model, meeting these objectives and criteria required extensive redevelopment and enhancement of the earlier departmental model (IQQM) which was built for a different purpose, primarily to model in-channel diversions.

2.2 Type of model and modelling platform used

The models that are used by the department to underpin water management in NSW are quantitative, simulation models. Simulation models are widely used in water resources management to improve understanding of how a system works and could behave under different conditions.

The Gwydir Valley model has been built using updated versions of the IQQM software, continuing on from the model also previously built using the IQQM software (Simons 1996).

2.3 Modelling steps

After we understand key aspects of the river system through model conceptualisation and assess the available information, a model of the system can be constructed. The IQQM software platform contains a variety of model components that represent different processes, such as inflows, water storage, water movement, crop demands and environmental flow rules, that can be connected together, progressively, to represent a full river system.

These components all have many attributes that are configured to represent the relevant aspect of the river system, a process known as parameterisation. The parameterisation process is described in Section 2.3.4.

The model build process requires the model inflows and outflows to be accounted for at all scales. The model is built systematically using a number of stages. The concept of a water balance, stages of model building and scales of model building are described in Section 2.3.1 to Section 2.3.3.

2.3.1 Water balance

A water balance is a common approach in hydrology based on the conservation of water in a particular river system. This means that all the inflows, outflows, or changes in water stored must balance over a given time step, whether one day or one hundred years. This is useful when we know most of the inflows and outflows and have one unknown that can be solved to make the system balance each time step.

Water balance assessments are used to estimate various model components such as ungauged inflows to storages or river reaches and unmetered water use. Components of the water balance at irrigation farm, river section (known as a reach) and valley scale are visualised in Figure 2, Figure 3 and Figure 4 respectively.

2.3.2 Stages of model building

As the total number of parameters in the model is large, a systematic, multi-stage process is used to progressively parameterise valley-scale surface water models. Many stages can be completed independently from each other, but they are subsequently combined together in an assembly sequence that is outlined in Table 2. This sequence recognises which stages rely on the results of previous stages. As recorded data are progressively replaced with simulated data during the model assembly process, simulation results are re-checked at each stage, and adjustments made to parameters where necessary.

The river system is divided geographically into river reaches for the initial four stages for practical and methodological reasons. The practical reasons are the sheer complexity of the whole river system and the computing time for this. This subdivision also allows more people to work concurrently on the model.

This approach manages uncertainty by firstly setting observed data as a boundary condition for most of these stages, and varying parameter values of the component models to calibrate their response to match observed data, whether this is matching observations, a prior estimate, or system behaviour more generally. Once parameter values have been calibrated, the observed data are progressively replaced with calibrated parameters, and outputs validated.

Table 2 Stages of model assembly

Stage number	Process	Modelling approach section
1	Climate	Sections 4.2.2 and 4.3.2
2	Directly gauged inflows	Subsection in Section 4.4.2
3	Indirectly gauged inflows and losses	Subsection in Section 4.4.2
4	Irrigation diversions	Subsection in Section 6.2.2
5	Irrigated planting areas	Subsection in Section 6.2.2
6	Supplementary access diversions	Subsection in Section 5.3.2
7	Water management	Subsection in Section 7.1.2
8	Storage operation	Subsection in Section 7.5.2

2.3.3 Scales of model building

Farm scale

The farm scale is the computational unit with the greatest complexity, combining several physical and management processes. The main water balance components of the farm scale water balance are illustrated in Figure 2 for the 4 principal areas of an irrigation farm. The focal point for most of these farms is the on-farm storage(s) (A) which regulate the water at this scale. Most of the water that enters the farm is stored, before being used later to meet crop water requirements. The exception to this is rain that infiltrates into the soil (6).

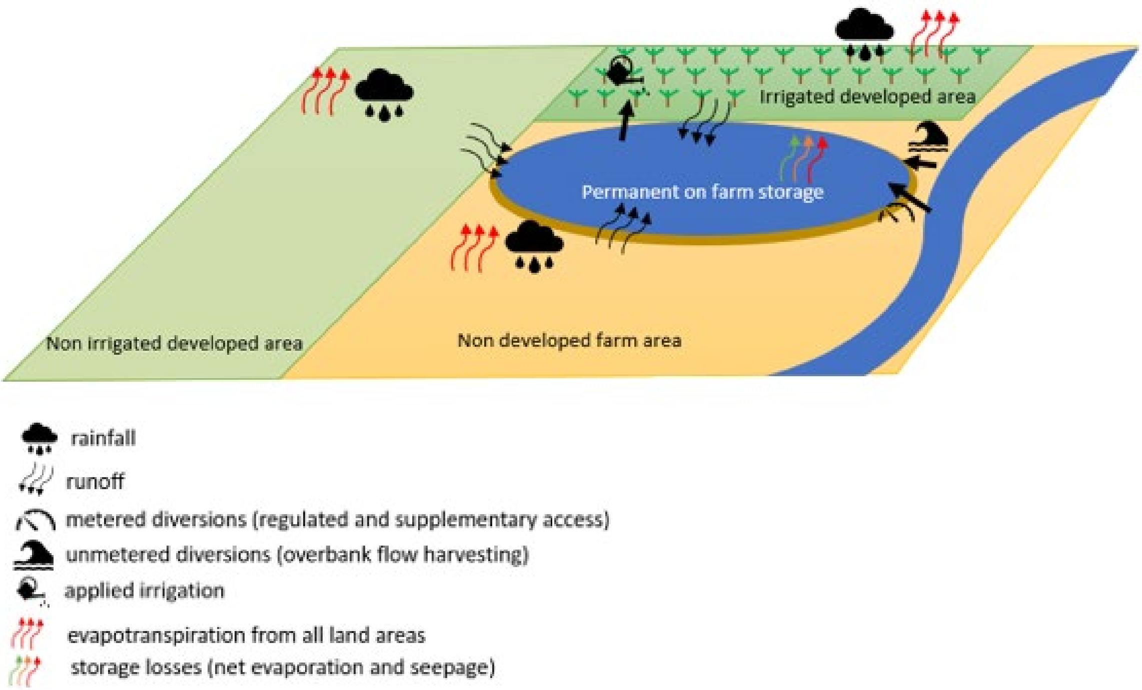

Figure 2 Farm scale water balance components

Modelling the on-farm water balance provides an understanding of the **total volume** of water required to meet irrigation demands based on the area of crops planted.

When unmetered diversions are not actually a significant component of the on-farm water balance, metered diversions can be assumed to represent the surface water diversions for irrigation purposes.

Where unmetered diversions such as floodplain harvesting are a significant component of the on-farm water balance, modelling the total irrigation demand (referred to as crop modelling) allows us to estimate the additional unmetered diversions through subtraction of metered diversions. This estimate of total irrigation demand using crop models provides an estimation of the take from rainfall–runoff harvesting and floodplain harvesting.

We would not expect a perfect water balance to be achieved at all individual properties due to a number of uncertainties (such as different management practices) at that scale. We place more emphasis on ensuring that the reach and valley scale results make sense in terms of historical production. We use multiple sources of information to configure floodplain harvesting access, rather than relying on perfect water balance at individual properties.

The estimation of these components is described in Section 6.2.2.

Reach scale

The reach scale allows for the combining of the sources of water availability (principally inflows) with the largest source of consumptive water demand – the irrigation farms. The reach water balance is illustrated in Figure 3. Note that depending on the physical characteristics of the reach, some components may be negligible or zero, e.g. in upper reaches breakouts or irrigation diversions may not exist.

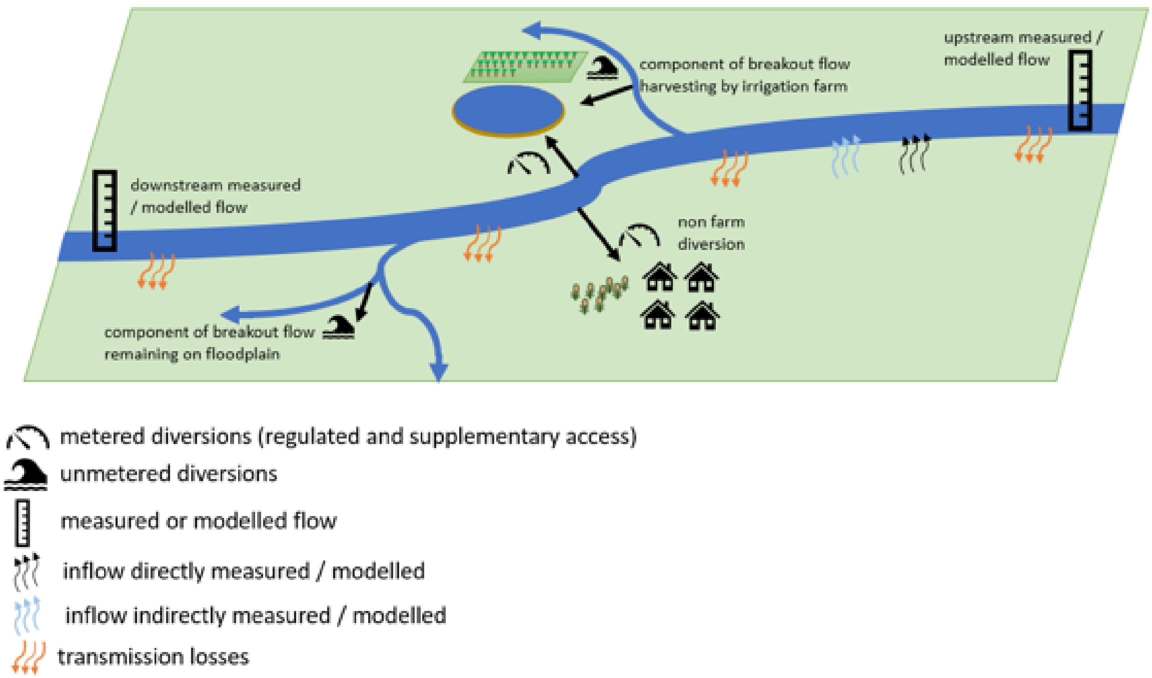

Figure 3 Reach scale water balance components

Valley scale

The complete river system is an assemblage of the reach calibrations, to which is added the management arrangements operating in the river system. In the upper reaches, especially on unregulated reaches, the inflow components dominate. Downstream of the major headwater storages all components become increasingly important (Figure 4).

The assemblage of all the river reaches allows the processes that operate at a river system scale to be configured, specifically Stages 5 to 8 (irrigated planting areas, supplementary access diversions, water management, storage operation) in Table 2.

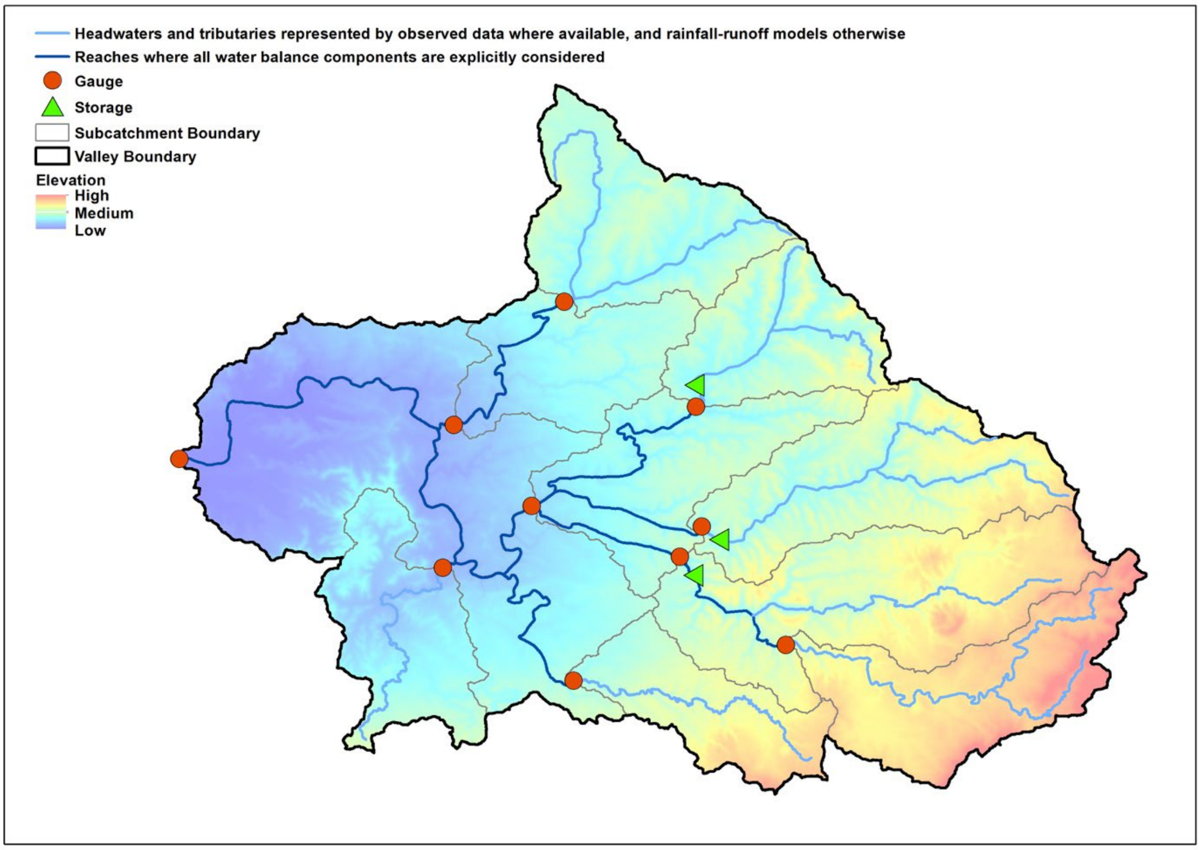

Figure 4 Valley scale water balance components

2.3.4 The parameterisation process

Most river system model software is developed to be generic, with parameter values configured within the software to describe the system being modelled. Parameter values are estimated using one or a mix of the following methods:

- assigned directly, based on the best available measured data, such as where we have surveyed or LIDAR data of on-farm storages
- assigned based on published advice from industry or research
- calibrated by systematically adjusting to match recorded data at the site or of system behaviours – this method iteratively checks how well model outputs match recorded data and parameters are adjusted to improve performance.

Model calibration with climate data as the primary inputs is conducted on a reach-by-reach basis using available recorded data such as gauged flows, metered diversions, infrastructure, and crop areas. These individual calibrations are then combined and validated at a whole of river system scale.

The method used to parameterise each of the component models varies depending on the availability of good quality data. Data availability also determines time periods available for calibration. It is good practice to use the longest period possible to represent natural system behaviour for a range of different climatic conditions. For some components such as water demand, the data should reflect the period of time most appropriate (e.g. for CAP modelling, need data for that period); for a model to represent current behaviour, the most recent data should be used.

Where possible, a number of parameters are pre-defined based on research or industry data. This approach streamlines the calibration process by reducing the number of parameters to be calibrated at the same time, which reduces the risk of unrealistic parameters that may not result in the model being robust when simulating outside the calibration period.

2.3.5 Model assembly and data extension

Model components are progressively and systematically assembled to represent the total river system, from headwater inflows, indirectly gauged inflows, through regulating structures, water demands and end-of-system flows. These processes are worked together along each section of the river, i.e. each reach.

As we assemble the model, observed data are progressively replaced with modelled data. The last two stages of model calibration listed in Table 2, water management and storage operation, are parameterised only when the model is assembled. The whole assembled model is shown in Figure 5 to highlight the geographic scope and detail.

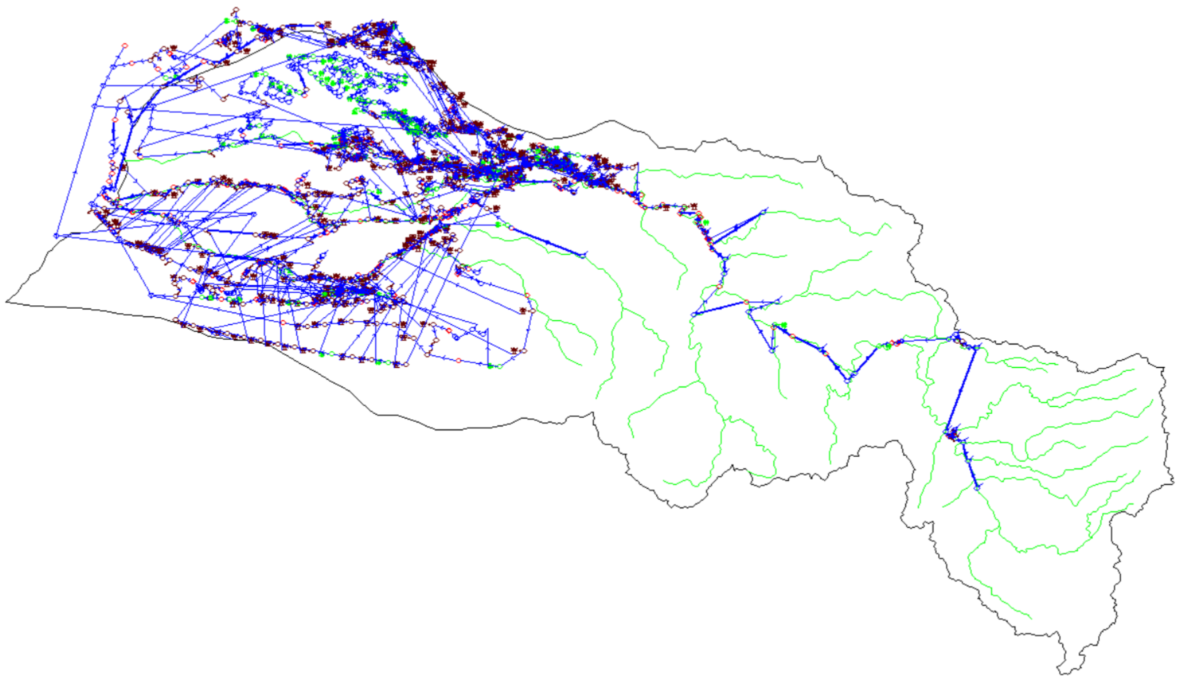

Figure 5 Assembled node-and-link model (as represented in IQQM). The model includes a node for every irrigation property assessed as eligible for a floodplain harvesting entitlement

2.3.6 Data periods

The last step is required to enable use of the model for scenario analysis and to extend all the input data to its fullest temporal extent. During earlier build stages, the component models and the fully assembled models were simulated for shorter climate periods depending on data availability. The scenarios need to be simulated for at least the climate period 1895–2009 for *Basin Plan* Sustainable Diversion Limit compliance purposes, and for longer to account for more recent data. The full climate period for all rainfall and evaporation stations was input directly to the model, as well as used to generate inflows at all points for input to the model.

Table 3 Time periods used in the Gwydir Valley modelling

Period term	Period	Note
Long term record	1/1/1890–30/6/2019	1890–1895 is the model warm-up period[1]; reporting commences from 1895
Reference climate period for reporting	1/7/1895–30/6/2009	*Basin Plan* reporting period. Period used for long-term averages. Water years 1895–2009[2]
Available climate data period	1/1/1890–30/6/2019	SDL compliance process requires extension of climate period each year.
Period for calibration and validation of flow modelling	various	Based on data availability at flow gauging sites.
Assessment period for diversions and water management using fully configured model	1/7/2004–30/6/2013	Water years 2004/05 to 2012/13 Covers key benchmark years for the NSW Floodplain Harvesting Policy and the *Basin Plan* and was based on data availability at time of model development
Base model conditions	2008/09	Represents development conditions at the start of the 2008/09 water year

[1] The first few years of long-term model scenarios are often excluded from reported results to avoid impacts from the choice of starting storage volumes and river flows.

[2] This is the short form of 1895/96 – 2008/09

[3] The model is run for the full period of available climate data 1890 – 2019, but results are assessed against observed data for the 2004 – 2013 period only.

2.3.7 Model validation

The assembled model is then tested to evaluate its performance by comparing model results with observed data over the period of calibration. For this model, the diversions and water management components were tested over the period 01/07/2004–30/06/2013, which includes key benchmark years for the policy and the *Basin Plan*.

To ensure that our assembled model can simulate the key processes of flows, diversions, and water management, a scenario was configured to represent the 2008/09 level of development. The 2008/09 water year is in the middle of the calibration period for many of the model components; it represents the key date by which floodplain harvesting works must be constructed or approved to be eligible for estimating the floodplain harvesting licences.

We do note there have been some changes in development from 2004 to 2013. Consideration has been given to these and other factors in evaluating the results, as described in Section 8.

2.3.8 Scenario development

The fully assembled model with the full period of available climate data is now ready to simulate scenarios. A scenario for managed river systems includes the following characteristics:

- fixed development conditions: including catchment and land use, headwater and re-regulating storages, areas developed for irrigation, on-farm storage volumetric capacity, and pump capacity.
- fixed management arrangements, including all rules, resource assessment and allocation processes, and accounting as set out in the *Water Sharing Plan*, as well as on-farm decision making regarding crop mix, crop area planting as a function of water availability, and irrigation application rates.

With these development conditions and management arrangements set in the scenario model, the model is simulated for the full climate period and results are analysed and compared. This is described in more detail in the companion Scenarios report (DPEDPE Water 2021a). The scenarios developed for the Gwydir and referenced in this report are listed in Table 4.

Table 4 Scenarios referenced in the Gwydir Valley model

Scenario name	Description
2008/09 Scenario	Uses the levels of irrigation infrastructure, water licences, and management rules in the Gwydir regulated river system in place at the start of 2008/09
Eligible Development Scenario	Uses the levels of irrigation infrastructure determined to be eligible[1] for floodplain harvesting entitlement, water licences, and management rules in the Gwydir regulated river system as at the start of 2008/09
Current Conditions Scenario	Uses the best available (more contemporary than 2008) information on current levels of irrigation infrastructure, water licences, and current water management arrangements, in the Gwydir regulated river system
Cap Scenario	Uses the irrigation infrastructure, water licences, and management rules in place at 30 June 1994, to assess the diversions permissible under the Murray-Darling Basin Ministerial Council's Cap on diversions
WSP Scenario	Uses the irrigation infrastructure in place in the 1999/00 water year, and the management arrangements and water licences set out in the water sharing plan
Baseline Diversion Limit (BDL) Scenario	Equivalent to the lesser of the Cap and WSP scenarios, also referred to as the Plan Limit Scenario

[1] This includes some works that were approved, but not constructed at the commencement of the 2008/09 water year.

2.4 Sources of data for river system modelling

Modellers rely on a range of sources of data – some are directly measured such as rain, flow or licensed diversions; some are indirectly estimated such as crop areas from remote sensing, or breakout relationships from hydraulic models. Table 5 describes the primary sources of data that are used in river system models, tailored to provide examples for the Gwydir Valley.

Table 5. Primary sources of data relevant to river system modelling and their uses for components: river network, climate, flows, regulating infrastructure, water users, farm infrastructure, crop areas, water management (X = used for this purpose; o = not used for this purpose)

Input / parameter	Primary data sources	Use – configure model	Use – direct input	Use – calibrate model	Use – validate model
Component: river network					
Model (node-link) structure	Maps, data layers in GIS	X	o	o	o
Effluents, breakouts	Farm surveys[3], State Emergency Service (SES), flow gauges, hydraulic modelling, remote sensing imagery of flood events	X	o	o	o
Component: climate					
Rainfall, evaporation	Bureau of Meteorology /SILO	o	X	o	o
Component: flows					
Observed flows and storage volumes	NSW flow gauging network (Hydstra database)	o	X	X	X
Simulated flows	Rainfall–runoff modelling	o	X	o	o
Component: regulating infrastructure					
Dams, weirs, and regulators	WaterNSW	X	o	o	o
Component: water users					
Licences, water sources, metered water use	NSW government (WaterNSW) Water Accounting System (WAS) and Water Licensing System (WLS)	X	o	X	X
Component: farm infrastructure					
Pump capacities, crop areas, developed areas, on-farm storage capacities	Farm surveys, remote sensing (LIDAR), site inspections	X	o	o	X

[3] Farm surveys refer to the Irrigator Behaviour Questionnaire

Input / parameter	Primary data sources	Use – configure model	Use – direct input	Use – calibrate model	Use – validate model
Component: crop areas					
Crop type and area planted each year	Farm surveys, remote sensing, survey records (WaterNSW, ABARE, ABS, industry groups)	X	o	X	X
Component: water management					
Water sharing, announcing allocations and supplementary access, planned environmental water requirements	Gwydir Water Sharing Plan, operational procedures	X	o	o	o

3 Overview of the Gwydir Valley

3.1 Physical description

The Gwydir Surface Water Resource Plan Area (WRPA) is located within the Gwydir catchment, which forms part of the Murray-Darling Basin in northern NSW. It rises on the southern part of the New England Tablelands in the Great Dividing Range, near the town of Uralla west of Armidale. It flows about 668 km generally north-west through the steep valleys of the tablelands and then, west of Pallamallawa, the valley widens into an almost completely flat alluvial floodplain. The Valley is bounded by the Namoi Valley to the south, the Barwon River to the west, the slopes of the Great Dividing Range to the east and the Border Rivers Valley to the north (Figure 1). The Gwydir Valley covers more than 26,000 km^2 and represents about 2.7% of the Murray-Darling Basin.

The main tributaries are Copes, Moredun, Georges and Laura Creeks, and the Horton River. The Mehi River leaves the south side of the Gwydir River, and Carole Creek leaves the north side of the river, with both watercourses being used to deliver regulated flows all the way to the Barwon River. The Ramsar-listed Gwydir Wetlands at the end of the catchment receive much of the river's flow.

Climate (rainfall and evaporation) and geography directly affect the volume of runoff generated within the Valley, and how, when and what crops are grown. The characteristics of the river network affect how runoff accumulates as streamflow through the system, including how some flow breaks out of the main channel into the floodplain zones, where most of the irrigation farms are located. This requires representing how water flows through the system, including the large volumes stored behind headwater dams and released in response to downstream demands.

3.2 Regulation

Water in the valley is principally regulated by Copeton Dam (1,364 GL) which is situated on the Gwydir River about 35 km south-west of Inverell. A number of weirs allow the diversion of flows into effluent creeks for the supply of regulated water, including:

- Tareelaroi Weir upstream of Moree that enables water to be diverted into the Mehi River system
- Boolooroo Weir near Moree that enables water to be diverted into the Carole Creek system
- Tyreel regulator west of Moree that enables water to be diverted into the south arm of the Gwydir River
- Combadello Weir south of Moree that enables water to be diverted from the Mehi River into Moomin Creek.

Access to regulated water is through licences and usage is metered. Unregulated water (such as in tributaries and headwater streams) can be accessed under licences when flows occur, subject to certain conditions. Groundwater can also be accessed under licences, subject to conditions. Under natural conditions, the river system would exhibit high flow variability in response to climate variability. However, regulation of the river has reduced this variability.

3.3 Water users

Water users include urban areas, irrigators, the environment, and water for stock and domestic supply.

The largest water demands in the Gwydir Valley are from the irrigation farms in the floodplain areas around and downstream of Moree to upstream of the junction with the Barwon River.

These areas are principally cotton growing, although comparatively small areas of other summer and winter crops are irrigated. A map of the primary irrigation areas is provided at Figure 7.

3.4 Legislation, policies and operating procedures

NSW policies/legislation that are referred to in this report are:

- *Water Management Act 2000 No 92*
- Water Sharing Plan for the Gwydir Regulated River Water Sources 2020 (draft) (the Gwydir WSP)
- Water Sharing Plan for the Gwydir Unregulated River Water Sources 2012
- Floodplain Management Plan for the Gwydir Valley Floodplain 2016
- NSW Floodplain Harvesting Policy 2013 (revised 2018) (the policy).

The Gwydir WSP applies to all regulated river sections in Gwydir. The management components described in this report closely reference key provisions of the Gwydir WSP and their practical implementation, as well as how water users in the valley choose to use their water based on water availability.

3.5 Summary

This section has provided an overview of the valley which translates into a suite of components for modelling. The next 4 sections (Sections 4 to 7) describe each of the components, including the sources of data selected to best characterise them for the purposes of modelling floodplain harvesting. Typical sources of data for these components have already been listed in Table 5. For ease of navigation through this report, the components are grouped into:

- flows (Section 4)
- water sources and licensing (Section 5)
- water users (Section 6)
- water management (Section 7).

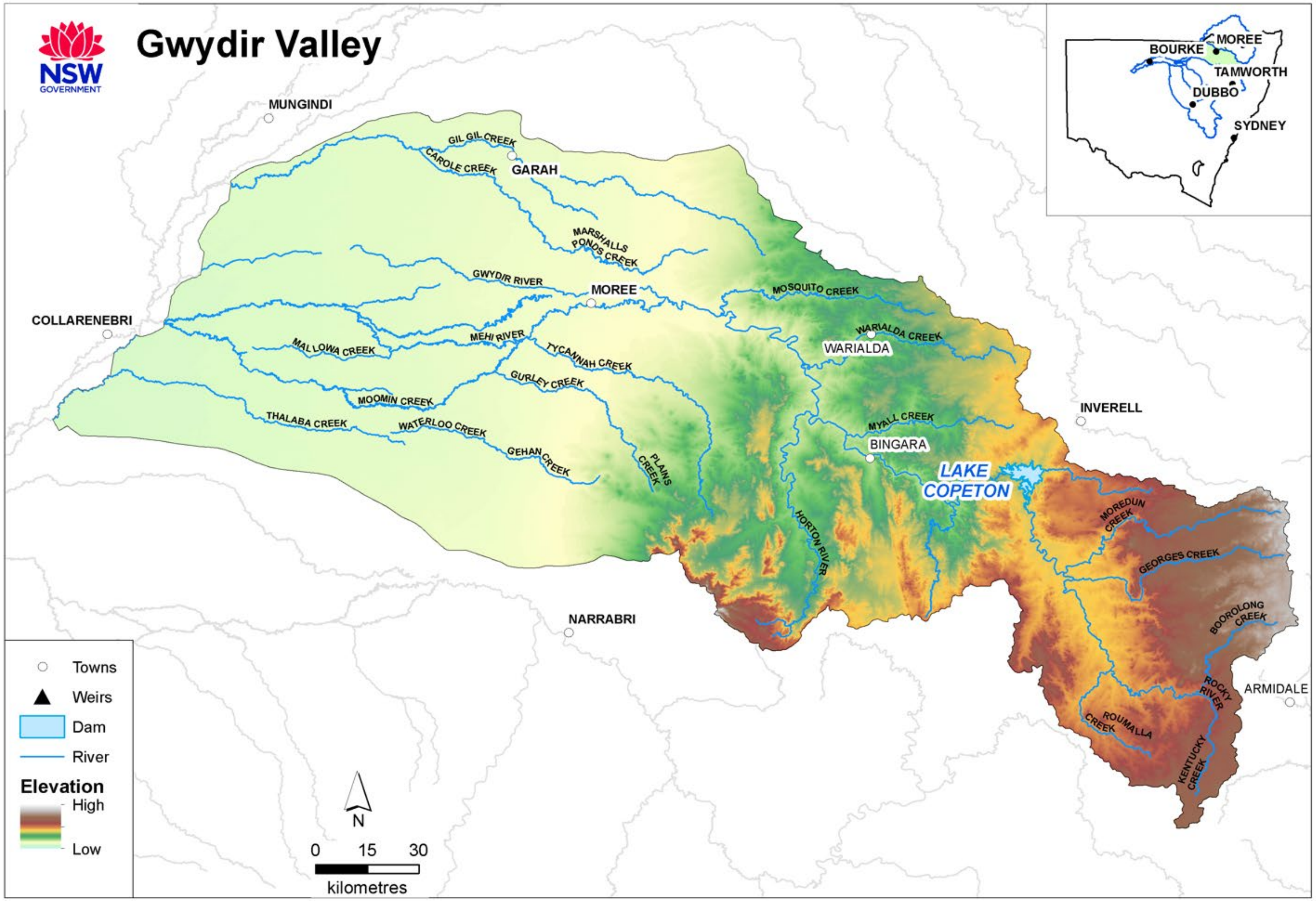

Figure 6 River network (main channel and tributaries) and locations of main towns and water storages in the Gwydir Valley

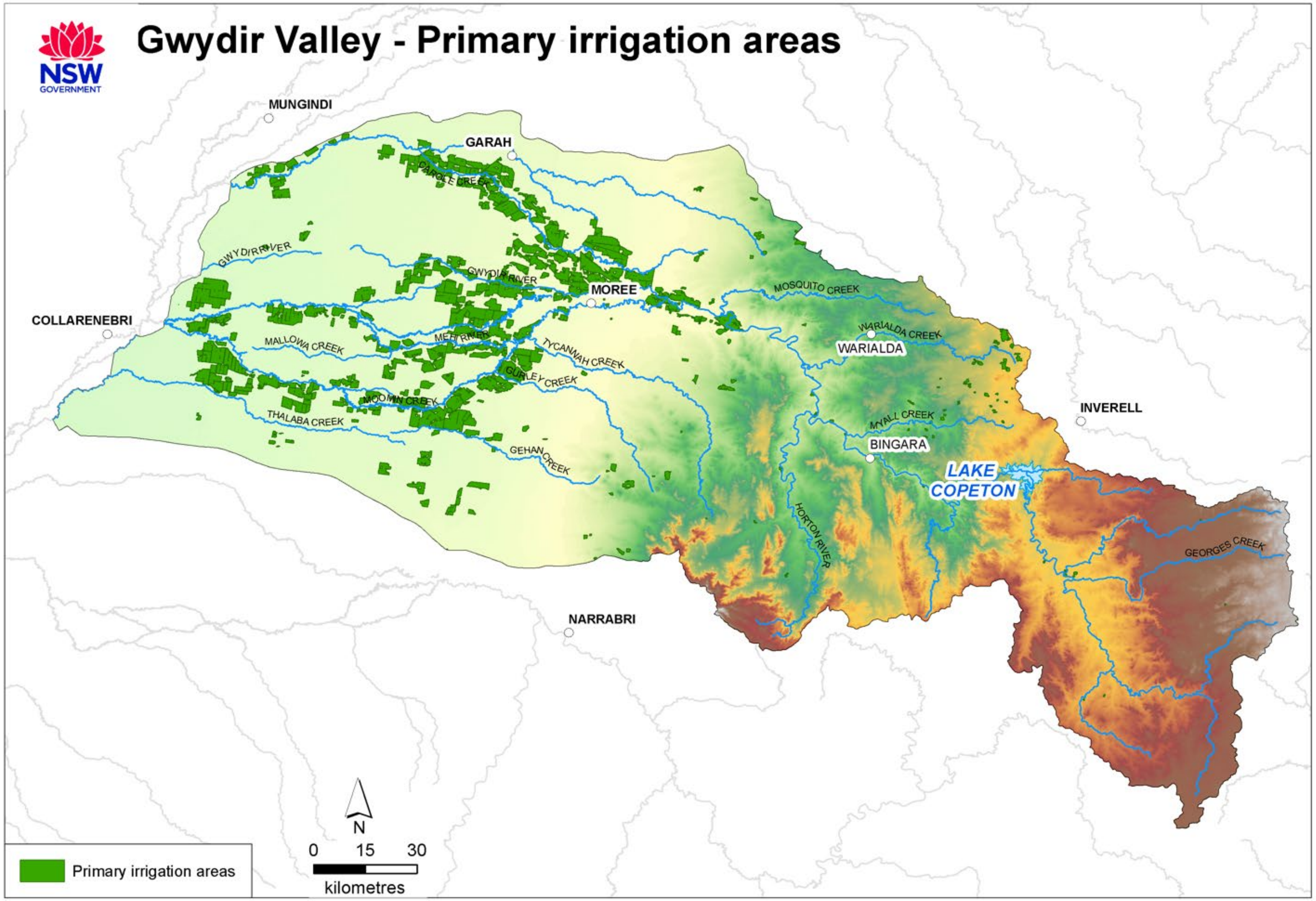

Figure 7 Primary irrigation areas in the Gwydir Valley

4 Modelling flows

This section describes the data sources and adopted modelling approach for the key physical components of the Valley that affect flows along the river system.

4.1 River network

The main rivers and tributaries are listed in Section 3 and shown in Figure 6.

The river network is used to define the spatial relationship of components that cause changes in water balance, and of the movement of water along the river system from headwater tributaries to the end of the river system. To simulate this movement of water, the valley has been broken up (discretised) into 35 modelling units (catchments and sub-catchments (sub-reaches)) (Figure 8).

Reaches are defined as discrete sections of the river with a flow gauge at the downstream end, and in many cases at the upstream end. These gauges must have good available observed streamflow data. Reach types are headwater reaches which do not receive inflows from upstream reaches; and mainstream reaches which receive flows from one or more upstream reaches.

4.1.1 Data sources

Locations of climate stations (Appendix B) and flow gauges (Appendix C), maps and a digital elevation model were available to delineate the valley at multiple scales for modelling.

Information on the river network is readily available from mapping maintained by NSW Spatial Services and digital modelling maintained by the NSW government. Much of this information was collated for earlier modelling of the Gwydir (e.g. the earlier version of this IQQM Gwydir model).

The catchment areas and stream lengths were derived from direct measurement, using standard GIS routines.

4.1.2 Modelling approach

Data availability and design criteria of being able to report at multiple scales (property, reach and whole-of-valley) informed the number of discrete modelling areas needed.

Reaches for the Gwydir model are shown in Figure 8. The downstream end of the headwater reaches are the inflow gauges listed in Appendix C. The mainstream reach upstream and downstream gauges are defined in Appendix I.

Models are developed for each reach representing each significant component of the water balance (see Figure 3) and then progressively linked to form the final aggregated catchment model.

The configuration of river reaches is typically the same as those in the previous Gwydir Valley model, except for some cases where a river reach has been sub-divided into two smaller reaches to improve the representation of access to over-bank flows.

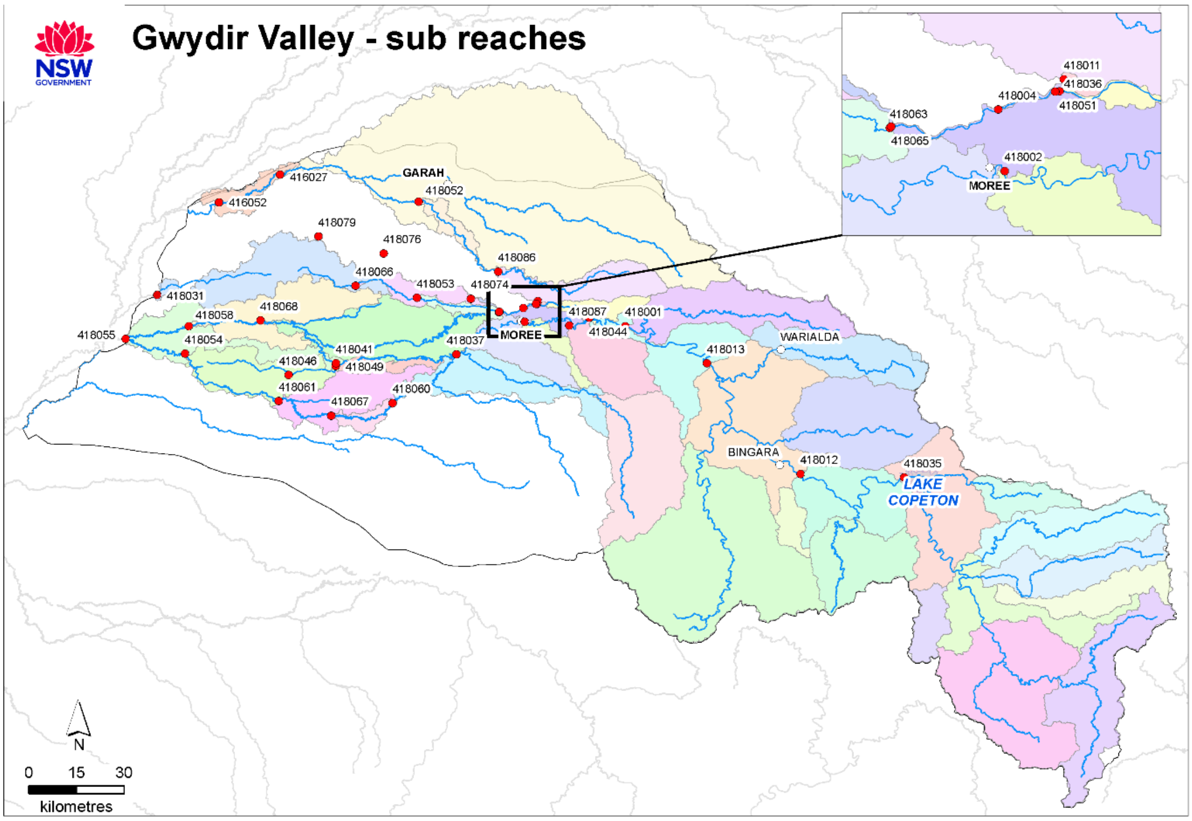

Figure 8 Map of modelling units of the Gwydir Valley

4.2 Rainfall

Average rainfall ranges from 1,000 mm per year in the north east to around 500 mm in the west. Rain is generally summer dominant with the heaviest rainfall occurring from October to March (Figure 9).

The rainfall is strongly seasonal with the highest volumes during the summer months occurring through summer storm activity.

4.2.1 Data sources

Rainfall data are used extensively through the model, as input for rainfall–runoff modelled inflows, storage water balance, and crop water demands. Departmental guidelines recommend the use of the Queensland Government's Scientific Information for Land Owners (SILO) patch point data[4]. These data are based on official Bureau of Meteorology datasets with well documented routines to infill missing data at stations. The SILO datasets extend back past the period required for our statutory reporting under the *Basin Plan*. We have also found point data more suitable for rainfall–runoff modelling.

We chose the rainfall stations for each reach based on their location, length and quality of the record. We also used correlation with observed reach inflows during flow calibration. Any significant periods of infilled data were checked whether it introduced bias in the data.

The rainfall stations used within the Gwydir Valley model are shown in Figure 9. In addition to these stations, a larger number of rainfall stations are used in rainfall–runoff modelling which is

[4] https://www.longpaddock.qld.gov.au/silo/

used to generate inflow time series data for the model. This modelling occurs separately to the river system model. A full list of rainfall stations including spatial coordinates and long-term annual average is included in Appendix B.

Map of evaporation gradient, details in caption

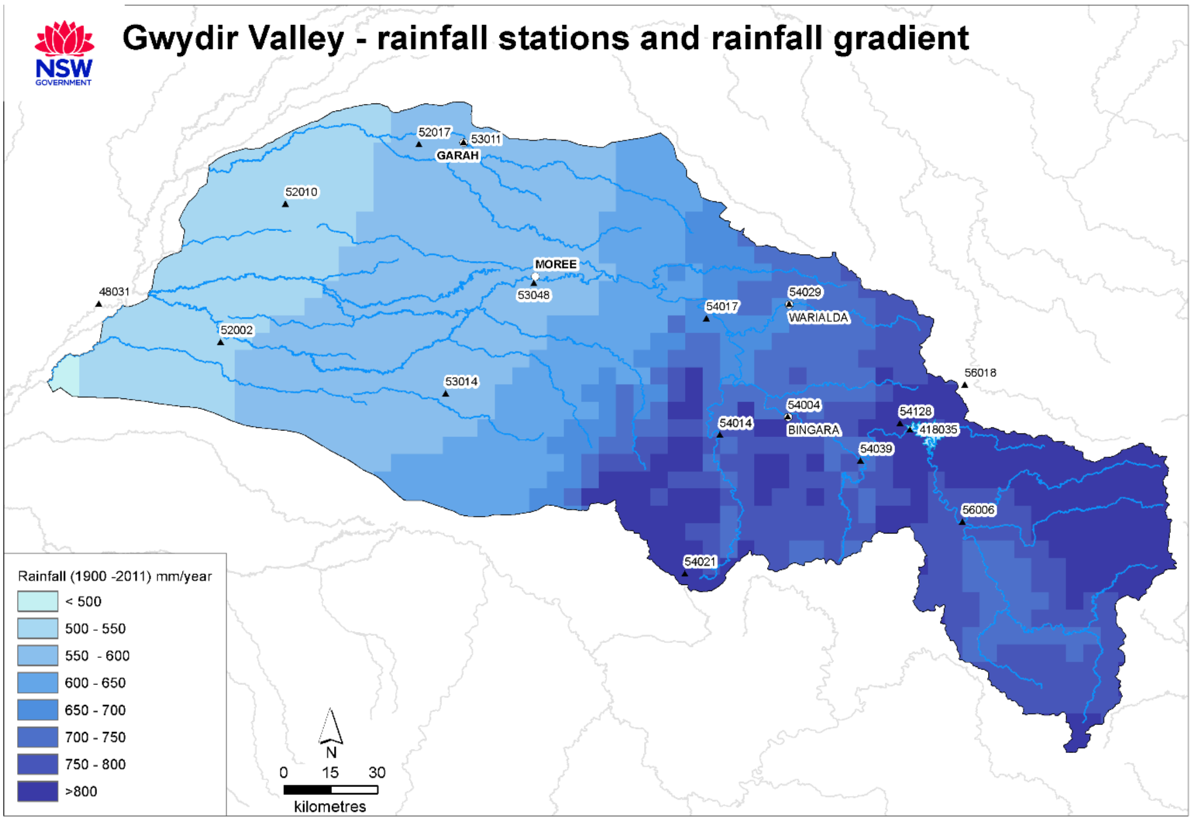

Figure 9 Map showing the rainfall gradient (1900 to 2011) across the Valley and location of rainfall stations used within the model

4.2.2 Modelling approach

Corresponding to Stage 1 of the stages of model assembly (Table 2), rainfall data are used as an input to rainfall–runoff modelling, simulation of rainfall on storages and river surfaces and the modelling of irrigation demands.

We adopted the nearest suitable climate station in each part of the model. Sensitivity testing indicated that long term results for each irrigation property are relatively insensitive to choice of climate station, with less than 5% change in floodplain harvesting with change between the nearest two climate stations.

4.3 Evaporation

Evaporation (Class A pan evaporation) in the Gwydir Valley has a strong east-west gradient. Yearly evaporation varies from around 1,500 mm in the south-east to over 2,000 mm in the west (Figure 10). Evaporation significantly exceeds average monthly rainfall throughout the year. The greatest exceedance occurs during summer when nearly 300 mm of evaporation occurs per month at Moree compared to around 80 mm of rainfall.

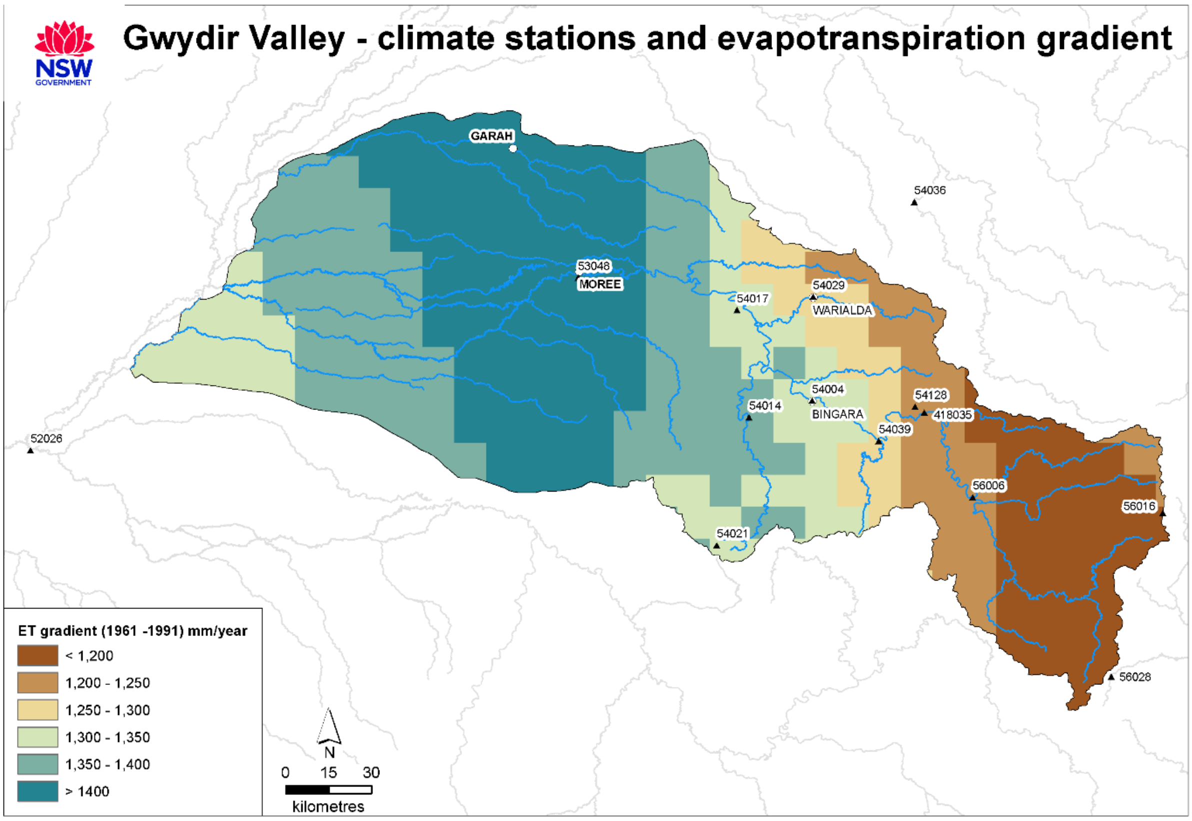

Figure 10 Map showing the evapotranspiration gradient (1961 to 1990) across the Valley and the location of climate stations used for rainfall–runoff modelling

4.3.1 Data sources

Evaporation data are used as input for rainfall–runoff inflow models, storage water balance, simulation of stream losses, and estimating crop water demands.

Estimates of daily potential evapotranspiration were obtained from evaporation stations in and around the Gwydir Valley from the SILO database which provides Morton's estimated potential evapotranspiration data. We used two forms of potential evapotranspiration:

- Morton's Wet evapotranspiration (MWet) data to estimate potential evapotranspiration for rainfall–runoff inflow modelling. MWet represents the potential evapotranspiration from a wet environment, such as catchment or soil moisture stores after rainfall. We smoothed the MWet data using a 7-day centred moving average to remove spurious daily variations.
- Morton's Lake evaporation (MLake) data to estimate evaporation from the surface of water bodies, including reaches and storages.

The evapotranspiration station locations used for the flow calibration components of the river system modelling are shown in Figure 10 and listed in Appendix B. Additional evapotranspiration data were used for crop modelling, using the SILO data for FAO56 method. These are the same as the climate stations shown in Figure 9.

4.3.2 Modelling approach

When choosing evaporation stations for rainfall–runoff modelling, stations with a significant number of cloud-free records were preferentially chosen, as this is typically the limiting observational ingredient to the Morton's calculations. When choosing evaporation stations for all other purposes, nearby stations were preferred, as local effects may be important.

4.4 Streamflow

As with many northern NSW inland rivers, the Gwydir River system experiences high flow variability in response to climate variability. A long-term modelled flow is shown graphically for the Moree (Station 418002, Figure 11) demonstrating this.

This is a modelled (pre-development) flow, and is used here in preference to observed flow which, due to regulation, does not give an indication of natural flow variability. This data shows that while the annual average is around 300 GL/year, it is highly variable with extended low flow periods from 1930 to 1948, and 2002 to 2010, and wet periods in the 1950s and the 1970s.

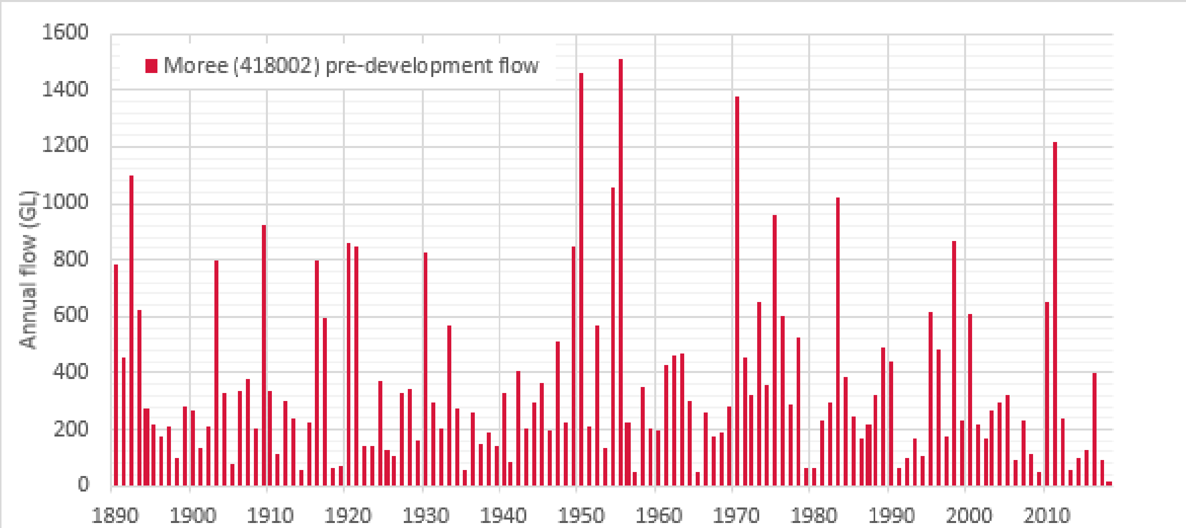

Figure 11 Modelled historical annual flow (GL) at Moree (418002) for the period 1889 to 2019

As well as the annual flow variability, daily flow variability also matters. A large event in an otherwise low volume year can still provide significant runoff.

4.4.1 Data sources

NSW maintains a network of river flow gauging stations across the Gwydir Valley to support water management activities. Data for each station are archived in the Department's Hydstra hydrometric database (Kisters Pty Ltd 2010). These continuous flow records are the foundation of the river system modelling.

Flow gauging stations are operated and maintained by trained hydrographic staff who estimate flow based on established procedures and standards. Most flow gauging stations consist of a water level measurement device with a continuous data logger that continually records the output. These water levels are converted to flows using a height–flow relationship (known as a rating table) developed by hydrographic staff using flow gauging over a period of time.

There are 51 flow gauging stations currently operating in the Gwydir Valley (including storage level gauges. Storage level gauges can be used to estimate inflows to that storage using daily mass balance calculations of changes in volume, rainfall and evaporation, and known outflows.

The stations used to calibrate flow in the model are listed in Appendix C. Data from 12 stations were used to calibrate headwater inflows from catchments that cover about 8,900 km^2 area. A further 38 stations were used to calibrate flows for 31 river reaches. Location of these stations is illustrated in Figure 12.

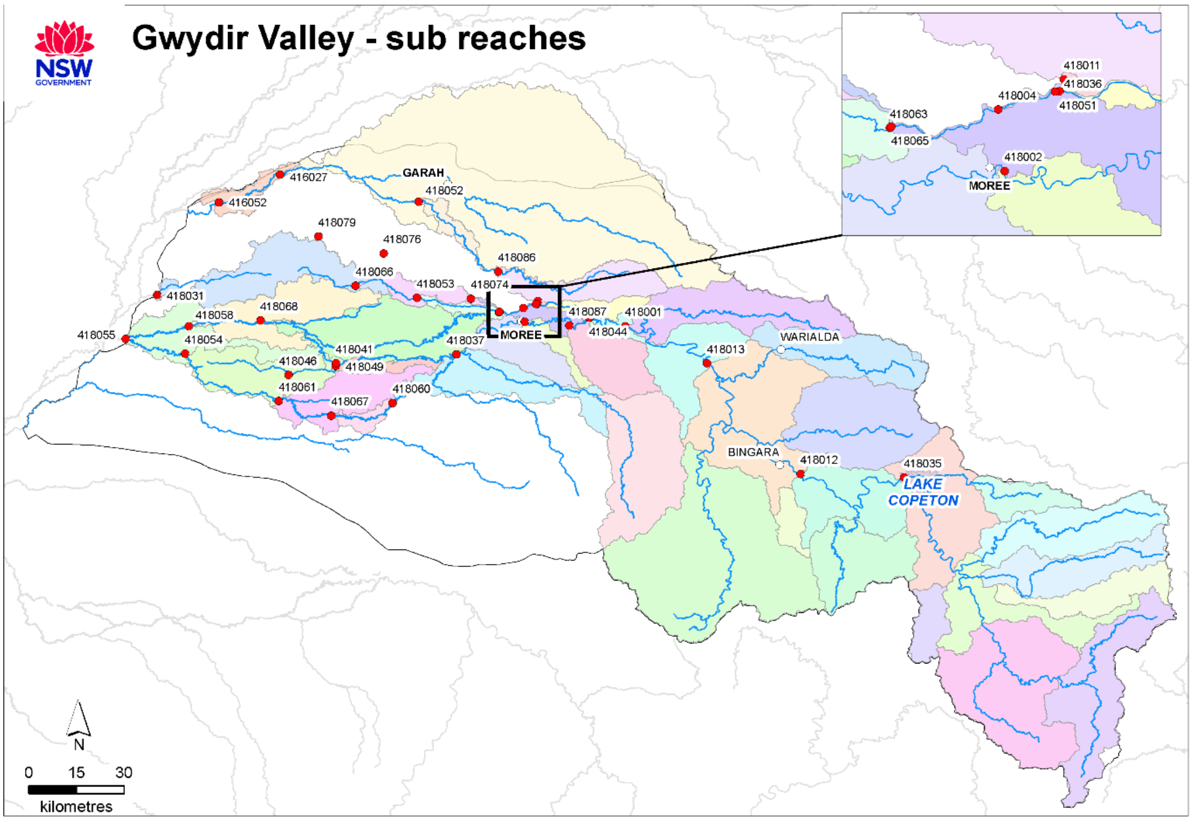

Figure 12 Map showing location of flow gauging stations in the Gwydir Valley

4.4.2 Modelling approach

A summary of the parameters used for the tributary inflows and main river reaches flow calibration is described in Table 6.

Note that directly gauged inflows are for catchment areas where all the flow generated from that catchment has been recorded at a single point, for example the most upstream gauge on a tributary. Indirectly gauged inflows are from catchment areas where the flow generated needs to be estimated based on the difference between an upstream and a downstream gauge.

Table 6 Calibration approach for tributary inflows and main river flow

Step	Fixed input data	Target	Parameters
Tributary inflow	Rainfall Potential evapotranspiration Catchment area	Directly gauged catchment inflows	12 Sacramento model parameters describing soil storage components and flux rates
Main river flow	Rainfall Potential evapotranspiration Gauged flow at reach's upstream gauges and tributaries Metered diversions	Downstream gauged flow in river reach	Routing parameters Indirectly gauged catchment inflows Effluent relationships (including flood outbreaks) Instream losses

Directly gauged tributary inflows

Corresponding to Stage 2 of the stages of model assembly (Table 2), inflows are estimated for the gauged headwater tributaries with significant catchment areas. The flow gauging station network does not cover all tributaries for the full simulation period. We use gauged flows directly as input wherever possible, and calibrated modelled inflows elsewhere.

Rainfall–runoff models simulate the conversion of rainfall into streamflow from a catchment (see Figure 13 for an example).

Use of these types of model enables us to take advantage of the more extensive rainfall records to fill gaps and extend the period of record for the tributary inflow gauges, and to explicitly represent sub-catchments that may not have a flow gauge on them. We use the Sacramento rainfall–runoff model for this purpose because we have found it performs well, and we have considerable experience and skills in obtaining good calibrations with this rainfall–runoff model.

A Sacramento rainfall–runoff model was built for each headwater reach in the model (12 models). Each Sacramento model was calibrated to reproduce the flows for the recorded period. For headwater reaches the calibration target was the recorded flow at the gauge or a derived storage inflow sequence.

Inflows to Copeton Dam were calculated by performing a water balance on a daily basis using the gauged releases, change in storage levels, and climate data (rainfall and evaporation) measured at the site.

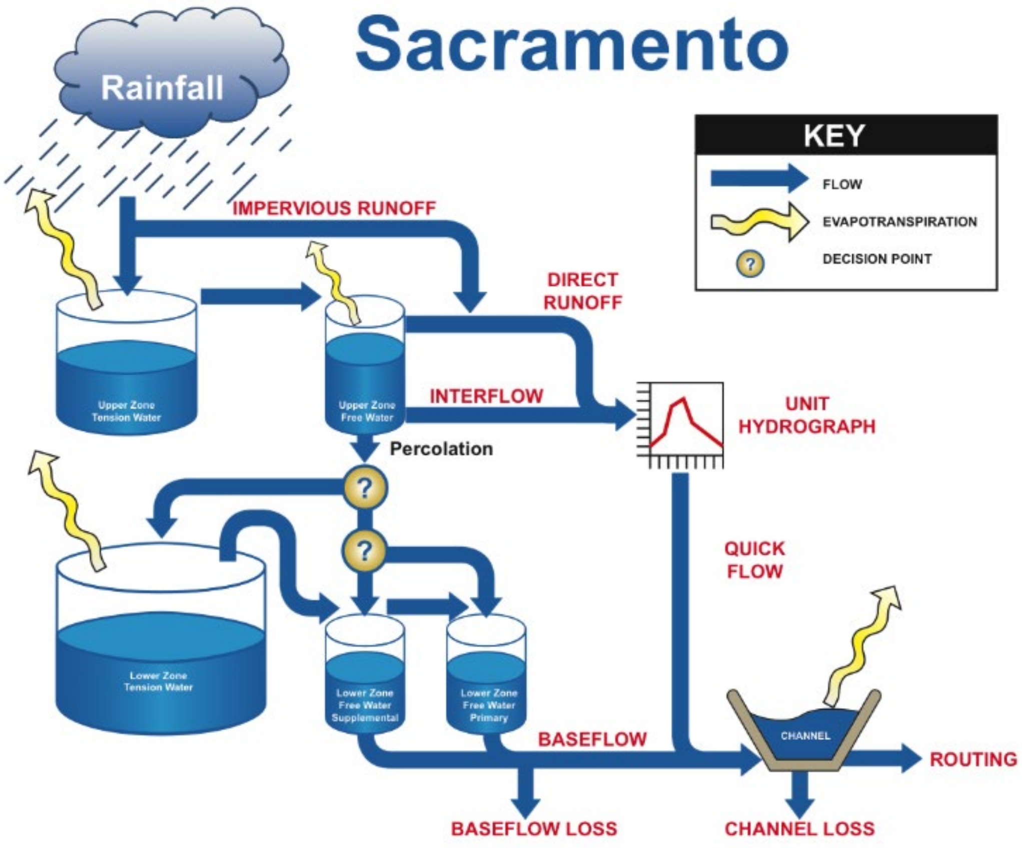

Figure 13 Conceptual diagram of the Sacramento rainfall–runoff model [Source: eWater Scientific Reference Guide]

Calibration

Each Sacramento reach model was calibrated firstly by setting it up with the local climate station data and catchment areas as input, and then applying an automated calibration process using software developed by the Queensland Government.

Rainfall can be quite spatially variable, and a single rain gauge may not be representative of the rainfall received across a catchment area. This can be an important issue for rainfall–runoff modelling, and rainfall at individual stations in a catchment are weighted initially based on how representative they are of rainfall across the catchment.

This calibration systematically adjusts model parameters to get the best overall match of modelled flows with recorded flows for the period of flow record. This method aims to match certain statistical characteristics of the flow record, including matches of daily values, flow distributions, and overall volume.

The optimised parameter set is checked by manually comparing the modelled and observed flows over the full flow range using time series flow plots at daily, monthly and annual time steps, flow-duration curves, cumulative mass and residual mass curves. Summary statistics, including statistics associated with daily flows and peak flow discharges, are produced and checked. Report cards are produced which summarise the comparison between modelled and observed flow sequences. These results can be found in Appendix J.

Indirectly gauged inflows and regulated river system flows

Estimation of indirectly gauged inflows is Stage 3 of the stages of model assembly (Table 2). This step is undertaken iteratively with estimating transmission losses.

Once headwater inflows enter the regulated river network, either from tributaries or as releases from the major storages, the model must route the flows down the river network. Flow routing simulates the time taken for water to move through the river, and the change in the shape of the hydrograph because of channel and floodplain storage effects.

The model must also simulate the river transmission losses and the indirectly gauged catchment inflows. These processes are configured in the model using a structured series of steps at a reach scale, considering the components shown in Figure 3.

Flows contributing from ungauged catchments were estimated in the Gwydir IQQM using a combination of correlation with other gauged catchments and mass balance calculations within each reach along the river. The river reaches that have ungauged or 'residual' catchment inflows estimations are listed in Appendix C.

Flow was calibrated at the downstream gauge in a structured series of actions, in the process estimating routing parameters, ungauged tributary inflows, transmission losses, net evaporative losses, and in some cases breakout relationships.

As a final step, we link all the individual calibrated river reach models to the full flow network, run the full model and check that this has not significantly changed simulated flows at all gauges.

4.5 Effluents, breakouts and floodplains

An effluent river is a river that flows out of another river and may also have a local catchment. Some effluent rivers only start flowing when the flows in the main river reach higher levels. There are several effluent rivers that leave the main Gwydir River, sometimes with other smaller rivers and streams joining them at various points (as shown in Figure 6). The main effluent rivers generally do not re-join the main river channel further downstream.

Mehi River and Moomin Creek

Mehi River leaves the south side of the Gwydir River. It naturally receives higher flows from the Gwydir River and flows that are controlled by a weir structure across the Gwydir River (Tareelaroi Weir). The Mehi River continues to the west and joins the Barwon River near the town of Collarenebri.

Moomin Creek leaves the south side of the Mehi River. It continues to the west and then re-joins the Mehi River just above its confluence with the Barwon River. Moomin Creek naturally receives higher flows from the Mehi River, and flows that are controlled by a weir across the Mehi River (Combadello Weir).

Both the Mehi River and Moomin Creek are part of the regulated Gwydir River system, and WaterNSW control flows into them to meet the requirements of licensed water users and the WSP for the regulated Gwydir River water source.

Carole and Gil Gil Creeks

Carole Creek is a stream from the north side of the Gwydir River that naturally receives higher flows from the Gwydir River, and flows that are controlled by a weir structure across the Gwydir River (Boolooroo Weir). Carole Creek flows into Gil Gil Creek, which has its own small catchment area. Gil Gil Creek then flows into the lower Boomi River just above the Boomi River’s confluence with the Barwon River. The Carole Creek, Gil Gil Creek below the Carole Creek confluence, and the Boomi River below the Gil Gil Creek confluence are all part of the regulated Gwydir River system.

Gwydir Wetlands and Mallowa Creek

Downstream of Moree, the Gwydir River splits into two major streams: the Gingham Watercourse forms the northern arm, and the Lower Gwydir Watercourse (also known as the Big Leather Watercourse) forms the southern arm. These watercourses contain the wetland areas of the Gwydir Wetlands which are one of the most extensive and significant semi-permanent terminal wetlands in north-west NSW.

Mallowa Creek is a stream that leaves the Mehi River that naturally receives water during higher flows in the Mehi River but is not part of the regulated Gwydir River system. A weir structure across the Mehi River (the Gundare Regulator) downstream of Mallowa Creek allows flows to be diverted into Mallowa Creek, which are controlled by another weir structure across Mallowa Creek (the Mallowa Regulator). These regulators normally contain flows in the regulated Mehi River. Mallowa Creek then re-joins the Moomin Creek.

Thalaba Creek

Thalaba Creek is a stream that in addition to its own local catchment receives water pumped from the regulated Moomin Creek for stock and domestic supply purposes during dry periods. This supply of water is referred to as a replenishment flow, and there is 4,000 megalitres set aside in Copeton Dam to supply this water each year if natural tributary inflows downstream of Copeton Dam are insufficient.

Breakouts and floodplain areas

As the water level rises from within the channel, the most common points through which inundation initially occurs are low areas where the stream can spill over onto its floodplain. These flow breakouts can extend across many properties, sometimes flowing along indistinct flow paths that can inundate large areas of the floodplain. Some breakout flow paths only get water flowing in very high flows, and others happen more frequently. Local rainfall–runoff can also contribute to flow in these regions.

The Gwydir Valley model includes 35 high flow breakouts from both main rivers/creeks and tributaries and seven direct takes from the river above nominal overbank flow threshold (six in the regulated Gwydir Valley river system and one in an unregulated stream). While some of the configured breakouts are located upstream of headwater gauges, representing overland flow bypassing the headwater gauges, there are other breakouts configured at a reach scale to represent several breakouts along that reach.

A map of key breakout locations and breakout paths is presented in Figure 14, noting that how and when they 'break out' depends on river levels.

4.5.1 Data sources

Some of the major effluent offtakes have flow gauges and follow well-defined channels that are easily identifiable on mapping and digital terrain models.

High flow breakouts are well-known locally by river operators, State Emergency Service personnel, and landholders. However, they may be difficult to identify from maps and there are no direct measurements of flow rates. We used a combination of local knowledge (e.g. operators, hydrographers, local emergency services, and landholders), remote sensing and flow gauges to assist in representing where the breakouts occur, and the main channel flow rate at which breakouts commence.

In reality overland flow paths are very complex. Where appropriate, simplifications were made by amalgamating some flow paths and connections. Generally, two or more flow paths were amalgamated where they:

- flow in the same direction
- have significant connections along the length of the flow paths
- do not appear to be accessed by floodplain harvesters, or
- they do not carry a significant volume of water.

The flow paths for these breakouts, and the properties that have access to them, have been identified using multiple sources, including satellite imagery, modelling of floodplain flows, and information from the farm surveys. Figure 14 shows the identified breakouts in the models overlaid on overland flow paths derived from results of the MIKE flood model (see point 5 below).

The rate at which flow enters the breakouts was derived using:

1. cross-section and rating information at flow gauges
2. Healthy Floodplain Irrigator Behaviour Questionnaires (farm surveys)
3. Bureau of Meteorology flood warning levels
4. Landsat data to compare historical flood extent along reaches to recorded flows
5. a regional hydraulic MIKE flood model developed for the Floodplain Management Plan
6. water balance methods by comparing upstream and downstream flow rates (described in Section 4.4.2).

The breakout relationships from these information sources were also reviewed by assessing the frequency of harvesting compared to survey data where available. Where a consistent bias between simulated and observed reach water balance components was detected, the breakout relationships were reviewed.

A detailed flood model was developed to support the development of a Floodplain Management Plan for the Lower Gwydir but was not available until after this Gwydir Valley model was developed. Consequently, rather than use the flood model results to inform the initial model development, they were used to verify previous estimates and adjust them where required.

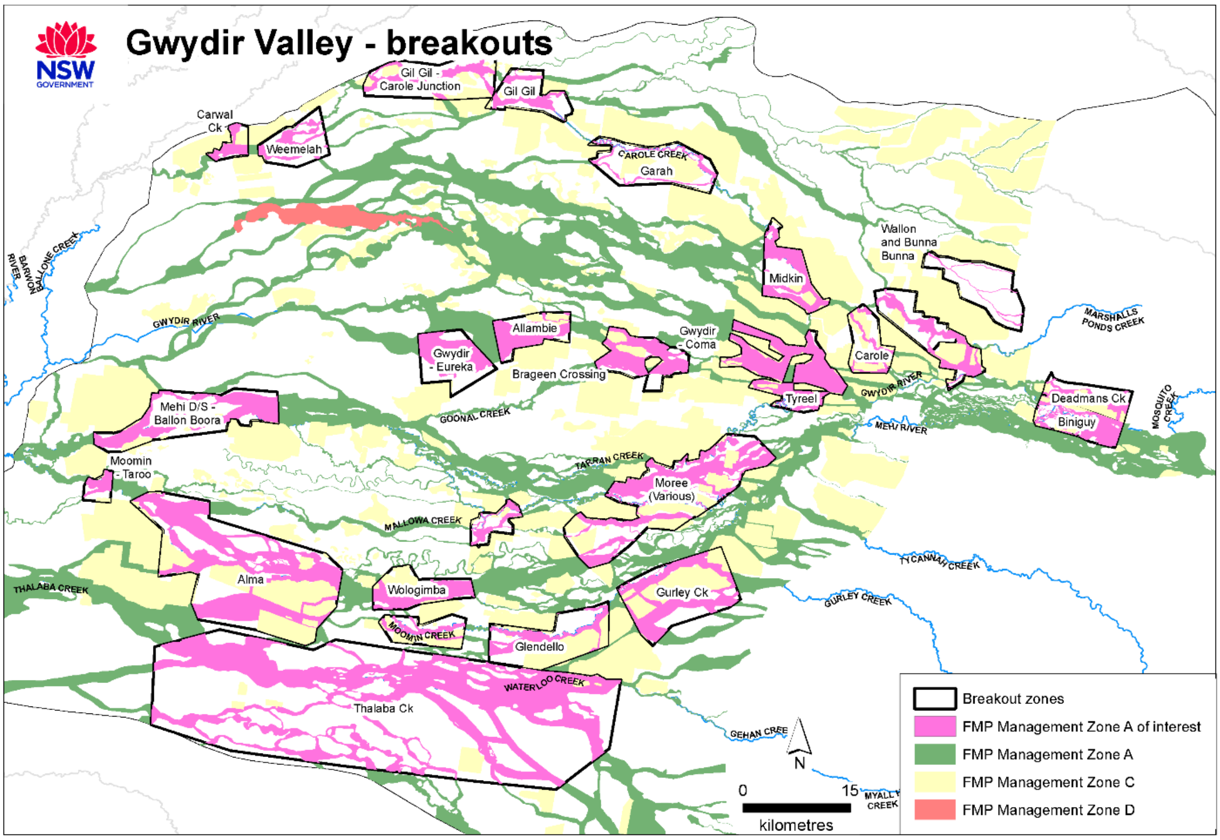

Figure 14 Floodplain Management Plan (FMP) zones and key breakout locations in the Gwydir Valley

The breakout zones, or areas of interest, was then further refined by using ArcGIS (10.3.1) to select environmental assets and values for the environmental outcome's analyses. This process is described in the companion Environmental Outcomes report (DPEDPE Water 2021b).

4.5.2 Modelling approach

Previous river system modelling included flows onto the floodplains as part of the flow-calibration for most river reaches and some tributary reaches (i.e. between headwater gauge and junction with the main river). This net flow onto the floodplain was treated as a loss to the system. This Gwydir Valley model represents floodplain breakouts explicitly, i.e. as an effluent, and flow calibration results more closely represent instream losses.

The flow rates at which breakouts from the main channel were determined from a range of sources as described above.

Gwydir Wetlands

The Gwydir Valley model initially represented the Lower Gwydir wetlands as a single non-consumptive water user. In 2010 a more detailed representation of the Gwydir wetlands was developed, based on a hydrodynamic MIKE Flood model developed by Water Technology Consultants. The IQQM modelling for the Gwydir wetlands is described in *IQQM Wetland modelling for the Gwydir Valley* (DECCW 2011).

4.6 Regulating infrastructure – dams and re-regulating storages

Major dams

The Gwydir River is regulated by one major dam (Copeton Dam) with a capacity of 1,364,000 ML. Copeton Dam was completed in 1976 and is situated on the Gwydir River about 35 km south-west of Inverell between Bingara and Bundarra. Water is released from these storages to supply water to downstream licensed water users and environmental flows.

Copeton Dam has a gated spillway that can actively manage spills during major floods.

Re-regulating storages

A series of weirs and regulators assist in the diversion of water to the various watercourses of the lower Gwydir Valley, as described in Table 7.

Table 7 Water regulation infrastructure in the Gwydir regulated system

Infrastructure	Function	Description	Storage and discharge capacity (ML)
Tareelaroi Weir	Control flows into the Mehi River	Concrete structure with five vertical lift gates, each 13.1 m wide by 4.3 m high	Max storage: 2,360 ML Max discharge to Mehi River: 5,800 ML/day
Boolooroo Weir and Carole Creek Regulator	Control flows into the Carole Creek	Concrete structure with 4 vertical lift gates, each 12 m wide by 3.3 m wide	Max discharge to Carole Creek: 2,200 ML/day
Tyreel Weir and regulator	Control flows into the Lower Gwydir River and Gingham watercourse	Low sheet piling structure	Max discharge to Lower Gwydir: 2,000 ML/day Max discharge to Gingham watercourse 10,000 ML/day
Combadello Weir and Mongyer Regulator	Control flows into the Mehi River into Moomin Creek	Concrete structure with two vertical lift gates, each 12 m wide by 3.3 m high	Max discharge to Moomin Creek: 2,200 ML/day
Gundare regulator	Control flows from Mehi River into Mallowa Creek	Concrete structure with two vertical lift floodgates, each 6 m wide by 1.5 m high	
Mallowa regulator		Concrete structure with two radial floodgates, each 3.7 m wide by 1.5 m high	

4.6.1 Data sources

WaterNSW manages releases of water from the major storages to meet environmental and licensed water user requirements, and operates and maintains the regulating infrastructure, including keeping records of key parameters such as the storage capacity, volume-surface area relationships, and maximum release rates at each structure.

4.6.2 Modelling approach

Major dams

The major water storage and key weirs in the Gwydir Valley model were configured using the relevant engineering parameters provided by WaterNSW. Capacities are listed in Table 7 and storage curves provided in Appendix D.

The IQQM storage node in the model simulates a range of physical processes at the storage, including the effect of rainfall and evaporation on storage volumes, and seepage. It also includes simulation of key management actions, including releases of water to meet downstream demands and other operating rules.

Weirs

Boolooroo, Tareelaroi, Combadello, Tyreel, and Gundare Weirs were configured as diversionary weirs that control diversion of flows into the main effluent rivers and creeks subject to specific operating rules at each site.

Limitations in the capability of IQQM has meant that the relatively small re-regulating function of the weirs has not been represented.

5 Modelling water access and licensing

Water can only be taken from rivers and streams in NSW under a licence or a right. The major categories of water access licences used in this report to describe water access are:

- regulated water access
- supplementary water access
- floodplain harvesting water access
- unregulated water access
- groundwater access

5.1 Water licences

The main licence categories for access surface water sources are listed in Table 8. Some water can be taken without the need for a licence under basic landholder rights as described in the *Water Management Act 2000* and the Gwydir WSP.

Table 8 Surface water access licence types in the Gwydir regulated river system

Licence type	Note
High security	Includes local water utilities, horticulture, permanent plantings, stock and domestic
General security	Water able to be ordered from storages
Supplementary water access	Water not reliant on infrastructure for storage or distribution

Higher security (water utilities, stock and domestic) licence categories receive full allocations of water each year except in extreme drought conditions.

There are a small number of high priority licences issued to towns (local water utility licences), and high-security water access licences for some agricultural purposes, such as horticulture or permanent plantings (e.g. orchards or vineyards). Most irrigators hold general security water access licences with larger volumes of water designed to support irrigation of annual crops such as cotton and winter cereals. Water allocation varies from year to year with the prevailing climatic conditions and the resulting inflows to the regulated river system.

Under the *NSW Water Management Act 2000*, extraction of water for basic stock and domestic rights from a property with river frontage, and for native title rights, does not require a water access licence. There are currently no extractions for native title rights in NSW.

5.1.1 Data sources

Licences in NSW are issued by the Department of Planning and Environment Water (the department) who maintains a database of all surface and groundwater access licences and works approvals. This database, known as the Water Licensing System (WLS) is linked to the formal public register of licences maintained by NSW Land Property Information.

All information used in our models regarding the category and number of water access licences, the shares they hold, the works (pumps, etc) they are attached to, and the location of those works are taken from the WLS. For some scenarios that are historical (e.g. Cap on diversions which requires some 1993/94 data), prior records within the department are used. The total number of share components issued for each licence category is shown in Table 9.

Table 9 Share components in the Gwydir regulated river system (as at 30 June 2020)

Category	Consumptive	Environmental water	Total
Domestic and stock	2,824	0	2,824
Local water utility	3,836	0	3,836
Regulated river (high security)	14,503	5,757	20,260
Regulated river (general security)	403,048	106,617	509,665
Supplementary water access	157,807	23,591	181,398
Total	582,018	135,965	717,983

No information is available on water use under Basic Landholder Rights, other than the estimated total non-licensed water requirement for domestic and stock rights of 6,000 ML/year in Part 4 of the Gwydir WSP.

5.1.2 Modelling approach

Licences are configured for all the individual water user nodes in the model representing each irrigation property, and all groups of properties. Representation of licences in the model has been simplified to represent the main licence categories: high security, general security and supplementary access licences.

Irrigation enterprises based on high security and general security licences have been modelled as such. Small amounts of high security, stock, or domestic entitlements belonging to enterprises based on general security have also been modelled as general security, but with a higher priority for allocations than general security licences. Where water users have significant groundwater or unregulated water access licences, these have also been configured.

Water use under Basic Landholder Rights is not explicitly included in the model but are implicitly accounted for in the calibration of instream flow–loss relationships.

5.2 Regulated water

Water controlled by the major dams is assessed each month, and the available water is shared to water access licences (except supplementary water access licences) via allocation announcements.

This water is known as regulated water, and licence holders may order delivery of this water from the river operator (WaterNSW) from time to time, up to the limit of the water in each licence's account. During wet periods, river operators may make use of tributary inflows downstream of the major dams to deliver water orders. During very dry periods, the river operator may defer delivery of individual water orders until there is a large enough volume, and release water during a specific period (known as a block release) to reduce transmission losses. Water meters measure the majority of regulated water that is pumped from the Gwydir regulated river system.

5.2.1 Data sources

Water users in major regulated river systems measure water use via flow meters installed and maintained at pump sites for all significant sources of surface water, except for floodplain harvesting and unregulated diversions. Very small water users are not currently required to order water or measure their diversions. WaterNSW maintains a database of water orders and use the Water Accounting System (WAS) and arranges for meters to be read at varying intervals. Prior to 2004, water use records are maintained in a predecessor database system. Larger water users may have meter readings undertaken monthly or quarterly, whereas smaller water users have meter readings undertaken less frequently.

These records are available for the reaches below Copeton Dam from the commencement of metering in the 1980s to the present. Operational data collected and used for daily management of releases from the major storages, such as flows, water orders, and water use (e.g. meter readings communicated to the river operator by irrigators), are available from the river operator (WaterNSW) and can be used where data are unavailable from WAS.

Accuracy of meter readings varies depending on the type of meter, and the nature of the installation. Meter manufacturers have layout requirements (usually the length of straight pipe either side of the meter) for meters to operate accurately. NRAR periodically undertakes verification tests on meters to ensure they are being maintained in reasonable condition and are operating correctly. Over time, propeller type meters have been progressively replaced with more accurate electro-magnetic or ultrasonic meters. The national standard for non-urban water measurement is intended to ensure measurement errors are within 5% of the volume diverted. NSW now requires meters and installations to meet these standards, with a phase-in period up to 2021.

Recorded water usage at monthly time steps or longer needs to be disaggregated to a daily time step for use in the model for simulating water use and to estimate water losses.

Records for the period prior to 2004 were disaggregated from monthly or longer periods for the previous Gwydir Valley model builds and have been re-used for the current work. Since 2004, metered data was disaggregated to daily time steps, using water order data.

The total metered diversions over the period used to calibrate water use in the model are shown in Figure 15.

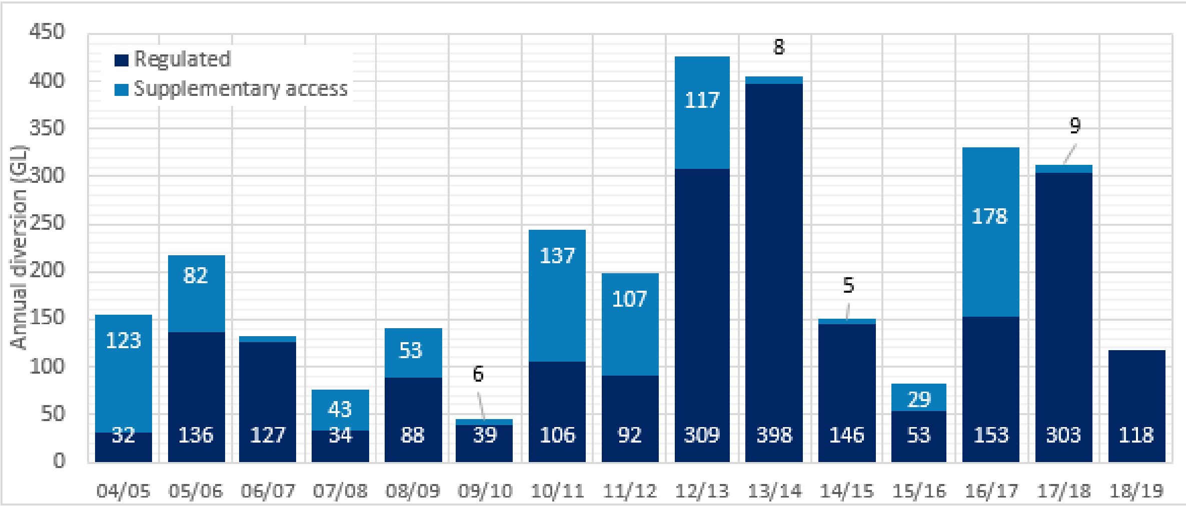

Figure 15 Total metered diversions in the NSW Gwydir Valley

5.2.2 Modelling approach

The supply of regulated water involves the sharing of water between the consumptive users and environmental requirements under the Gwydir WSP, and the allocation of water to licences, together with the ordering and delivering water in the regulated river system.

Water orders are generated by the simulation of irrigation demands. The simulation of water sharing, the allocation of water, and the delivery of water by river operators using water management infrastructure are described in Section 7 Modelling water management rules.

5.3 Supplementary water

When there are rainfall events resulting in significant inflows from tributary streams downstream of headwater storages, or spills from major storages, the river flows may exceed requirements for water orders or other flow requirements set out in the Gwydir WSP.

These excess flows are referred to as uncontrolled flows, which WaterNSW announce as available for supplementary water access.

Supplementary water access licences allow water to be taken during these flows up to the limit of the water in each licence's account. Water meters measure the take of water by most supplementary water access licences.

The river operator usually manages access via an expression of interest process unless the event is sufficiently large that there is more than enough flow for all the supplementary access licence holders. Within the Gwydir Valley, supplementary water access is a significant source of water supply for irrigators.

5.3.1 Data sources

Supplementary access periods announced by WaterNSW are recorded in the WAS. Diversions during these periods are measured from meter readings using the same meters as for regulated water use and are recorded in the WAS as a total volume for that event, or a set period of time (e.g. monthly). As with regulated diversions, where possible recorded supplementary diversions are disaggregated based on flow, announced supplementary access periods and pump capacity.

5.3.2 Modelling approach

Access to water from the river is permitted for supplementary water access licences when flows are more than required for regulated water in the river and exceed the flow requirements set in the regulated WSP.

The model controls access via uncontrolled flow river reaches, with at least one uncontrolled flow river reach designated for each river reach in the model. Supplementary access is made available to each uncontrolled flow reach when the model meets conditions set out in the regulated WSP, and also when flows exceed a user configurable threshold that are used to reflect Water NSW's operational practices.

Supplementary access licence accounts for each water user node are configured so that water access is shared based on the number of share components for that licence relative to the other licences in that river reach.

The simulation of supplementary water access is summarised in Table 10.

Table 10 Simulation of the components of supplementary water access

Component	Modelling method
Sharing between consumptive access and the environment.	Supplementary events in the system are not declared unless flows exceed immediate water use requirements plus the sum of the tributary inflows from the Horton River, Halls Creek, and Myall Creek, up to a maximum tributary inflow of 500 ML/day 50% of the flows in excess of immediate requirements and the protected tributary inflows are made available for consumptive use at the Pallamallawa flow gauge in the model
Uncontrolled flow reach definition	Uncontrolled flow reaches are aligned with operational river reaches with some additional sub-divisions for model requirements to handle bifurcations and confluences in IQQM
Thresholds	Event starts if: Flow > ‘threshold volume’ + Orders Event ends if: Flow < ‘threshold volume’ + Orders Threshold volumes have been calibrated to reproduce recorded supplementary access diversions, and vary widely between reaches and across each month of the year
Cap on usage	A 1 ML/share usage limit is defined on a reach basis (‘annual usage limit’)

5.4 Floodplain harvesting water

In addition to the regulated and supplementary licence categories described above, many irrigation properties can harvest water flowing across the floodplain that has either broken out from the main river (overbank flow) through breakouts, or which is the result of rainfall–runoff.

Floodplain harvesting is inclusive of both overbank flow harvesting (water from breakouts) and rainfall–runoff harvesting from local areas and within the properties. Floodplain harvesting has not been directly measured to date; individual irrigation property studies and other anecdotal evidence indicate that irrigators can and do take significant volumes of water in this way.

The harvesting of overland flows through Floodplain Harvesting Licences is being implemented. These licences limit the amount of water that water users can take from the floodplain either as the result of overbank flows or rainfall–runoff that enters or is generated upon the licence holder's property.

Figure 14 shows the area potentially covered by overland flow from breakout locations. Major irrigation properties are shown in Figure 7.

5.4.1 Data sources

Overbank flow

Water harvested from overbank flow is not as yet officially recorded. A small number of respondents for the farm survey included estimated overland flow harvesting volumes. Many properties indicated the timing of the overland flow harvesting events, while few provided estimates of volumes harvested. This part of the farm survey data was treated only as indicative.

Due to the absence of recorded data, we undertook a multiple lines of evidence approach to assessing floodplain harvesting. We used a capability assessment to consider the physical infrastructure used for floodplain harvesting and the opportunity irrigators may have to access floodplain flows based on their location and climatic variability. Where appropriate, additional checks using satellite imagery and aerial photography were undertaken. We also used a water balance assessment given historical crops grown and the estimated water requirements. This assessment focussed on the reach and valley scale to ensure that the total volume of water, including historical metered use and estimated floodplain harvesting, was representative of the estimated historical water use.

Runoff harvesting

The farm survey requested information on rainfall–runoff harvested from within properties. Harvesting occurs from areas developed for irrigation as well as other non-developed areas within the property. The non-developed areas reported as contributing to rainfall–runoff harvesting were smaller; around 55% of the developed area reported. In some instances, there is the ability to directly intercept runoff from local areas outside of the farm. This has been represented either through the overbank flow harvesting estimated, or it is represented as rainfall harvesting by adding additional area to the undeveloped area model.

Twenty (20) farm survey respondents provided estimates of summer rainfall runoff volumes harvested, and 10 respondents provided estimates of winter rainfall runoff volumes. These estimates were analysed to estimate what percent of annual rainfall these volumes represented. However, no positive trend with increasing rainfall was discerned. There was uncertainty in these estimates as to what area of land this runoff was from, and whether these separated out rainfall–runoff from outside of the property. To improve our confidence in runoff rates, alternate lines of evidence were considered as detailed in Appendix E. Further data collection is required to confirm the runoff patterns and volumes under different cropping conditions.

5.4.2 Modelling approach

Overbank flow harvesting

The water available for floodplain harvesting is simulated through the breakouts (as described in Section 4.5.2). The extraction of this water is simulated through supply point nodes; these use the overbank pump capacity to represent the floodplain harvesting capacity. This capacity, or intake rate, was generally set to the total capacity of on-farm storage pumps for the property, or the total capacity of overbank flow intercepting works was used where it was smaller. In cases of properties with temporary storages, the total lift rate to the on-farm storage and the total take rates are used.

All intake rate data were obtained from NRAR as part of the licensing process. Where there is eligible harvesting of localised rainfall–runoff, this is either added to the overbank flow or the rainfall–runoff modelling within the property. Further information is in Section 6.2.2.

Runoff harvesting

The upgraded models for floodplain harvesting use the best available information on rainfall–runoff, and account for differences in runoff rates between undeveloped, developed and irrigated areas. A separate rainfall–runoff model embedded in the crop water model is included for each property, continuously tracking the soil moisture of undeveloped, developed and irrigated areas. This enables the calculation of different rates of runoff from these areas based on soil moisture and rainfall. We calibrated these property area models to produce a long-term average rate consistent with available data as outlined in Section 6.2.2. Rainfall–runoff harvesting generally refers to harvesting within the property.

In a few instances eligible access to localised runoff from outside of the property has been either incorporated into the property area model and reported as part of the rainfall–runoff harvesting result, or it is represented as rainfall harvesting by adding additional area to the undeveloped area model.

5.5 Unregulated water

NSW has issued licences on rivers and stream that are not regulated by major infrastructure. These typically allow access when flows at a nearby river flow gauging station reach certain levels but does not guarantee that flows will be available at any time.

A small number of irrigators that access regulated water also have water access licences on a nearby unregulated watercourse. Most of the unregulated licences for water access on unregulated rivers and streams are either upstream of the regulated river reaches or for conveyance only. Conveyance licences allow the holder to take water from the river using their regulated river licence and then transfer the water to their fields or storage through an unregulated channel. The conveyance licence only allows them to take the volume which was extracted under the regulated river license and not any additional water which may occur at the extraction point due to unregulated inflows.

The diversion of water by most unregulated water access licences is not measured. However, larger water users will be required to install meters under the NSW metering policy.

5.5.1 Data sources

A significant number of regulated water users also have unregulated water licences that access another nearby unregulated water source, with approximately 38,500 shares of licensed entitlement, although metering data is generally not available.

A few properties have unconverted unregulated licences which are in the process of being converted (by WaterNSW). While most of these are for conveyance of water taken under a regulated access licence, some may receive an unregulated licence entitlement once converted.

5.5.2 Modelling approach

A significant number of irrigation enterprises on the regulated river system have been identified as accessing water from an unregulated stream, and this has been configured in the model for those individually modelled properties that are eligible for floodplain harvesting licences. For each such user, the access conditions on the unregulated access licences are configured. However, flow records in these unregulated streams are not usually available, and the simulated flow in the unregulated streams has only been coarsely estimated, by correlation with nearby catchments and/or river reach water balance.

Unregulated flow access in the upper parts of catchments is not explicitly represented. The effect of these diversions is recognised inherently in the gauged inflow data and hence the inflows (observed and modelled) are net of any such usage.

5.6 Groundwater

NSW has issued licences that allow taking of water from the alluvial aquifers that underlie the Gwydir River and other streams for irrigation and town water supply. NSW has issued approximately 34,000 ML/year of aquifer access licences, and water use is limited to an average of approximately 100% of the licensed entitlements each year under the Water Sharing Plan for the Lower Gwydir Groundwater Source, and the Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012[5].

[5] These water sharing plans were replaced in 2020 by the Water Sharing Plan for the Gwydir Alluvial Groundwater Sources 2020

5.6.1 Data sources

Approximately 30% of regulated water users eligible for a floodplain harvesting licence also have groundwater water licences. There is some metering data available for larger groundwater users. Farm survey respondents with groundwater access also typically provided information about the licences, and some information about how the groundwater was normally used.

5.6.2 Modelling approach

Access to groundwater has been configured in the model for those individually modelled properties that are eligible for floodplain harvesting licences with existing groundwater access. Groundwater volumetric entitlements and historical usage were sourced from the farm surveys, while the pattern of use was developed based on landholder's advice combined with diversion calibration at some properties with reliable records. Groundwater use in the model is linked to volume of water available in the on-farm storage during the irrigation season: that is extractions are triggered when volume in the on-farm storage drops below a certain level. In general, groundwater use is more prevalent in dry periods.

6 Modelling water users

The construction of major dams and the regulation of river flows have enabled the delivery of water to water users and issuing licences for the supply of water. There are a small number of high priority licences issued to towns (local water utility licences), and high-security water access licences for some agricultural purposes, such as horticulture or permanent plantings (e.g. orchards or vineyards). Most irrigators hold general security water access licences, that have larger entitlements to water designed to support irrigation of annual crops. Many of these irrigation farms also have licences that allow them to take water when there are uncontrolled flows in the river that are more than demands for water by the other forms of licences described above, known as supplementary water access licences.

6.1 Urban water supply

Local Water Utility access entitlements have been issued to Inverell (supplied by pipeline from Copeton Dam), Gravesend and Bingara (on the Gwydir River) and Weemelah (on the Gil Gil Creek). Apart from Inverell, these are very small licences compared to the larger licences used for irrigation, but they have the highest priority of supply.

6.1.1 Data sources

A small number of urban water utilities take water from the regulated Gwydir river system to supply domestic, commercial, and industrial users in the town. In all cases diversion estimates used in the previous IQQM were adopted for modelling purposes. These are sufficiently accurate for most model uses considering the much larger volumes used for irrigation.

6.1.2 Modelling approach

The very small volumes of town water supply in the Valley are represented as fixed monthly patterns with an annual use equivalent to the entitlement, as per previous modelling. The results in this report do not include these diversions.

6.2 Irrigators

Diversions in the regulated part of the Gwydir River system are predominantly due to irrigated agriculture, which accounts for over 95% of the total water use on average. These water users have access to a range of water sources: high and general security, supplementary access and floodplain harvesting. Some regulated water users also have access to unregulated flows and groundwater. General security and supplementary access licences form the basis of most irrigation. Some irrigators also have licences for stock and domestic use.

Most irrigated agriculture is for cotton, with varying amounts of winter cereal grown depending on seasonal conditions, and there are very few permanent plantings in the Gwydir Valley (there is one substantial planting of pecan trees).

Numbers and distribution

There are 454 individual regulated river licences as at March 2020, with most being in general security (173 licences) and supplementary (156 licences) categories. The upper parts of the regulated river system are where smaller licences that generally don't have on-farm storages are typically located, and only relatively small volumes of water are taken for irrigation. There is one significant high-security licence upstream of Pallamallawa with approximately 80% of the total high security shares in the valley that is used to support permanent plantings. Another 19 high security licences are distributed across the regulated river system, with 5 irrigators holding the majority of the remaining high security shares. Most larger water users are located on the floodplains below Moree (Figure 7).

6.2.1 Data sources

Diversion of water by irrigation enterprises is a major component of the water balance in a regulated river system. Information on metered diversions, private irrigation infrastructure and the areas of crops irrigated in the regulated Gwydir river system each year are essential for configuring the model and for calibrating the modelled demand and water use patterns by irrigators. A summary of data sources is presented in Table 11.

Table 11 Data sources for data types used for parameterisation of irrigation property modelling

Data type	Data source	Model use
Diversions	Water Accounting System (WAS) where available, internal records otherwise	Flow calibration and diversion calibration. Not used as an input during model simulations
Licences	Water Licencing System (WLS). During initial model development we also adjusted for permanent and temporary trades where consistent trends were identified. The final model uses licences fixed to a point in time depending on which scenario is being run.	Configuring Resource Assessment which links the licence to an individual water user node
Farm infrastructure (storages, developed area, additional rainfall harvesting areas, pumps)	Permanent on-farm storage capacity initially based on farm survey and updated based on NRAR advice which was based on a combination of LIDAR and physical survey data. On-farm storage losses modelled through Morton's Lake evaporation data and seepage based on 2 mm/day based on data from Wigginton (2012a)	Farm infrastructure (storages, developed area, additional rainfall harvesting areas, pumps)
Area on farms developed for cropping, and undeveloped area contributing to rainfall–runoff	Farm survey for individually modelled water users. For other relatively small water users estimated based on either earlier survey data or estimated based on the year of maximum diversions and an assumed application rate of river extractions per hectare	Configuring upper limit to planted areas, and contributions to rainfall–runoff for relevant water user nodes
River pumping capacity	Farm survey and WaterNSW's water ordering records were used for individually modelled water users	Configuring rate of water diversions from the river for regulated and supplementary access for all water user nodes

Data type	Data source	Model use
Floodplain harvesting rate	FPH rate was generally set to the combined on-farm storage lift rate. This was initially based on farm survey data; however, the final model was based on NRAR's data. Where appropriate the FPH rate was set higher or lower than the on-farm storage pump rate: • reduced rate if the total FPH intake into the developed area is restricted due to pump/pipe capacities • allowance for higher rates where properly constructed temporary storages confirmed by NRAR allow for a higher rate of intake to property before transfer to permanent storage NRAR supplied pump rates, using standard conversions for pump type and size (Appendix F). They also supplied estimated rates for pipe	Configuring rate of water harvesting from floodplains and rainfall–runoff for relevant water user nodes
Crop watering efficiency	Efficiency factor (30% loss) based on industry advice and research Note that tailwater returns are not explicitly modelled – efficiency and hence application rates are net of returns	Configuring rate of on-farm losses during irrigation watering for relevant water user nodes. Some allowance for channel losses was included in this parameter
Crop factors and soil parameters	Crop factors and root depth based on FAO56, however specific values derived in consultation with agronomists from Department of Agriculture for different climatic zones in NSW (DLWC 2000). Some refinement of the cotton crop factors was implemented after more recent consultation with DPI Agriculture. Adopted values listed in Table 18. Total available water is defined based on root depth for each crop type (DLWC 2000) and also for fallow and undeveloped areas. Soil moisture capacity (20%) based on industry advice (MDBA 2018)	Configuring crop models for relevant water user nodes to simulate total crop water requirements
Crop planting dates each year	Planting date based on farm survey data where available (preferred date), else based on NSW Dept Agriculture advice (DLWC 2000)	Configuring crop models for relevant water user nodes
Climate data	SILO patch point sites data (Morton Lake for on-farm storage evaporation, Penman Monteith for crop modelling)	Input to crop models that drives simulation of crop water requirements for relevant water user nodes

Regulated and supplementary metered diversion data are described in Sections 5.2 and 5.3 respectively. Information on entitlement distribution is maintained in the Water Licensing System (WLS). Information on some on-farm infrastructure has been collected in the past by WaterNSW. However, the farm survey and NRAR field verification of farm infrastructure represents a significantly expanded and updated dataset and has undergone various verification checks.

These structured farm surveys undertaken for the Floodplain Harvesting Project for every property that registered interest are the most contemporary and detailed source of information on farm infrastructure, area planting decisions, irrigated crops for the period 2004/05 to 2012/13. The participants in the farm survey represented over 90% of the licensed entitlement to water and over 95% of the annual water use in the regulated Gwydir river system. Infrastructure information in these surveys was verified by NRAR staff. However, other data gathered in the surveys were sometimes incomplete.

The farm survey data were reviewed using other lines of evidence and updated or supplemented for missing data where appropriate. The principal alternate lines of evidence considered were the results of farm inspections by NRAR staff, and the use of remote sensing data to estimate on-farm storage volumes and verify date of construction. The various lines of evidence used to supplement the farm survey are discussed in the following sub-sections on irrigator infrastructure, crop areas, and floodplain harvesting.

Numbers and distribution

Data relating to numbers and distribution of irrigators and the licences they hold were obtained from the Water Licensing System (WLS).

Infrastructure

On-farm infrastructure such as areas developed for irrigation, storages and pump capacities allow us to model likely water harvesting and usage volumes in the model. Current levels of infrastructure were well documented from the farm surveys, however, information on historical development for many surveyed farms was either incomplete or uncertain because of change in ownership and gaps in recordkeeping.

On-farm storage volumes and surface areas were derived using remote sensing (LIDAR) data. Where good quality physical survey data was provided this has been used instead. In both instances a 1 m freeboard was assumed for permanent storages. Either of these methods provide an objective basis to determine capacity. Remote sensing methods were also used to validate history of development of storages. This is explained further in Appendix F.

River pump capacities were based on information from farm surveys. On-farm storage pumps were initially based on information in the farm survey; however, the final model is based on NRAR data for pump size and type, and NRAR advice on the associated capacity and intake restrictions if any (Appendix G). Allowance was also made for higher rates where NRAR staff confirmed that properly constructed temporary storages allow for higher intake rates prior to transfer to a permanent storage. Standard rates for pipe size and intake rate were also used to review intake rates.

Historical on-farm storage pump capacity was determined at key dates based on which storages were constructed at that date. This means that if the storage did not exist, we assumed the pumps associated with that storage did not exist. In some instances, storages are a collection of cells attached to each other with one pump station; if one of the cells existed at the scenario date then we assumed that all the pumps existed at that date. We also reviewed farm survey data and NRAR data for any advice about pump and pipes upgrades that occurred over time.

Areas developed for irrigation were primarily based on information from the farm survey and verified by NRAR staff. We also compared the developed area to maximum historical cropping, which was also verified using remote sensing.

The latest data for on-farm infrastructure for different parts of the regulated Gwydir river system are set out in Table 12. The developed area and river pump capacities are predominantly from a combination of farm survey data and WaterNSW's data processed in 2014/15 so represent

2014 level of development. The permanent on-farm storage capacity and pumps represent a more contemporary estimate of capacity. LIDAR data was also supplemented by photogrammetry in 2019 and by many professional physical surveys obtained in 2020 as part of the floodplain harvesting farm scale validation process.

Comparative levels at prior dates used in scenario development are summarised in Table 13, which shows a 6% increase in developed area, and a 80% increase in on-farm storage capacity from 1993/94 to now.

Table 12 On-farm irrigation infrastructure current estimates

Reaches	Developed area (ha)	Permanent on-farm storage capacity (ML)	Temporary on-farm storage capacity (ML)	River pump capacity (ML/day)#
Gwydir River	28,386	84,308	2,810	6,269
Mehi River	33,965	148,642	248	4,121
Moomin Creek	39,192	155,034	18,535	3,188
Carole / Gil Gil Creeks	32,923	135,474	6,165	6,584
Total	134,467	523,458	27,758	20,162

Note: # - Refers to operational rather than installed/nominal capacity, the latter being about 13% higher

Table 13 On-farm irrigation infrastructure estimates at prior dates

Development level	Developed area (ha)	Permanent on-farm storage capacity (ML)	Temporary on-farm storage capacity (ML)	River pump capacity (ML/day)
1993/94	121,030	310,927	28,058#	20,162
1999/00	129,466	398,186	As above	As above
2008/09 (existing)	135,861	462,708	As above	As above

Note: # - Higher capacity in earlier years is due to one of the properties converting surge area into irrigation fields post 2009

Irrigated crops, crop areas and crop water use

Having access to the history of crop areas and types planted is important. It improves the ability of the model to simulate the planting of crops under a range of climate and water availability situations, providing a more robust estimate of water requirements and diversions from rivers and floodplains over the longer term.

About 85% of the surveyed irrigators provided complete or partial irrigated cropping records for the 11-year period covered in the farm surveys. About 55% provided crop areas for at least 8 out of the 11 years surveyed. Overall, across the period survey, farms did not report irrigated crop areas in approximately 41% of years. The coverage of information arising from the farm surveys is described further in Appendix G.

To improve our understanding of irrigated crop areas, remotely sensed imagery[6] was used to identify paddocks with irrigated crops in the summer period. Areas were then measured using

[6] The analysis used a combination of MODIS (Moderate Resolution Imaging Spectroradiometer), IrriSAT and Landsat imagery

the online IrriSAT service[7] to provide an independent measure of crop areas and to provide information about how much water has been applied to crops. The crop water application rates from IrriSAT also enabled the measured area to be scaled to provide an equivalent area of fully watered crop in cases where there was significant underwatering occurring.

The derived irrigated crop areas were used to fill the gaps in the farm surveys for years where crop areas were not reported. Through the gap filling process, and as part of reviewing submissions made as part of the farm-scale verification process, approximately 17% of areas reported by farm surveys were also checked and adjusted to match the remote sensing results.

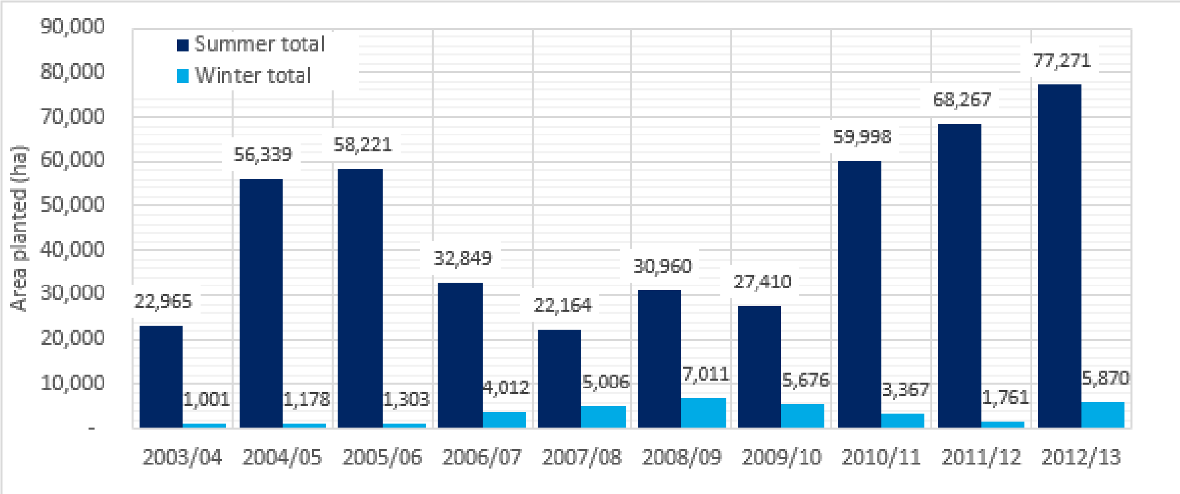

Figure 16 Reported summer and winter planted crop areas over the period 2003/04 to 2012/13 [Source: IBQ farm surveys]

Analysis of reported crop types shows it is dominated by cotton grown during the summer growing season, with significant areas of sorghum, and small areas of beans and corn also grown in summer. Wheat is also grown in the winter growing season on an irregular but increasing basis.

The farm surveys indicated that areas planted in summer were strongly related to water availability, whereas for winter crops this was not as significant a factor. The decision on how much crop to plant based on water availability varied between individual properties in the range of 3 to 10 ML/ha for cotton and other summer crops, and in the range of 1 to 4 ML/ha for winter wheat.

The farm survey did not provide planting decision information for other crop types, so these were estimated as is described in the following section.

The farm surveys included estimates of rates of water use by crops, including pre-watering and tailwater return flows. Analysis of this information indicated a large range of water use rates reported, varying from 3.6 to 11.5 ML/ha for cotton. The reasons for this wide range of water use was difficult to reconcile, there was no geographic basis for this. Potential reasons for this wide range include different periods this may have been calculated over, whether this factored in pre-watering and efficiency, possibly different approaches to recordkeeping and different practices.

[7] IrriSAT is an irrigation decision support system. It uses satellite images to derive vegetation condition to inform farmers how much water their crop has used and how much irrigation they need. https://IrriSAT-cloud.appspot.com

The estimate of total water use by irrigation is critical for the water balance on a reach basis and to develop confidence that the total water inflows to the farms are sufficient to irrigate crops. Further lines of evidence were required to arrive at a robust set of parameters, and included data from the Australian Bureau of Statistics, WaterSched Pro software, remote sensed data from the IrriSAT platform and parameters prescribed by the FAO crop model method. These sources are discussed in Appendix H. Using these evidences, a common set of parameters (apart from climate station and planting decision and date) were adopted for all properties.

6.2.2 Modelling approach

This section deals mainly with Stage 4 (Irrigation diversions) and Stage 5 (Irrigated planting areas) of the stages of model assembly (Table 2).

Irrigation farms are modelled concurrently within the context of a reach as they rely on the volumes of water breaking out from the river as a source of water.

Modelling of irrigation water use is based on a water balance approach as described in Section 2.3.1 and illustrated at Figure 2, where all of the water that enters a farm (metered and unmetered diversions, rainfall on the land), and the water that leaves the farm (evapotranspiration from land and storages, and seepage) must balance each other. We use the irrigator model within the water user node in IQQM for this purpose. We refer to this as the irrigator node.

Overview

The representation of each irrigator node has used the best available data and methods for long-term simulation modelling as outlined in Table 14. In the model, all processes operate on a daily time step.

Table 14 Steps in the simulation of irrigation diversions and irrigated planting areas

Component	Modelling process
On farm infrastructure	On-farm storages along with pump capacity simulate diversion and storage of multiple water sources, including regulated water and floodplain harvesting Evaporation and seepage losses and rainfall on the storage are explicitly modelled Usage for irrigation is simulated based on demands On-farm infrastructure also includes areas of land developed for irrigation
Crop area planting	For calibrating parts of our model, we can use actual planted areas as advised by farm survey and supplemented by remote sensing. However, in long term simulation modelling, the crop areas are simulated based on a relationship with water availability. This enables the models to be representative of the planting and diversion behaviour over diverse climatic periods
Crop models	IQQM provides crop models that simulate total irrigation demand for a given area and type(s) of crops. This is done by simulating the soil moisture balance, based on the of use climate data (rainfall, and evapotranspiration) to estimate the water use by each crop type. When the soil moisture falls below configured trigger levels the crop model orders water
Rainfall–runoff harvesting	Simulates rainfall–runoff from within the property boundaries from fallow, irrigated crop and undeveloped areas In a few instances is also used to simulate localised rainfall–runoff harvesting from outside of the farm
Overbank flow harvesting	Simulates the diversion into storage of water on the floodplain outside of the property and may include localised rainfall–runoff

The parameter summary for the simulation of water demands is given in Table 15.

Table 15 Water demands calibration approach

Step	Fixed input data	Target to meet	Parameters
Demand	Climatic data Cropped area Infrastructure	Metered diversions Published data on crop requirements	Crop requirements (a set of model parameters, either calibrated or pre-set to defined values, are derived to achieve crop requirements in line with literature and reported application rates, i.e. ABS, IrriSAT) On-farm storage operation (discussed further below)
Crop areas	Water available at planting decision date (simulated)	Reported crop areas and checked against remotely sensed data	Planting decision function

The Gwydir Valley model includes a number of different scenarios representing development at different points in time. The primary model has development set at 2008/09 levels.

Each irrigation farm or group represented in the model was initially parameterised as described in the following sub-sections. Further assessment and refinement occurred in subsequent stages of the model building process when system operation and management rules were simulated. Adjustments made during these later stages are noted in relevant sections. While the period 2004/05 to 2012/13 was used as an initial calibration period for some components of the model, many components were configured or calibrated using other periods of time as is noted throughout this report. For example, rainfall–runoff rates were calibrated using a longer period of time to match published data. We therefore refer to the period 2004/05 to 2012/13 as an assessment period for the final model performance. This period was chosen for the following reasons:

- best available relevant data at the time of model development
- sufficiently long enough period to represent climatic range in the region (Table 16). This is important to ensure that the model is robust during different periods of water availability
- includes key benchmark years for the NSW Floodplain Harvesting Policy and the Basin Plan.

Table 16 Comparison of rainfall statistics over assessment period to long term record

Metric	Long term (1890–2019) (mm)	Short term (2004–2013) (mm)
Average	578	633
Maximum	1,061	1,012
Minimum	258	438

Note: Statistics are for Moree (053048) and are based on July to June year

Numbers and distribution

Those Irrigation farms that were assessed as eligible for floodplain harvesting entitlements have been represented in the model either individually or as a group. The remaining, generally smaller, farms and other water users have been aggregated in the model within the reach they are located. As a result, 114 individual eligible floodplain harvesting farms within the Gwydir Regulated Water Sharing Plan area were represented using 86 irrigator nodes, of which 13 represent groups of up to five individual eligible properties (mostly enterprises consisting of several properties with one owner and properties that have been subdivided post 2008).

Farm infrastructure

Each irrigator node has been configured to represent the key relevant infrastructure, including: pump capacities for regulated and supplementary access, the rate at which any floodplain harvesting access can be taken, the capacity and volume-surface area of on-farm storages, the total area developed for irrigation, and any undeveloped areas that contribute to rainfall–runoff harvesting.

The model generally only includes one permanent on-farm storage for each irrigator node. This represents all such on-farm storages. The volume-surface area relationship has been defined based on the assumption of storages being filled sequentially, generally from most to least efficient. This means that it can reflect smaller surface areas when held volumes are low and not all storages or cells would be in use. We tested the sensitivity of the model to this assumption (Section 9) and found that the simulated floodplain harvesting was not sensitive to this assumption.

Crop area planting

For long-term simulation of planted areas, the model needs to simulate the crop areas to be planted each year for irrigation. The planting decision determines the crop area planted as a function of water availability. Other socio-economic variables which in reality affect the area planted in any one year are not taken into account as data are not generally available for this, and the objective is to provide a reasonable and consistent representation over a long climatic period.

A ‘risk factor’ is used to define the planting decision. This is the volume of water required to be available before a water user would plant one hectare of a given crop (i.e. megalitres required per hectare).

In previous river system modelling, planting decisions were estimated using independent data analysis relating crop areas to water availability at the time of planting. This approach is no longer suitable for much of the Gwydir valley because the volume of water in on-farm storages is a significant component of water availability and we do not have recorded data for this. This means that water availability needs to be simulated.

The planting decision application rate for cotton was based on risk values reported in the farm surveys and varied between 3–10 ML/ha between properties with the average being 6.8 ML/ha. In some cases, the reported value was adjusted slightly to achieve a better match between simulated and historical planted areas. The survey data did not include risk values for crops other than cotton. A default risk value was assumed for other crops and calibrated if required. These are summarised in Table 17.

Table 17 Adopted crop planting decision rates, i.e. the volume of water required to be available before an irrigator decides to plant 1 ha of a given crop

River section	Summer decision rate (ML/ha)	Winter decision rate (ML/ha)
Carole – Gil Gil Creek	7.17	2.93
Gwydir River	6.86	1.35
Mehi River	6.63	1.00
Moomin Creek	9.10	1.11

As noted in the Data sources section, winter crops are planted irregularly and do not appear to be related to water availability. The model was configured to replicate average winter diversions rather than replicate the time series of planted areas by calibrating a maximum winter crop area such that the average winter diversions match recorded over the assessment period.

For properties with one summer and one winter crop type the planting decision for each crop is relatively simple:

1. The model calculates water availability as the sum of the volume currently stored in on-farm storages and licence account balances
2. This is then divided by the ‘risk factor’ which defines how many hectares to plant per megalitre of water available, constrained by a maximum area
3. The total area planted cannot be larger than the developed area but can be less due to crop rotation. Where required, a smaller maximum area was specified for example if the maximum area historically planted was consistently less.

For farms with more than one crop type per season, the planting decision takes into account the water required to finish the existing crop and also ensures that the total area planted does not exceed the developed area. For areas where floodplain survey data were available, the crop mix was simplified to the most representative crops, i.e. those which were planted more often. This reduced the crop mix to largely cotton and winter wheat, with minor exceptions.

Crop water use

Crop models simulate the total water requirement of the crops being irrigated and are the core of the irrigator nodes in the model. The crop model uses recorded climate data and either recorded crop areas (for calibration) or simulated crop areas (validation and long-term scenario simulations) as primary inputs and simulates the water requirements of those crops. These water requirements are used by the irrigator node in the model to either take water already stored on farm, or to order water from the major dams. Fallow areas are also simulated as a crop type to allow for the continuous simulation of the soil moisture through to the next crop planting.

Crop models simulate a soil moisture balance on a daily basis using climate data (rainfall, and evapotranspiration) to estimate the water use by each crop type (e.g. cotton, wheat) and need for irrigation. To ensure irrigation requirements vary with climate appropriately, the nearest climate station (rainfall, evapotranspiration) is used for each irrigator node. When the soil moisture falls below the trigger levels configured in the model, it will order water (Figure 17). In the right hand figure, the bottom line represents the target level at which irrigation is triggered; this represents irrigation scheduling in practice. Rather than attempting to represent discrete irrigation events, the model simulates smaller volumes of water being applied more frequently such that soil depletion is maintained around a specified target value.

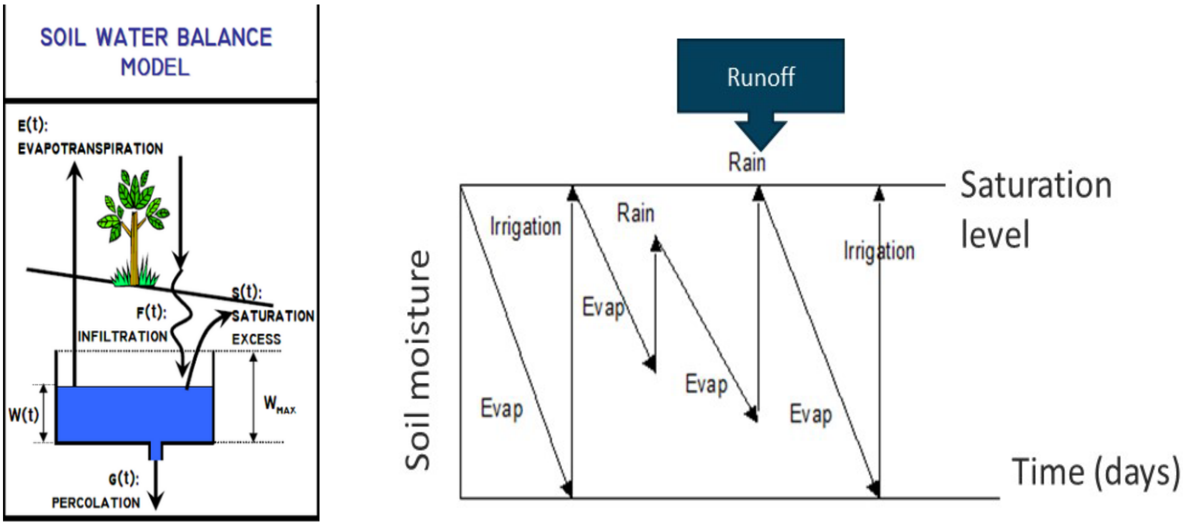

Figure 17 Soil water balance model (left) with accounting for evapotranspiration, rain, and irrigation (right)

Parameters in the crop model were pre-defined or narrowly bounded where possible based on research and industry values or expert knowledge, some of which have already been detailed in Table 11. This was done to avoid inappropriate calibration of parameters in the model, and to ensure the overall calibration is robust outside of the calibration period.

The delivery of water to the crops is subject to an ‘efficiency factor’ that represents delivery and application loss; a value of 30% has been adopted as defined in Table 11. Surface water irrigation efficiency can vary widely. Gillies (cited in Wigginton 2012b, p26) application efficiency results were based on data collected from 2000/01 to 2011/12. The average was 76% with tailwater recycling but efficiencies up to 90% were recorded. As the industry improves efficiency over time, this dataset may under-estimate efficiency for the more recent period. Gillies highlighted that an optimised irrigation approach results in average application efficiency of around 85% with tailwater recycling. We assume that this is likely to more representative of most irrigation enterprises over the recent period. The following application losses have been adopted:

- 30% application loss for all scenarios. This is based on Gilles average result plus some allowance for channel losses.
- 15% application loss is proposed for future versions of the Current Conditions Scenario; however, this will need to be considered along with other lines of evidence of contemporary water use and assessment of model performance before being implemented.

Tailwater return flows from a crop after watering are not explicitly modelled; rather the crop demands, and efficiency have been defined to be net of these returns.

A single soil moisture capacity for crop types and fallow is defined directly in IQQM as referenced in Table 11. An upper and lower moisture store can also be specified to limit the effect of evaporation from the soil moisture store for fallow areas. Actual soil moisture capacity will vary depending on soil type and farm management practices. While this is an averaged approximation, it is used in combination with other parameters to ensure that the generated crop demand is reasonable. This reduces the sensitivity of the results to this one parameter (further described in Appendix H). Similarly, the soil moisture capacity will affect the rates of rainfall–runoff; again, it is used in combination with other parameters to produce realistic overall runoff rates (discussed in the next section).

The basis for the crop model parameterisation is the method set out in the Food and Agriculture Organisation of the United Nations Irrigation and drainage paper 56 (FAO56, Allen et al. 1998). This method uses crop factors (Kc) to convert potential evapotranspiration to crop evapotranspiration. The FAO56 method provides a range of values for the coefficients (Kc) used to estimate evapotranspiration by each crop from the reference evapotranspiration values calculated at the nearest climate station. These factors change as the crop develops over time from planting to harvest or between seasons for perennial crops (Figure 18).

Derivation of crop factor values, soil parameters and crop planting dates is provided in Table 11 and values summarised in Table 18.

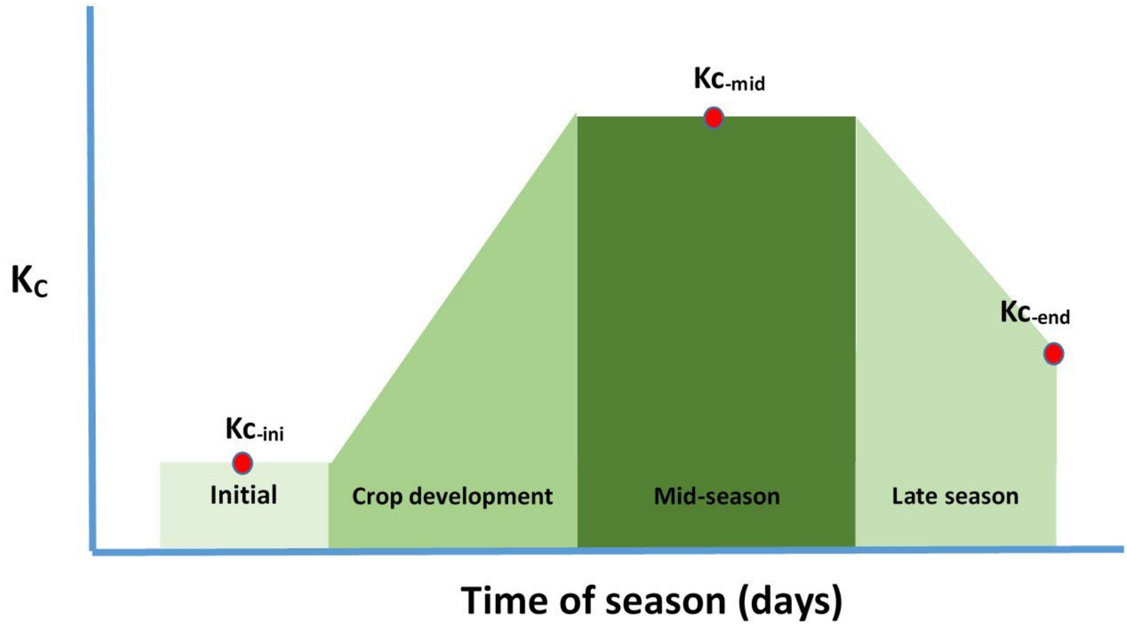

Figure 18 The relationship of Kc crop factors to time of season [adapted from figure 34 in Allen et al. 1998]

Table 18 Crop factors (Kc) used in the Gwydir Valley model

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Multiplier
Cotton	1.20	1.20	0.90	-	-	-	-	-	-	0.35	0.35	0.78	1.35
Wheat	-	-	-	-	0.30	0.73	1.15	1.15	0.70	-	-	-	1.32
Fallow	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.00

Cotton crop factors stop earlier than the harvest date to enable the crop to draw on the remaining soil moisture at the end of the season.

Rainfall–runoff harvesting

Individually represented water users in the model that are capable of floodplain harvesting simulate rainfall–runoff harvesting based on the same soil water balance component of the crop model (Figure 17). In this model, the soil moisture profile is simulated separately for areas developed (planted and fallow), and areas undeveloped for irrigation. The model continuously tracks the soil moisture of cropped, fallow and non-irrigable areas separately, enabling calculation of runoff following a rainfall event with consideration of antecedent conditions.

Runoff occurs when the soil is saturated. Given that the soil water balance model is a much-simplified representation of runoff generation, as this was not its prime intent, these simplifications of processes and associated parameterisations require a simple basis to calibrate. Rather than explicitly represent other processes, a percentage return efficiency parameter is applied to calibrate available runoff to pre-calculated long-term averages. The results were also checked for annual variability compared to nearby gauged inflows. This simulated runoff is then collected into an on-farm storage; in some instances, the runoff is not captured as either the runoff rate is greater than the pump rate or the storage is full.

The parameters used for runoff are summarised in Table 19. The supporting literature is further described in Appendix E.

Table 19 Calibration of parameters which control rainfall–runoff harvesting

Parameter	Adopted value	Comment
Fallow crop factor (for both developed and undeveloped areas)	0.4	Estimated and in conjunction with the other parameters produces the expected runoff response (Appendix E)
Rainfall–runoff return efficiency for fallow and winter irrigated areas	40–50%	Assumption that winter crops are often not fully irrigated. 50% was adopted for Moree climate to ensure the resulting runoff was within expected range (Appendix E)
Rainfall–runoff return efficiency for summer irrigated areas	100%	Assumption of highest efficiency due to elevated soil moisture
Rainfall–runoff return efficiency for undeveloped areas	20–30%	30% was adopted for Moree climate to ensure the resulting runoff was within expected range Defined as lower than fallow rates, but within the bounds suggested by the Budyko framework (Appendix E) on the basis that the efficiency of collecting from these areas is likely to be lower Where these areas become more significant, or there is evidence of significant unaccounted for volumes, this assumption will be reviewed

Rainfall–runoff harvesting has also been configured for the non-floodplain harvesting farms represented in the lumped irrigator nodes in each river reach. However, these are minor areas with small on-farm storage capacity on these farms, and hence relatively small rainfall harvesting volumes that fall into the exemption category under the policy.

Overbank flow harvesting

The breakouts described in Section 4.5 and verified through flow calibration, deliver water onto the floodplain when their flow thresholds are exceeded. This outflow is simulated as a permanent loss from the river system. In some instances, the breakouts are flood runners that may return a portion of that water to the river.

This portion is difficult to determine in practice. If the breakout and return flows are localised to the same river reach, the returning flows will be included in the observed flows measured at the bottom of the river reach. The flow calibration process seeks to simulate the flows as measured at the downstream flow gauge, and this may result in the overbank flow relationship more closely representing the net breakout of water from the river.

The accumulated volume of water above this threshold that leaves the river is held in a conceptual floodplain storage, which functions as a source of water for harvesting by one or more properties that are hydraulically connected to that storage, as illustrated in Figure 19.

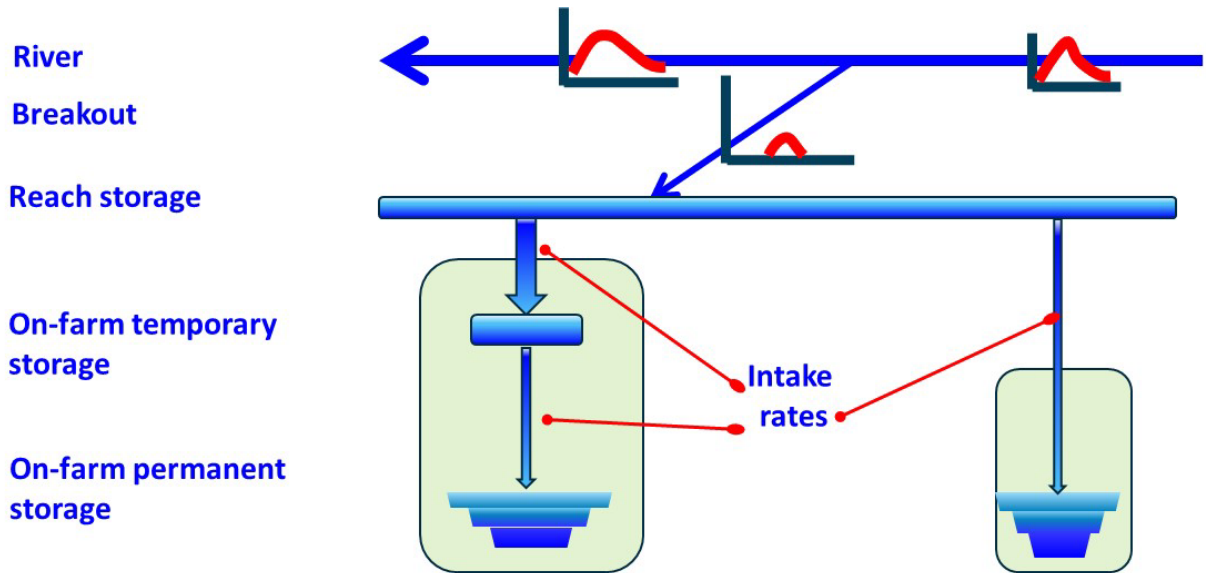

Figure 19 Schematic showing the relationship between breakouts, floodplain storages and overbank flow harvesting

The conceptual storage size is based on the estimated number of days over which harvesting can occur. This is a simple approach to representing routing and temporary storage of flows on the floodplain. Choice of values and rationale for these choices is given in Table 20.

Table 20 Setting of parameters which affect modelling of Irrigator overbank harvesting

Parameter	Adopted value	Rationale
Maximum number of days over which harvesting occurs	14 days for all but 2 farms where 10 and 30 days adopted	Selected in an attempt to replicate routing that is occurring on the floodplain and is based on landholder's information This information is not available from gauged river flow data and sensitivity testing indicated that it was not a source of significant uncertainty The 14-day access means that in addition to the first day of breakout flow, an additional maximum of 13 days access is required, meaning that the maximum volume available in the virtual storage following an overbank flow event is limited to 14 times the total of all downstream floodplain harvesting intake rates[8] While 14-day long access can be an overestimate in some reaches, daily release of water available for harvesting from the virtual storage at a maximum total rate means that the total reach take is almost always less than the estimated volume available in the virtual storage with exemption of small events (see below)

[8] This is the rate at which the water user node pumps water onto the property

Parameter	Adopted value	Rationale
Release of water from the floodplain storage	Rate equal to 1 day's pumping for properties with access to that storage	This means that in a small event, the water held in on-farm storage may be released quickly

Multiple properties that access water from the same floodplain storage are modelled with their order of access to the breakout flow represented. Some areas required a more distributed approach to access, and this was based on farm survey information, Landsat data and, in some cases, equity of access between neighbouring properties. The rate of filling of eligible on-farm storages was initially based on farm survey data; however, final rates were based on NRAR data for pump size and type and recommended rates.

Appendix F provides an example of how we configured the breakout, floodplain storage and individual farm works.

Storage operation and water balance

The combined on-farm storages on a property are configured to allow for sequential filling or emptying of the cells. It is assumed that the emptying order is the reverse of the filling order. The filling sequence of permanent storages adopted for each property has been estimated based on a number of assumptions; that the most efficient (deepest) storages are filled first and checked based on an assessment of whether they are likely to be the primary storage (based on largest, order presented in farm survey, and proximity to water extraction point).

The combined storages are filled by all sources of water diversions that each farm has access to. The total rate of filling the storage is based on the combined rate of filling each individual storage.

Access to floodplain harvesting was configured with intake rates from the floodplain storage. These rates were generally the same as the total storage pump rate. Some variations occurred, for example if intake pipes restrict harvesting, or if higher rates of intake occur into temporary storages and have verified history of use. Where temporary storages are known to have operated such that they allow for a large intake rate and later slower transfer to permanent storage, this has been accounted for in the model. This was configured by explicitly modelling temporary storages.

Seepage from storages was not captured in the farm surveys, and an industry average of 2 mm/day is used based on results from Wigginton (2012a).

The model software includes the ability to define a target reserve volume to hold in the storage during the cropping period. The size of this reserve was requested in on-farm survey data. However, most surveys stated no such practice is used, and a few checks of individual properties supported this, and no reserves have been configured in the model. In all cases the capacity of the storages has been defined such that it excludes a 1 metre freeboard (airspace at the top of a storage). This information is summarised in Table 21.

Table 21 Setting of parameters which affect modelling of Irrigator on-farm storage and water balance

Parameter	Adopted value	Rationale
Storage capacity	variable	Based on NRAR data which excludes 1m freeboard
Storage intake rate	variable	Set at total storage pump rate using NRAR data
Storage seepage	2 mm/day	Industry average from Wigginton (2012a)
Reserve volumes of storage	0 ML/ha	Based on combination of farm survey data and diversion validation

Non harvesting properties

Several river reaches have an irrigator node to represent smaller farms and/or water users that did not participate in the farm survey[9]. The irrigated crop areas outside of the individually represented farms/enterprises are relatively small. There is no crop area data available for these properties in the assessment period, and a planting decision was developed to achieve a match to overall valley recorded diversions only. In some cases, a nominal on-farm storage was also configured at such irrigator nodes. These irrigator nodes have been configured as set out in Table 22.

Table 22 Setting of parameters which affect modelling of non-harvesting properties (irrigator groups)

Parameter	Adopted value	Rationale
Crop model parameters	As used for individual farm simulation	Consistency
Crop mix	Based on prior 2000/01 area data	Used in previous modelling
Developed area	Estimated on available 2000/01 area survey data AND/OR on remote sensing	Balancing available 2000/01 area survey data for the valley and 2013/14[10] individual farm survey data with cross checking satellite imagery where required
Rate of river extractions	Based on WaterNSW's ordering history	As per all other water users

6.3 Held environmental water

Held environmental water refers to any water access licence that is held and used to achieve environmental outcomes. It is not a separate category of licence, just a different type of use. These licences are generally used to improve the health of rivers and their environs through re-introduction of some natural variability in river flows to reconnect with the river's floodplains and wetlands.

Under the Riverbank Program, which operated between 2005 and 2011, the NSW Government has purchased water licences with approximately 21,500 shares, across the general, high, and

[9] Most if not all the landholders and/or other water licence holders which did not participate in the farm survey were deemed to be ineligible for floodplain harvesting entitlement despite their great majority registering their interest for it.

[10] Most of the IBQ information were gathered in 2014 with data provided generally limited to 2004/05–2012/13

supplementary licence categories to use for environmental outcomes. The management of these water licences is undertaken by the department (Energy, Environment and Science).

Under the Basin Plan, the Commonwealth Government has purchased water licences with approximately 114,500 shares across the general, high, and supplementary licence categories to use for environmental outcomes. The management of these water licences is undertaken by the Commonwealth Environmental Water Holder (CEWH).

6.3.1 Data sources

The department maintains a register of HEW entitlements linked to the NSW Water Licensing System. Total holdings presently are approximately 136,000 unit shares which comprise:

- 5,757 unit shares of high security licences
- 106,617 unit shares of general security licences
- 23,591 unit shares of supplementary licences.

This represents approximately 19% of the total entitlement in the regulated Gwydir River system.

6.3.2 Modelling approach

There were only a small number of water licences purchased for environmental purposes in 2008/09, and held environmental water is not represented in the validation scenario model described in this report. These licences continue to be modelled as if they remained with the original licence holders, i.e. modelled as a consumptive use. Representation of water use for environmental purposes will be addressed in separate reporting for other model scenarios where relevant.

6.4 Stock and domestic use

Landholders in the regulated Gwydir River system can access water for stock and domestic purposes through either:

- basic landholder rights for properties with river frontage
- a specific purpose access licence
- replenishment flows diverted into the Thalaba Creek.

There are 2,744 shares for stock and domestic licences in the regulated Gwydir River system. Use of this water often occurs via the same pumps and meters as the larger general security licences, and the water use is reflected in metering records. However, some of the water use under these licences may occur through separate smaller pumps that are not currently required to be metered.

6.4.1 Data sources

Where metered, records of water use by these licences are maintained in WAS by WaterNSW.

No information is available on water use under Basic Landholder Rights.

Flows diverted into Thalaba Creek are measured at the pump site and stored in WaterNSW Hydstra database.

6.4.2 Modelling approach

Small stock and domestic licences that are held in conjunction with larger general security licences for irrigation are included as water available for irrigation.

Stock and domestic replenishment flows are represented in the model, as a demand at the Thalaba Creek offtake.

The relatively small volumes of diversions by Basic Landholder Rights are not measured and are not explicitly represented in the model. However, the effect of such water use is captured in the estimated volumes of water lost as river transmission losses.

7 Modelling water management rules

7.1 Resource assessment

WaterNSW undertakes a resource assessment every month to formally assess any improvements in water available, either through a substantive inflow or lower than forecast river transmission losses.

When there is an improvement in water available, the department undertakes an available water determination (AWD), as set out in the Gwydir WSP, of the volume of that improvement and announces allocations in the form of a percentage of the total shares in each licence category.

The AWD considers the need to set aside water to cover additional river transmission and operational losses, evaporation from dams, and any other requirements such as minimum flow rates or environmental water requirements as set out in the Gwydir WSP.

7.1.1 Data sources

Announced AWDs are gazetted when made, and the results subsequently incorporated in the Water Accounts System (WAS). Records of water set aside for transmission and operating losses are maintained by WaterNSW.

The history of the announced allocations for general security class licences is shown in Table 23 (announced allocations for Local Water Utility, Stock and Domestic, and High Security entitlements are not included as they were 100% for all years).

The effects of drought in allocations can be seen in the years 2013/14 to 2015/16, and again from 2017 to 2020.

Table 23 Gwydir announced allocations (%) for general security licences [Source: NSW Water register, 27 March 2020]

Year	General security licence allocations (%)
2004/05	4.6%
2005/06	21.9%
2006/07	0%
2007/08	24.3%
2008/09	0%
2009/10	0%
2010/11	83%
2011/12	307%
2012/13	162%
2013/14	0%
2014/15	0%
2015/16	5%
2016/17	79%
2017/18	18%
2018/19	0%

7.1.2 Modelling approach

Resource assessments are simulated on a daily timestep in the model.

Additional unallocated water is assessed and credited to individual water accounts according to the volumes available via the water accounting parameters described in Section 7.2.

7.2 Water accounting

All regulated water licences have an associated water account to manage their share of available resources. These accounts are managed differently between access licence categories.

Water accounting rules are set out in the relevant water sharing plan (WSP).

In the Gwydir regulated river system, a **continuous accounting system** is used to allocate the water available for diversion by licensed water users and to cover transmission and operation losses.

- Water is allocated to a bulk account for higher priority licence categories (local water utilities, domestic and stock, and high security) and a separate bulk account for General Security licences. Individual licences then receive a share of the water in these bulk accounts according to their licence category and then according to the proportion of the licence shares they have.
- Whenever water is allocated to the bulk accounts for water users, water must also be allocated to a separate bulk account to cover the transmission and operation losses incurred when delivering water along the river to water users. These Transmission and Operational Loss (TOL) accounts receive 30% of the volume credited to the water user bulk accounts.
- If losses incurred exceed 30%, any further improvements must be used to first top up the TOL accounts to reach 30% of the water in the water user bulk accounts before allocating any further water to both accounts in the required proportions.

Individual licences in the higher priority categories are managed under an **annual accounting approach**, where they receive annual allocations each year, and cannot carry over water from one year to the next. Individual water accounts cannot exceed 100% of the share component for that licence.

Under the Gwydir WSP, a **continuous accounting system** operates for general security, with individual accounts for each licence allowed to maintain up to 150% of their entitlement within their account at any one time. From the commencement of the Gwydir WSP in 2004 to 2016 the annual water use limit was 125% of the share component, after which it was relaxed to 300% of their share within a water year, provided a maximum of 300% of their entitlement is used within any three consecutive year period.

To deliver water as efficiently as possible, general security licences operate under a **water order debiting system**, with the greater of the water ordered or the metered water use debited from individual water accounts.

7.2.1 Data sources

Individual water accounts are maintained within the WAS, including all account transactions and balances. Individual account holders can view accounts online, and the WAS provides a variety of reports that describe water in accounts and the various types of transactions that have occurred. Prior to 2004, a continuous accounting database was used to record account balances, but only a limited set of data were maintained.

Information sources to inform the model include:

- Water Sharing Plan for the Gwydir Regulated River Water Source
- Water Allocation Plans for the Gwydir Valley from 1999/2000 to 2002/03
- various resource assessment spreadsheets.

7.2.2 Modelling approach

Continuous accounting

The modelled continuous accounting system has been developed to represent operational practice as closely as possible.

Key parameters are summarised in Table 24.

Table 24 Key parameters for modelling of NSW continuous water accounting system

Component	Comment
Debiting type	Water order
Timestep	Daily
Assigned storages	Copeton Dam. Other weirs are not included in the resource assessment. However, any increase in water use will be picked up in the apparent inflows as part of the monthly reconciliation
Transmission & Operational Loss (TOL) share	Minimum: 10% of allocated general security Maximum: 30% of allocated general security
Usage limits	1.25 ML/share and 3 ML/share annually for general security pre and post-2016 respectively and rolling 3 ML/share limit across any three-year period
Account limits	General security – 1.5 ML/share account limit
Maximum Environmental Contingency Allowance (general security) storage share	1.5 ML/share and 2 ML/share pre and post-2004
Maximum Environmental Contingency Allowance (general security use	Unlimited
Storage loss reserve	As per storage reserve calculations used in water allocation determinations

7.3 Water trading

Trading of licence shares (known as permanent trade) and account water (known as temporary trade) has been permitted since the 1980s.

There is no direct hydrologic connectivity between the Gwydir and other regulated river systems, and there is no inter-valley or inter-state trade permitted.

7.3.1 Data sources

Records for all water trading are maintained by WaterNSW in the Continuous Accounting database prior to 2004, and in the WAS from 2004 onwards.

Figure 20 shows permanent trading within the regulated Gwydir River system. All entitlement categories (including supplementary) are included.

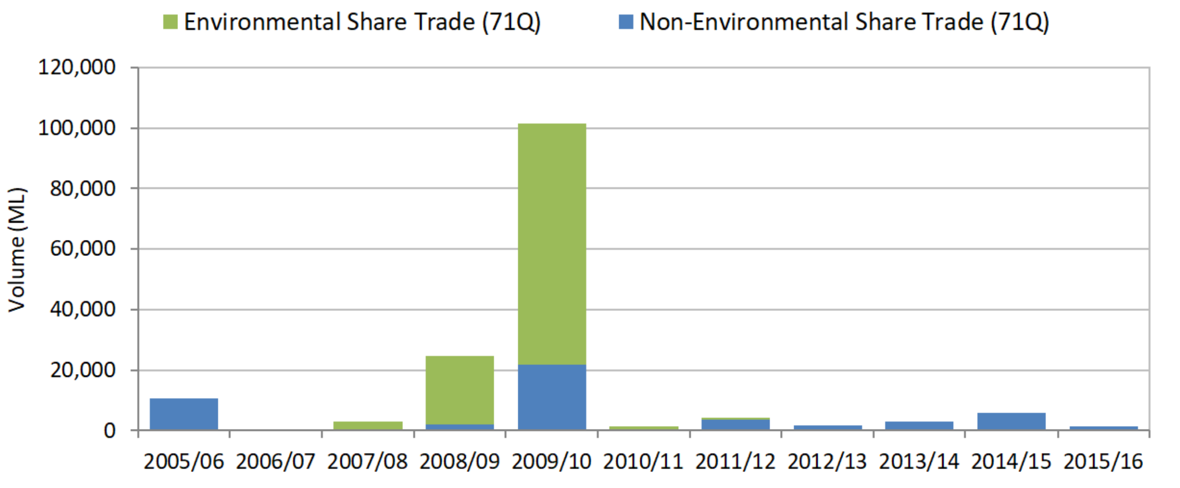

Figure 20 Volumes of annual permanent trade of environmental and non-environmental licence shares for the years 2005/06 to 2015/16[11]

Figure 21 shows temporary trading within the regulated Gwydir river system. All licence categories (including supplementary) are included.

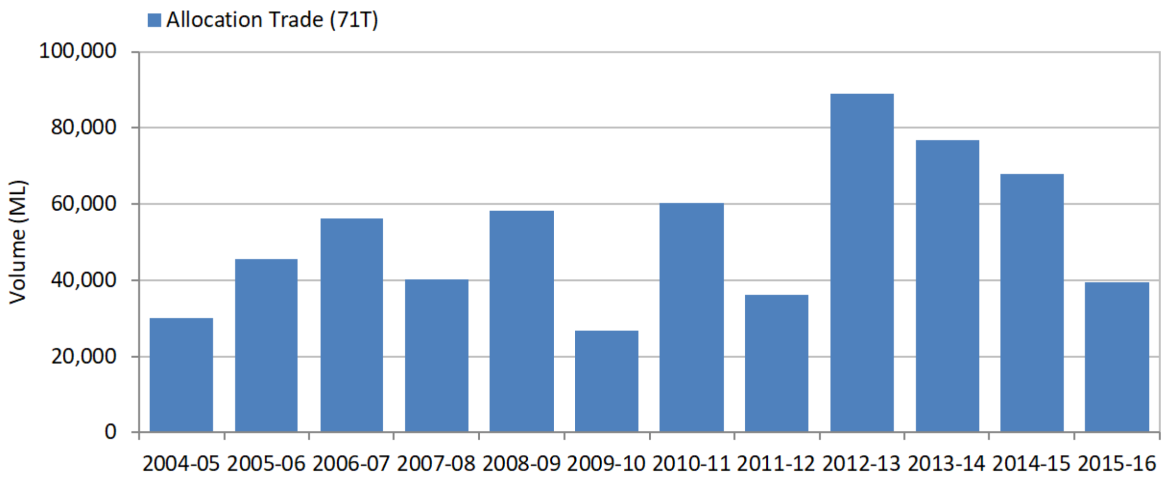

Figure 21 Volumes of annual temporary (including interstate) trade of all licence categories for the years 2004–05 to 2015–16[11]

7.3.2 Modelling approach

Temporary water trading is not represented in the model due to software limitations. However, a number of licences in the upper reaches of the regulated system regularly trade water allocations to other irrigators across the valley. This behaviour has been represented by simulating the use of that water by the licences in the upper reach, with an average annual total of on-allocation and supplementary water use from 3.2 to 4.3 GL/year under the 2008/09 and current conditions development conditions respectively, and 7.5 to 8.5 GL/year under the 1999/00 and Cap scenarios respectively.

Further, when assessing the results of the model (Section 8), significant water trading was considered. Permanent trades are considered in scenario development. While assessing the

[11] 71Q and 71T are sections of the NSW *Water Management Act* that permits trade in shares between water access licences.

calibration of individual irrigation properties, the importance of error in representation of temporary trade was considered.

7.4 Planned environmental water

Gwydir Valley Environmental Contingency Allowance (ECA)

The Gwydir WSP sets out an Environmental Contingency Allowance (ECA) which provides for up to 90,000 ML to be set aside for the environment. Water is allocated to the ECA on the same basis as allocations to general security licences. Releases may be made for a wide range of purposes related to wetland or river health or for the direct benefit of water birds, fish or other fauna.

Figure 22 shows the usage of Environmental Contingency Allowances in the Gwydir Water Resource Planning Area. Most releases of water from the ECA are made to the Gwydir wetlands.

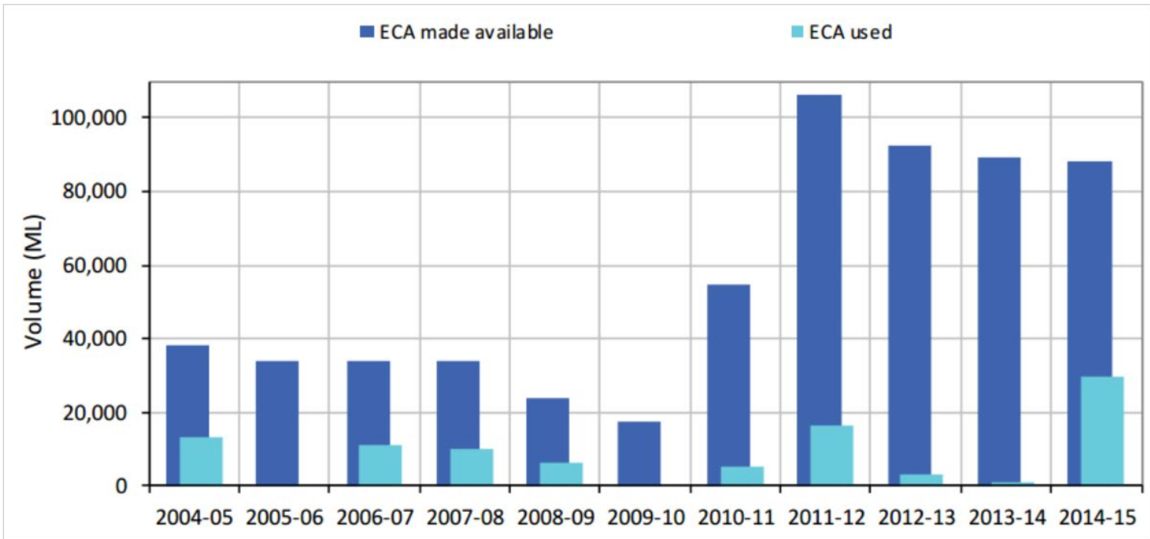

Figure 22 Environmental Contingency Allowance availability (ECA made available) and usage (ECA used) in the Gwydir Water Resource Planning Area for the years 2004–05 to 2014–15

A set of ECA triggering rules focused on supporting water bird breeding have been developed for the Gwydir Valley model in collaboration with environmental water managers from the department's Environment Energy and Science division and its predecessors. An initial set of rules were based on a small number of historical environmental releases taking place in 1995 and 1997, and an expectation of ECA use in about 75% of the years. These triggering rules have since been progressively updated to align with the evolving use of the ECA by environmental water managers. A summary of the triggering rules for the operation of the ECA between 2004 and 2009 is shown in Table 25.

Tributary inflow sharing

Passing tributary inflows through to the Gwydir wetlands is another main provision of the regulated WSP. The WSP sets out sharing provisions for what is known as the three tributaries (3T) rule that provides the combined flow from the 3 tributaries between Copeton Dam and Gravesend Gauge – Horton River, Myall Creek, and Halls Creek – to be passed to the Gwydir wetlands. This combined inflow up to maximum of 500 ML/day is protected from extractions and allowed to flow through to the Gwydir wetlands.

Supplementary sharing

The WSP contains sharing arrangements for supplementary events, such that no more than 50% of supplementary water event volume can be taken under supplementary water access licences.

7.4.1 Data sources

WaterNSW prepares reports on compliance with environmental flow rules set out in the WSP for the regulated Gwydir river system on an annual basis. These reports set out the volumes of flow for the Environmental Contingency Allocation (ECA) account and the volumes of flow for individual events, how much of that water was diverted by licensed water users, and how much water flowed out of the regulated river system.

7.4.2 Modelling approach

Gwydir Valley Environmental Contingency Allowance (ECA)

The Gwydir Valley model represents delivery of water from the General Security ECA to the Gwydir wetlands according to specified event-based triggering rules, and delivery is accounted as the flows delivered at Millewa and Tillaloo that are in excess of ordered water for other licences. How the model represents the trigger rules is provided in Table 25.

Table 25 Summary of pre-2009 Environmental Water Allowance triggering rules

ECA portfolio	Allocation	Model representation
Entitlement	45 GL (general security)	General security licence of 45 GL
Maximum balance	2 ML/share	Maximum balance of 90 GL
Colonial waterbird breeding	15 GL	First priority use Deliverable to Gingham Watercourse at Tillaloo (418076) Triggered when accumulated flow over 28 days between August to May above regulated requirements at Yarraman Bridge (418004) equals or exceeds 100 GL Once triggered, allocated volume is fully utilised to maintain 450 ML/day at Tillaloo in conjunction with 3T flow Ordered ECA water is protected throughout the regulated river system
Watering of water bird feeding sites	30 GL	Second priority use Aimed to replace water extracted by consumptive users from supplementary events at a later date Deliverable to Gwydir River at Millewa (418066) and Gingham Watercourse at Teralba (418074) at 50:50 Colonial water bird breeding event and supplementary event at Gravesend (418013), i.e. above any consumptive orders and 3T

Following large purchases of water licences by the Commonwealth and NSW governments, and water savings projects, environmental water management in the valley has been evolving to use the held environmental water in conjunction with the environmental contingency allowance (ECA).

To represent evolving management of the ECA post 2009, the ECA operation rules have been configured using four IQQM generic 'marsh' nodes to account for water at the key reference points within the Wetlands.

Protection of tributary inflows

The operational interpretation of the 3T rule is that the measured flows at Rider (Horton River, GS418015), Mollroy (Myall Creek, GS418017) and Bingara (Halls Creek, GS418025) are summed and, taking into account travel time, are protected to ensure appropriate corresponding flows are measured at Tillaloo (GS418074) and Millewa (GS41066).

The configuration of the 3T rule in the model has been adopted from the previous Gwydir Valley model as:

1. pre-processing of relevant long-term gauged inflow sequences to determine each of the three tributaries' contribution to the total protected flow as well as total daily flow to be protected
2. using the 2-state IQQM capability, assigning State 2 to the environmental inflow sequence identified in Step 1
3. aligning model structure with IQQM capability, which allows State 2 water to be 'forced' downstream of the Mehi River and Carole Creek offtakes.

Supplementary sharing

The 50% of supplementary water event volume that is protected under the WSP is protected throughout the system in the model.

7.5 Storage and weir operation

Releases from the major dams and access to water for licensed water users and other statutory purposes are managed by WaterNSW. Central to the operation of a regulated river system is a daily process to set a release rate from each major storage to meet downstream water requirements. River operators optimise the release of water to the river so that they can meet downstream demands for water without any unnecessary flows passing out the end of the regulated system (referred to as operational surplus).

The travel time flows to reach the lower end of the regulated river can take up to two weeks, and river operators must take many factors into account when setting daily releases, including water orders, other flow requirements, and short-term forecasts of weather and inflows. Required releases from storage are particularly sensitive to operational forecasts of inflows from downstream tributary streams.

7.5.1 Data sources

In addition to the volumes in storage and the releases made at each Dam and Weir that are recorded with other flow information, WaterNSW maintains a spreadsheet-based decision support system known as Computer-Aided River Operations (CAiRO), which has an associated database of the water orders and flow requirements that were used to determine target releases from each storage, and any target storage level at weirs along the regulated river system. The CAiRO database records the various elements used to inform the release from the major storages each day, including forecasts of tributary inflows and transmission losses.

The operational staff at each major dam also maintain ancillary records, such as which valves or outlets were used to make the target releases each day.

At each weir along the regulated river system, the gate openings, upstream and downstream water levels are continuously logged.

7.5.2 Modelling approach

Storage operation

Use of tributary inflows

The model considers forecasted inflows when determining how much water needs to be released from Copeton Dam to meet orders, reflecting operator practice. Model parameters in this part of the model were configured using advice from WaterNSW river operators, and adopted unchanged from the previous model.

The model allows us to forecast a rate of inflow from an unregulated tributary based on the previous timestep flow. The forecasted inflow is defined as yesterday's inflow multiplied by a factor. The adopted values are summarised in Table 26. For headwater inflows, the forecast rate was generally 1, which means inflows are assumed to be 100% of yesterday's flow when determining how much regulated water should be released. The factors adopted in the model are listed in Table 26. Confluences with a forecast inflow of zero are not shown in Table 26.

Table 26 Adopted tributary recession factors to forecast rate of inflow from unregulated tributaries

Tributary	Tributary recession factor (trend forecast rate)
Keera Creek	0
Halls Creek	1
Myall Creek	1
Horton River	1
Warialda Creek	0

Weirs and regulators operation

Weirs are represented as controlling structures for regulated and supplementary flows between the main river and effluent. Effluent relationships for each of weirs represented in the model were derived using operational flow records.

8 Model assessment

8.1 Overview

This section reports the results of:

- the calibration of the component models, i.e. how well the modelled flow matched observed flows
- the fully assembled Gwydir Valley model.

It describes the criteria that has been used to evaluate the ability of the model to address key objectives.

The results in Section 8.3.1 graphically show long term climate used in the model to demonstrate that a range of climate variability is included in the full simulation, and those periods used to calibrate the sub-models sample this range.

This is followed by the results of the flow calibration, how well the modelled flow matches recorded flow at various points in the system. For all the directly gauged inflow sub-catchments, we provide a tabular summary of long-term annual volume replication, with time series aggregated results demonstrating that daily and interannual variability is also reproduced. Similar results will be reported for the flow calibration along the main stream. It is important to replicate various parts of the flow regime, especially medium to high flow events that break the banks and flow overland onto the floodplain. A selection of time series plots will demonstrate how well this is reproduced.

We report on the volumes of water diverted for floodplain harvesting. A key component for estimating total floodplain harvesting is the estimation of total irrigation water use based on historic crop areas and a crop model which is in line with published information. The important results here are whether there is enough water from all sources, including floodplain harvesting, to irrigate the historic crops. These checks are primarily at the valley and reach scales. While checks are completed at individual properties, some variation is allowed for given known differences in irrigation behaviour and potential inaccuracy of metered diversions at individual farms.

We used the fully assembled model for the validation of regulated diversions and report average annual volumes and annual time series of planted crop areas, general security diversions, and supplementary access diversions, as well as graphically reporting the storage behaviour in the headwater storage. In the following sections, the key simulated results from the model (flows, diversions, crop areas, and system operation) are compared with recorded information to assess model performance. All results in this report reflect the final fully simulating 2008/09 conditions[12] model unless otherwise noted.

8.1.1 Model assessment criteria

We have designed a suite of numerical and graphical indicators to evaluate how well the component models and the complete model have met objectives and design criteria (as set out in Section 2.1). They were selected on their ability to:

- meaningfully determine the relative performance of the model, i.e. ability to be confident that, based on the metric, we can determine whether model performance is better or worse than an alternate model

[12] These refer to existing at the time farm infrastructure, i.e. including ineligible and excluding eligible but yet to be built infrastructure.

- measure how well the model reproduces system behaviour – e.g. inflows, diversions, flow distribution – necessary to meet the modelling objectives, i.e. its 'goodness-of-fit'.

There are many metrics that meet these requirements, including comparisons of means, or some goodness of fit metrics for sets of corresponding data pairs. However, we have found that some standard goodness-of-fit metrics can be misleading in determining relative performance, e.g. where getting a model right during dry periods, for example, is more important than during wet periods and the metric measures across the whole model. A possible solution to this shortcoming is using more than one metric, e.g., one for wet and one for dry, or try to customise a metric that satisfactorily describes both. Often having multiple metrics describing an aspect of model performance can be beneficial, and we have taken this approach where necessary.

As well as getting the 'big terms' (i.e. average annual inflows, diversions, and end of system flows) correct, getting their distributions correct is equally important, i.e. we want our models to reproduce inflows, diversions and outflows well in wet and dry periods. It is not possible to replicate every historical flow event; however, the overall characteristics such as frequency of low, medium and high flows as well as replicating wet and dry periods are important.

We have selected graphical techniques which implicitly factor in multiple model metrics. Some examples include time-independent distributions such as comparisons of modelled v observed results as either; an exceedance graph; and/or a time series at daily or longer time steps; and/or the spatial distribution of results. For modelling practitioners, this is a more intuitive way to assess model performance, but not as simple to describe the conclusions from these assessments without including significant background information learned from modelling experience. In these cases, we include key graphs indicating model performance and describing relevant characteristics.

Assessment criteria/methods are summarised in Table 27.

Table 27 Overview of assessment criteria for flow and water use simulation

Component	Performance test	Metrics and/or visuals
Flow simulation for headwater inflow and main river	How well long-term average volumes are replicated, especially medium to high flow events, as well as daily and interannual variability	Summary statistics listed in Appendix J
Water use simulation		
Crop water use	How well total irrigation water use is estimated	Model configured to 2 availability conditions to allow comparison to 4 other data sources
Runoff harvesting	How well runoff from developed and undeveloped areas on farm is simulated	Rainfall–runoff rates from fallow and irrigated areas compared to industry research estimates Interannual variability in runoff depth compared to nearby catchments
Overbank flow harvesting	Interannual variability in runoff depth compared to nearby catchments	Modelled flow events exceeding overbank flow thresholds compared to observed

Component	Performance test	Metrics and/or visuals
Crop water use rates	How well crop water use rates (ML/ha) are reproduced	Modelled crop water use rates compared to industry and remote sensing estimates. Sensitivity testing to variations in simulated crop water demand
Planted areas	How well historical irrigated areas are simulated	Modelled crop area compared to combination of farm survey and remote sensing crop areas
Metered diversions	How well general security and supplementary access metered diversions are simulated	Total, general security and supplementary access diversions over 2004/05 to 2012/13 period compared to observed, model bias (%) metric
Supplementary access diversions	How well supplementary access diversions are simulated	Supplementary access diversions over 2004/05 to 2012/13 period compared to observed, model bias (%) metric
Storage operation & harmony management	How well storage volumes are simulated	Daily time series of storage volumes compared to observed

8.1.2 Model validation – 2008/09 Scenario

The model that we have assembled using various calibrated model components has been configured as a scenario that is representative of the calibration period. This allows us to evaluate the overall model performance by comparing model results with observed data over the period of calibration. For this Gwydir model, the diversions and water management components were initially calibrated over the period 2004/05 to 2012/13. The choice of the calibration period was based on the data available at the start of the floodplain harvesting modelling in 2014/2015, which is a period that also includes key benchmark years for the policy and the Basin Plan. To ensure that the assembled model can simulate all the key processes (flows, diversions, water management), a scenario was configured to represent the 2008/09 existing level of development.

We know that there were some changes in irrigation infrastructure development over the period from 2004 to 2014, mainly for floodplain harvesting activities. However, there were only a few years with large floodplain harvesting potential between 2004/05 and 2008/09, and there has only been 3% growth in on-farm infrastructure since 2008.

We considered any changes in irrigation infrastructure and water management rules that actually occurred over the comparison period when reviewing results[13].

8.2 Flow simulation assessment

The quality of the calibration of simulated flow influences the overall model performance. Several characteristics of the flow regime are important, overall volumes, distribution across the full flow range from low to high, daily variability, and interannual variability in particular. The methods to calibrate the models are intended to reproduce those characteristics.

[13] Early calibration models forced infrastructure changes over time.

The department has previously developed a workflow to standardise the reporting of results for all flow comparisons. The results include multiple metrics as no single metric alone can inform the suitability of a model result for a particular purpose. A subset of results from the standardised reporting is described in Figure 23 for the Gwydir River at Pallamallawa and summarised in Appendix J for all flow calibrations.

These multiple lines of evidence are presented as a report card (Figure 23) and show the degree to which the model has reproduced the quantity, distribution, and variability of streamflow that affects water availability for allocation, as well as instream variability for supplementary access, overbank flow harvesting, and environmental flows.

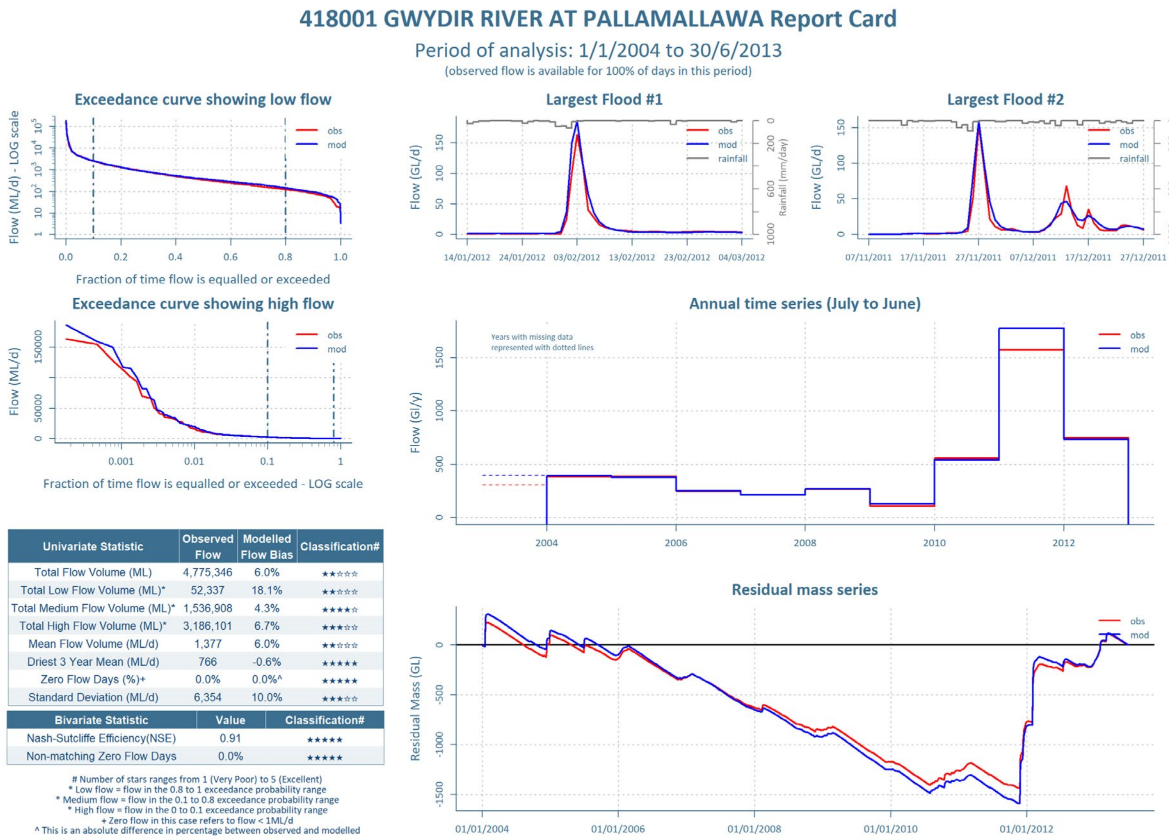

Figure 23 Example of graphical comparison of flow calibration reported in Appendix J

Further information on events is presented at Section 8.3.1 for a key location at Pallamallawa that demonstrates how well daily variability relevant to overbank harvesting is reproduced.

Table 28 Flow metrics used to assess flow calibration

Metric	Importance
Tabular metrics	
Station Number	Identifier and location
Mean Annual Flow	Relative importance to total flow. For comparative purpose, values in Appendix J are over the full simulated period and not the observed data period. Other comparisons are modelled v observed
Runoff % of rainfall	Confidence in water balance if spatially coherent and within published ranges for rainfall versus evaporation

Metric	Importance
Daily Nash Sutcliffe	Goodness of fit modelled to observed – sensitive to high values and timing offsets
Flow bias – full range	Overall volume match – important for storage filling and overall water balance
Flow bias – low range	Volume match in low flow range (upper threshold defined in flow exceedance graph)
Flow bias – medium range	Volume match in medium flow range (between high and low flow ranges)
Flow bias – high range	Volume match to in high flow range (threshold defined in flow exceedance graphs)
Graphical metrics	
Flow exceedance – full	Distribution of flows – indication of degree of match for all flow ranges
Flow exceedance – high	Distribution of highest flows – indications for flood events
Flood hydrographs	Shapes of hydrographs well represented – flow components work together
Annual time series	Wet and dry years appropriately simulated for flood and drought sequences

8.2.1 Headwater inflow rainfall-runoff modelling

As an initial step towards the transition of the Gwydir Valley from IQQM to Source, a new flow calibration was undertaken in 2019 for the catchment above Pallamallawa, including new Sacramento rainfall runoff models for headwater and residual catchments from headwater sources above Copeton Dam to the Pallamallawa gauge (418001) using the FORS calibration tool. This work produced more robust, defensible, and significantly improved headwater and reach calibrations. This Source based calibration has now been incorporated into the IQQM floodplain harvesting model.

These results refer to Table 44 and Figure 44 to Figure 81 in Appendix J with reference to the flow metrics described earlier.

Mean annual flows for the headwater catchments range from 7 to 176 GL/y, and collectively account for 521 GL/year of inflow. The results have also been assessed using the Budyko framework to see if the estimated inflows sit in the boundaries obtained from the gauged catchments analysis in the Murray-Darling basin (Figure 44 in Appendix J). In all cases, the simulated runoff coefficients with relation to the aridity index sit inside the suggested boundaries, which indicates realistic inflow estimates are being produced.

The daily Nash-Sutcliffe values range from 0.49 in the case of 418025 Halls Ck at Bingara to 0.85 for 416054 Gil Gil Ck at Boolataroo, with most results considered to be fair or good (classifications are indicated in the report cards in Appendix J). These results are influenced most of all by the representativeness of the rainfall data used, and so the influence of lower results is mitigated to some extent by focusing on the distribution of flows. Most of the Nash-Sutcliffe values are in the range 0.5 to 0.85.

The flow biases across the full flow range are within 2% of observed in total. The distribution across the flow ranges varies considerably more, with low flow bias for half of the inflow sites over-estimating by up to 10% of observed, and other cases overestimating by 10-30% for the low flow range. The discrepancies are much less for the medium flow range (most sites less than ± 2%, and three sites overestimating between ±3.9% to 6.4%) and for the high flow range (mostly less than ± 1%). The larger discrepancies in the low flow range are not a great concern in the context of the model suitability. In the worst case, this describes flows less than 2 ML/day for a tributary in the lower reaches and would not affect operational decisions or water availability calculations.

Reference to the graphs in Figure 44 to Figure 81 showing model performance is instructive. In all cases there is close match of the flow exceedance graphs, except in cases at the extremes. The matching of the highest flows is difficult as it is particularly sensitive to rainfall totals on rare events. The interannual variability also matches closely in most cases, where the patterns of high and low observed total flows are matched by the simulated flow.

8.2.2 Main river flow simulation

To validate the calibration of the simulated river flows in the model, a flow validation scenario was created with each irrigator in the model forced to divert the observed diversions, and flows from Copeton Dam forced to match the observed releases. The flow validation scenario was used over three separate periods where observed water use had been disaggregated into daily volumes: 1980–1991, 1997–2001, 2004–2013.

The Gwydir regulated river system bifurcates at several points, with much of the regulated flow forced into effluent creeks to supply irrigation requirements by operating weirs and offtake regulators. This complex distribution of flows from the Gwydir River into the Mehi River and then again into Moomin and Mallowa Creeks, into the Carole Creek, and into the Lower Gwydir (to the south of the Gwydir raft) and the Gingham Watercourse (to the north of the Gwydir raft) means that the simulation of flows through the system is also dependent on the operational management of the weirs and regulators.

The flow validation scenario was configured to divert flows into each effluent stream based on the water orders, with each irrigator in the model forced to place water orders equal to the observed general security diversions. For periods where there were little or no orders, a minimum flow was diverted based on the observed flows at these times. Where flows exceeded the general security requirements, regulator behaviour was approximated with a weighted ratio between the observed unregulated flows on the mainstream and effluent branches.

The results discussed in this sub-section refer to Table 45 and Figure 44 to Figure 81 in Appendix J with reference to the flow metrics described earlier.

For 18 of the flow gauges in the regulated system, the Nash-Sutcliffe values range from 0.52 to 0.95, which is considered reasonable. There are two flow gauges with values of 0.47 and 0.32, and there were five flow gauges in the regulated river system for which the modelling had very low Nash-Sutcliffe values. The model results for the flow gauges with poorer Nash-Sutcliffe values are examined further below.

Five of these poorer performing flow gauges are downstream of bifurcation regulators, and the reproduction of flow patterns is being affected by the operational management of the regulators that was not reproduced well.

The Nash-Sutcliffe value for the modelled flows on the Mehi River at Moree (418002) is near zero, primarily due to difficulties reproducing the patterns of high flows well, although the Nash-Sutcliffe value for the medium flow range of 0.77 and an overall flow volume bias of 6.9% was achieved. The Nash-Sutcliffe value for modelled flows on Gil Gil Creek at Galloway (418052)) of 0.47 reflects the long river reach from the upstream flow gauge, and the uncertainty associated with the daily disaggregation of historic metered water use totals, although an overall flow volume bias of 4.4% was achieved.

Overall modelled flow bias for most flow gauging stations is in the range of ±10%. For five of the modelled flow gauging stations, the overall flow bias ranged from 10% to 18%, and for two of the modelled flow gauging stations, the overall bias ranged from -10% to -18%. Four of the stations with higher modelled flow bias are downstream of flow regulators and are affected by the operational management of the regulators that was not reproduced well. The other three flow gauging stations with significant modelled flow bias are on the Gwydir River at Yarraman Bridge (418004), Brageen Crossing (418053), and Millewa (418066). The last two flow gauging stations are within the Gwydir wetlands, and higher flows may not be accurate.

The graphical comparisons in Appendix I and Appendix J showing model performance indicate that interannual variability is closely reproduced in most cases. There is also a close match of the flow exceedance graphs in most cases, except at the extremes which diverge in some cases. The low flows most affected are those at less than 100 ML/day This may be important for some applications and scenarios, however, not for overbank flow diversions.

The Gingham Watercourse is not part of the regulated system, and flows do not pass through to the Barwon River except during the larger floods. The Gingham Watercourse stream flows are simulated in the model, although there are few floodplain harvesting properties with access to Gingham's overbank flow. The results for the simulated flows leaving the regulated river system into the Gingham Watercourse at Teralba (418074) are included in the discussion of results above. Flows at the two flow gauging stations further downstream are generally less well simulated due to complex interactions with the floodplain wetlands along the watercourse.

8.3 Water use simulation assessment

8.3.1 Irrigation

This section describes the results of parameterising the major water balance components affecting water use by irrigation farms. The modelling methods adopted for these are described in Section 6.2.2.

This section reports on crop water use, runoff harvesting and overbank flow harvesting. Crop areas were held to observed for the initial calibration. However, the results presented in this section have been taken from the fully assembled validation scenario. Simulation of planting areas is reported in Section 8.3.2. The metered diversion results after using simulated planting areas is in Section 8.3.3. Sources of uncertainty in the simulation of irrigation diversions and use are described in Appendix H.

Modelled crop water use

Our approach to estimating irrigation water use was described in Section 6.2.2. The many parameters in the crop models used to simulate irrigated water demand were consistently configured to established values from industry and research advice. This was done in preference to calibrating to uncertain or only partially available data for each individual property or group.

There are several independent data sources or methods on average irrigation requirements that can be used to compare with the crop water use from the Gwydir Valley model. However, these data sources or methods use variable definitions (i.e., whether it includes some or all losses), which makes direct comparisons difficult. Data sources or methods that include data from large areas and over short periods of time also make it difficult to compare as different climatic conditions in each season need to be considered in order to compare to model results. These comparisons are summarised in the remainder of this section, with further detail in Appendix G.

Four independent data sources or methods have been used to assess the model estimates: farm surveys, WaterSched Pro software, IrriSAT remote sensed data, and Australian Bureau of Statistics (ABS) data. The model was configured to two different water availability conditions to enable comparison with these:

- with no restrictions; and
- with restrictions as estimated within the Gwydir Valley model.

The first test allows for comparison of the theoretical irrigation water use to WaterSched Pro. However, in practice, full irrigation may not be possible during dry years and the second test allows comparisons to be made to published data on actual application rates (e.g. ABS and IrriSAT).

Test 1: comparison with WaterSched Pro

The WaterSched Pro method provides an estimate of long-term average crop water use, assuming an unrestricted water supply. It also uses FAO based crop coefficients.

A simple test model was set up with a notional unit cotton crop area and the unrestricted water use was simulated using a long-term period of climate data. This test model has been used to calculate the simulated water use as a volume of water per hectare (ML/ha). The modelled application rates were defined as follows:

- includes application losses
- excludes rainfall, on farm storage losses and tailwater returns

Using climate data for Moree (station 053048), from 1890-2019, an average of 8.1 ML/ha irrigation water was applied to cotton using this test model. The model assumed that 30% of this water was lost between the water source and the crop water use. Removing the 30% loss means that cotton uses 5.7 ML/ha of irrigation water on a long-term average basis, in addition to effective rainfall.

The results for cotton compare well to the modelled results after adjusting for pre-watering.

Test 2: comparison with ABS data

The ABS collect data on irrigation application rates for various crop types across the Gwydir and Border Rivers, and these compare well with test 2 (modelled with restrictions). Modelled results are higher than ABS data in some years, which is not surprising given the large areas covered in the ABS reporting region.

Test 3: comparison with farm dam survey

The farm surveys resulted in a range of reported application rates for an average year, from 3 ML/ha to 12 ML/ha. Further detail is discussed in Appendix H. It is difficult to compare the survey data to modelled results (the second test described above) year by year over the validation period given the variability of the rates between the properties and between years, and that the relevant period these reported figures were averaged over is not known. It is presumed that the reported figures represent currently achieved rates at the time of the survey.

Test 4: comparison with IrriSAT

The IrriSAT website[14] publishes estimates of crop factors and actual ET, and the data can be assessed down to a paddock scale, based on satellite remote sensing information. These data can be used to show which paddocks have been irrigated, and to estimate the total crop water use for each paddock.

Crop water use estimates from IrriSAT have been reviewed by NSW DPI Agriculture. They found that in general, IrriSAT overestimates ETc by about 10% (as it doesn't simulate emergence or defoliation very well, effectively overestimating canopy cover). In some cases, the overestimate is up to 30 %. Conversely, industry sources have indicated that IrriSAT may under-estimate crop water use. Pursuing further ground-truthing data will help to better establish

[14] https://IrriSAT-cloud.appspot.com/#

the reliability of IrriSAT data. Despite this uncertainty, IrriSAT can still be used to detect large instances of under-irrigation and can still be used to check the irrigated areas.

We have used data from this website to produce detailed estimates of crop areas and water use from 2000 to 2018 for four individual farms to test the modelled water use estimates. These independent estimates of crop water use (ML/ha) have been compared to those produced by the Gwydir Valley model for a crop without water restriction. The results indicated that modelled crop water use was very close to the IrriSAT estimates, being within 10% of the IrriSAT estimates. The methodology used to estimate crop areas and crop water use is described further in 6.2.2.

All methods described above have their own sources of uncertainty as truly representing both crop water use for specific periods and long-term averages. These sources all provided estimates similar to that of the Gwydir Valley model's values and provide confidence that this is a robust estimate. The dynamic representation of water availability from both climate and management provide an advantage for Gwydir Valley model for the interannual variability.

Runoff harvesting

Runoff from developed and undeveloped areas on farm were simulated with climate variability and irrigation as inputs to a soil moisture accounting component model of the same simple crop water model used to determine irrigation application rates at Test 1 above.

There is significant uncertainty in the simulation of rainfall–runoff from developed areas because:

- rainfall–runoff rates vary depending on site specific soil, land, and irrigation management practices (e.g. Haghnazari 2015)
- the simple daily model for simulating rainfall–runoff does not account for many factors which affect runoff, such as rainfall intensity.

Our simple model does not consider these factors. Soil moisture content appears to be the primary predictor of runoff response to after rainfall in areas with high water holding capacity (e.g. Freebairn et al., 2009), which is the case for most of the study area. Soil moisture is accounted for in the crop water model as it tracks changes resulting from rain, evapotranspiration, and irrigation on a daily basis. Therefore, limitations in the ability to account for rainfall intensity does not appear to be a significant issue for a long-term simulation period. These considerations led to our decision to match these to long term averages to the best available data sources available.

Simulated **rainfall runoff rates** are summarised in Table 29. The runoff rates from both fallow and irrigated areas are in line with the results from the literature review described in Appendix E.

The **interannual variability in modelled runoff depths** from climate variability is well represented (Figure 24). As well as reinforcing the relative rates of runoff response summarised in Table 29, this also shows a clear relationship of higher annual runoff depths with more annual rainfall for each land use type.

Table 29 Rainfall–runoff rates for Moree (#053048) (calculated as total runoff over the period divided by total rainfall. The same parameters are applied for other climate stations however a small amount of variation occurs due to differences in rainfall characteristics

Area	1890–2015
Summer irrigated + summer fallow + winter fallow	8.0%
Continuous fallow	4.1%
Undeveloped	1.6%

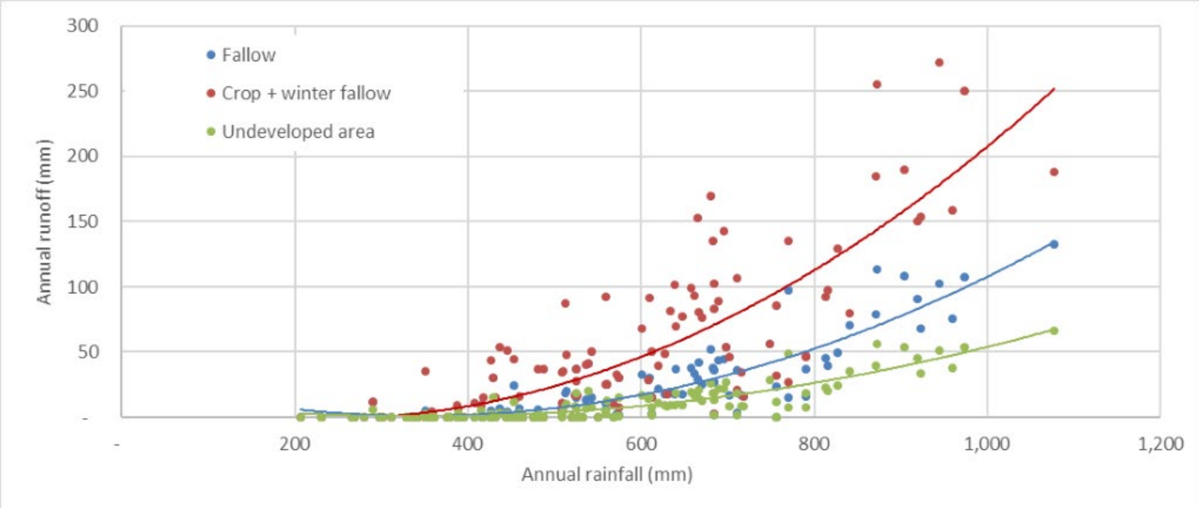

Figure 24 Annual runoff depth compared to rainfall for different on-farm land area types (fallow, crop + winter fallow, undeveloped area)

While the runoff depths are the best available, we acknowledge there is considerable uncertainty around this, and this uncertainty is largely because there is a paucity of data to indicate what the true value is.

Further data collection would be desirable to confirm the assumptions used noting that:

- data collection should be from properties with representative management practices.
- collection should be over several years to compare to modelled estimates. The runoff coefficient can be very high in individual years (Figure 24). An average obtained over a short-term period is likely to have a different average runoff coefficient compared to the long term.
- an overall farm water balance check is undertaken (described in a following section) where the combined metered use, rainfall runoff, and overbank flow harvesting is compared to the simulated total crop water requirements for each individually simulated irrigation enterprise. To achieve an overall balance, the bias in rainfall runoff rates are likely to be offset by a bias in overbank harvesting estimates. The access to overbank flow has been estimated using a farm water balance approach as described in Section 2.3.1. This means that when the assumed rainfall runoff rates are lower than actual, then the model is likely to have been calibrated to assume higher access to overbank flow compared to what happened.

Overbank flow harvesting

The simulated volumes of overbank flow harvesting are affected by the simulation of flow breakouts as described in Section 4.5 and the harvesting of those breakouts are described in Section 6.2. The opportunity to harvest overbank flow depends in part on their frequency and volume. This ability of the model to reproduce these is shown at Figure 25.

These show that the modelled **frequency and number of overbank flow events** reasonably matches the observed behaviour. The result is particularly close since 1970 with only one year where there was a difference between the observed and simulated number of overbank flow events. More weighting would be given to the more recent behaviour as there is better data for this period.

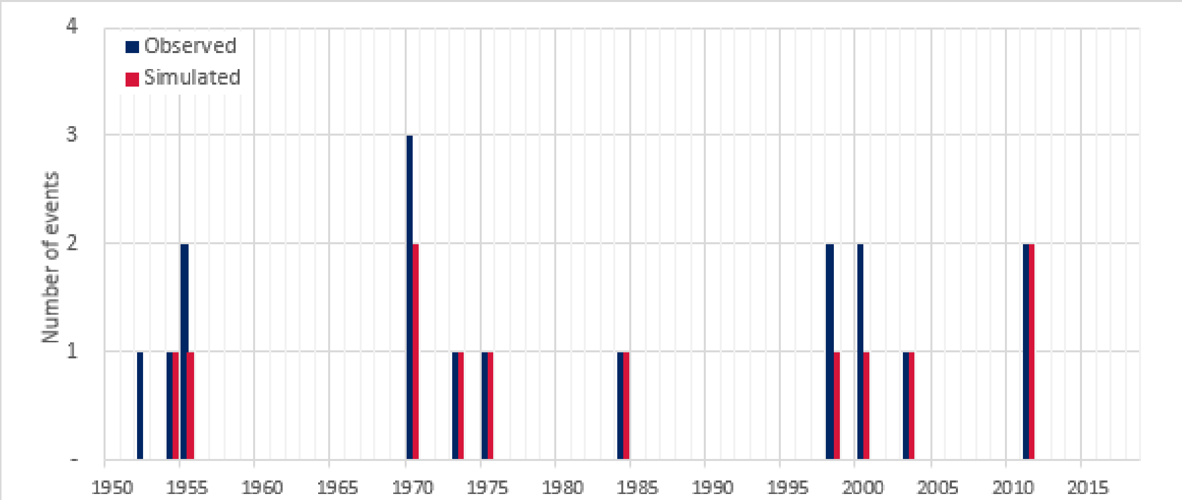

Figure 25 Annual simulated vs observed events at Pallamallawa above overbank flow threshold over the period 1950 to 2015

Apart from the data that was analysed to form the breakout relationships, there is no further data that can be used to validate the volume on the floodplain during an event[15]. We have investigated whether it will be possible to use remote sensing data to estimate change in on-farm storage volumes over an event. This type of data could provide much more confidence in the estimates than simply looking at volumes on the floodplain, as not all water can be and is diverted[16]. Very high-resolution data are required to undertake this analysis and we found insufficient historical data to undertake this assessment immediately prior and post a floodplain harvesting event.

Irrigation water balance check

As an overall check for each individually represented irrigation enterprise, the simulated water balance in the model was checked against diversions directly from the river. This checks how well the metered diversion components are reproduced. The remainder of the water taken by the farms is floodplain harvesting, combining rainfall–runoff harvesting and overbank flow harvesting.

The premise of this farm water balance check is that, where the model simulates a realistic crop irrigation demand such as was reported earlier, then the combined metered diversions and floodplain harvesting should be sufficient to water the reported crop areas, to the extent that they were in practice.

The model was checked to ensure that there was not extensive crop water stress from insufficient on-farm water availability. These checks were done at 3 scales:

- whole-of-valley
- reach

[15] We have considered whether remote sensing might be used to estimate volumes of water on the floodplain. However, given the uncertainties involved, and the need for volumes over the course of an event rather than on a single day, the method was not pursued. Remote sensing has been used however via the use of data from floodplain hydraulic models, as these have been calibrated using aerial photography and satellite imagery.

[16] Our long-term model results indicate that the proportion of breakout water harvested ranged from 3-61% in each valley. These results indicate that the breakout relationships are not a limiting factor in determining overall volumes harvested.

- property.

Valley scale results should match observed metered diversion data well to provide confidence in the estimates of total floodplain harvesting, and therefore established whether the model can reliably update diversion limits for long term baseline scenarios. Comparison to observed and modelled metered diversions shows that the valley total modelled results are 7.5% higher than observed over the 2004/05–2012/13 period, but are 0.4% lower than observed data over the longer 2003/05–2018/19. Further detail on metered diversion components is discussed in Section 8.3.3.

Reach scale results should be reasonable to indicate that the distribution between reaches is consistent. Table 30 shows that the bias is small between all the three main sections of the regulated river system, hence there do not appear to be any distribution issues.

This water balance check at the individual **property scale** was undertaken at various stages of calibration. In early stages of the calibration model components were forced to observed values over the comparison period (e.g. supplementary diversions), and at later stages these were replaced with simulated values.

Simulation of individually modelled irrigators was reviewed to check the following:

- the simulated metered diversions against metered diversion records
- farm survey information regarding periods and volumes of harvesting
- remote sensing information (e.g. cropping, water in on-farm storages)
- any recorded temporary trading of water (not simulated in the model) which may account for some properties running out of water in their account within the model.

These individual results are assessed for large anomalies, and if so whether there is a reasonable explanation. Other supporting information such as comparison to farm surveys, nearby properties, and remote sensing are also assessed.

We would not expect a perfect water balance to be achieved at all individual properties. There are several reasons for this. The method to parameterise the crop model uses assumptions about average irrigation water use to ensure that the valley scale results are robust. Given the reported variation in individual water use efficiencies, allowance was permitted for some variation in water balance results at individual properties. The accuracy of metered water use is also expected to vary, and this may also cause differences in the water balance result.

8.3.2 Planted areas

The Gwydir Valley model estimates the area planted based on water availability. Other factors such as markets also affect planting decisions, hence some variability between years is expected.

The modelled planted areas have been compared with the combination of Farm Survey and remote sensing areas at a valley scale in Figure 28, noting that the period for area comparison is limited to data availability[17]. This shows that the model simulates approximately 8% less area on average and follows annual variability well. Given that there can be changes in other socio-economic variables that influence crop areas for individual years, some variability at the annual level can be expected.

In particular, differences between simulated and observed irrigated crop areas can be seen between 2010 and 2013 and appear to be due to seasonal changes in planting risk and decision

[17] The individual farm survey area data over 2003/04 to 2012/13 was able to be gap-filled and (for some farms) checked using IrriSAT.

dates for planting. The model uses a constant planting risk that was taken from the farm surveys.

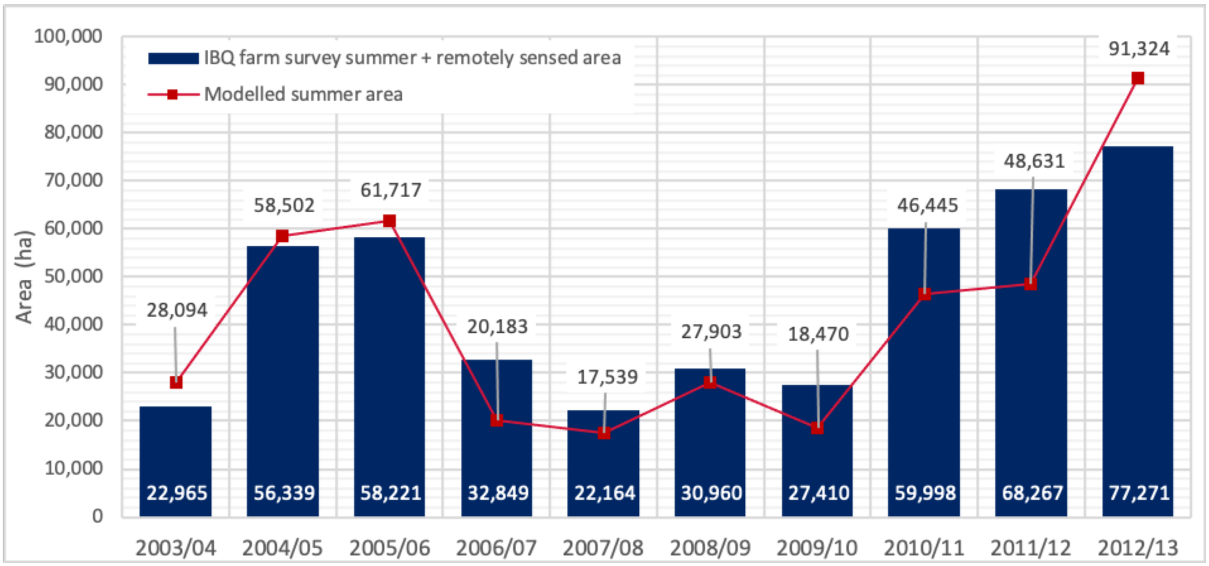

Figure 26 Observed (farm survey and remotely sensed) and simulated summer crop areas for floodplain harvesting properties for the years 2003/04 to 2012/13

8.3.3 Metered diversions

Results of simulated diversions from the fully assembled, calibrated model for the 2008/09 validation scenarios were compared with recorded diversions. This scenario simulates all system operations and management rules such as supplementary announcements and general security allocations. Totals for the 2003/04 to 2013/14 comparison period are illustrated in Figure 27 with summary results reported in Table 30.

Table 30 Comparison of general security, supplementary and total simulated and observed metered diversions over two periods: 2004–2013 and 2004–2019

Section	General security 2004-2013	General security 2004-2019	Supplementary 2004-2013	Supplementary 2004-2019	Total metered 2004-2013	Total metered 2004-2019
Carole-Gil Gil	+25.0%	-0.2%	-17.3%	-0.8%	+4.4%	+0.4%
Gwydir	-6.0%	-24.8%	+58.8%	+79.3%	+10.8%	-5.5%
Mehi-Moomin	+29.0%	+11.7%	-20.2%	-16.5%	+7.3%	+2.5%
Valley	+17.1%	-2.6%	-6.3%	+4.8%	+7.5%	-0.4%

Note: Negative/positive sign indicates whether modelled value is lower/higher than observed

A closer match with recorded data is observed when compared to the longer validation period. This can be partially explained by consecutive very dry years between 2004/05 and 2009/10 (i.e. 50% of the validation period), during which planting decisions and irrigation practices used in reality are likely to be more variable than those adopted for long-term scenario modelling. These may include:

- different crop being planted
- different planting configuration/s used
- underwatering/

The model closely simulates **total diversions** from the river over the assessment period; but over-simulates **supplementary access diversions** along the main stem of the Gwydir valley, with an associated under-simulation of **general security diversions**. Figure 27 compares the annual observed and modelled diversions, and shows that the model reproduces the inter-annual pattern of water use reasonably well. The modelled diversions in 2010/11 are higher than observed diversions, although modelled crop areas are lower. However, the modelled diversions are close to observed in 2011/12 despite (again) lower modelled crop areas. Possible reasons for the variations between modelled and observed diversions include annual variability between modelled and actual volumes of floodplain and rainfall runoff harvesting, and variability in crop watering practices such as under-watering and non-cotton crops that are not represented in the model. There was some evidence for variable crop watering practices noted in the analysis of crop areas using IrriSAT described in Section 6.2.1.

In 2012/13 modelled diversions were higher than observed, consistent with modelled crop areas also being higher than observed.

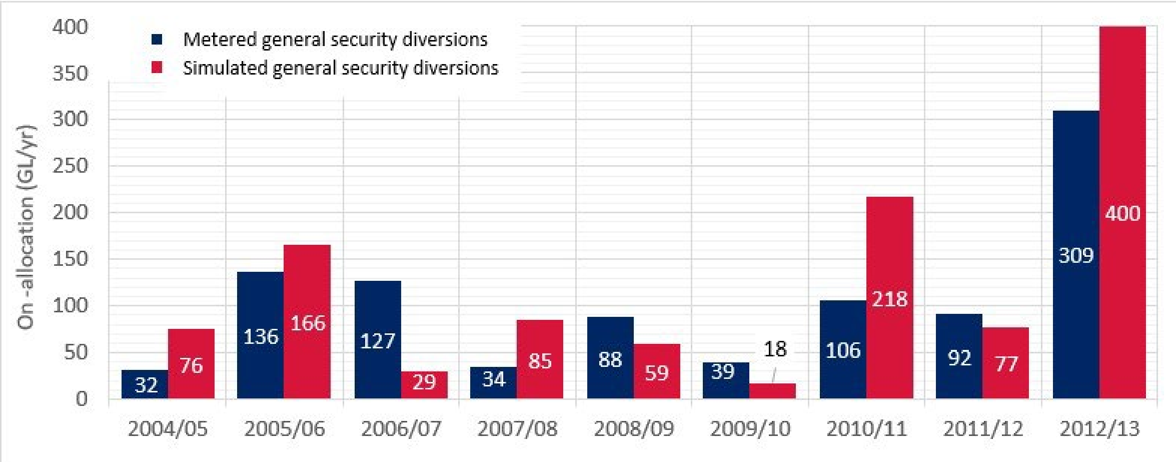

Figure 27 Observed (metered) and simulated annual general security diversions for the years 2004/05 to 2012/13

Supplementary access diversions

Simulating supplementary access is inherently difficult, as it is more sensitive to mismatches between the observed and simulated timing and size of flows and water orders on a daily basis. There is also an element of variability to forecasting orders and flows made by river operators when assessing whether flows will be supplementary to requirements, and the operational practice of rostering supplementary access between river sections between events.

The total modelled supplementary access compared reasonably with observed supplementary access diversions at a valley scale, as reported in Table 30, but the model has a bias towards supplementary access along the main stem of the Gwydir system. This bias may be the result of operational management of supplementary flow events in this section. The annual modelled and observed supplementary access diversions are shown in Figure 28. These results show that inter-annual variability is reproduced reasonably well, given the dynamic nature of this process over short time scales.

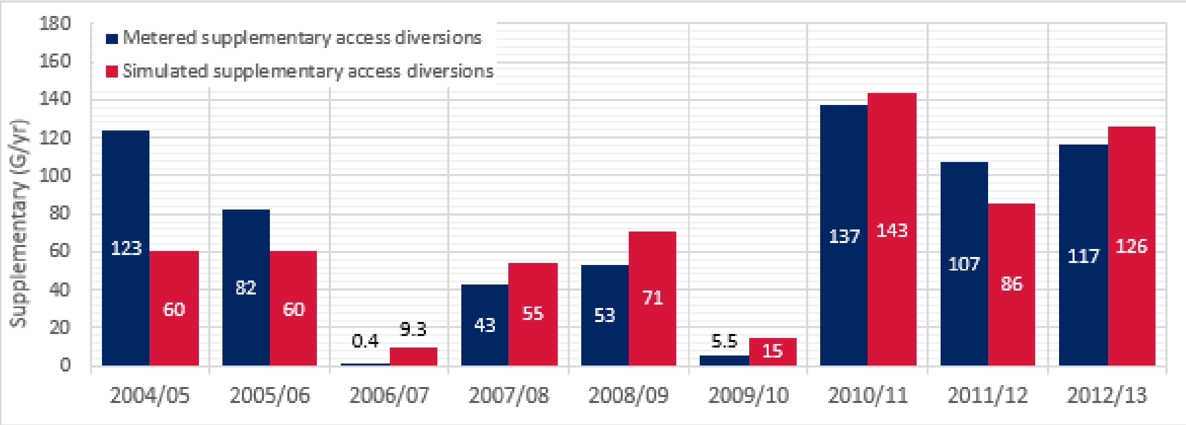

Figure 28 Total observed (metered) and simulated annual supplementary access diversions for the years 2004/05 to 2012/13

8.4 Water management rules

8.4.1 Storage operation

The simulated **total storage volume** from the freely simulating 2008/09 Scenario is compared to the observed storage volumes in Figure 29.

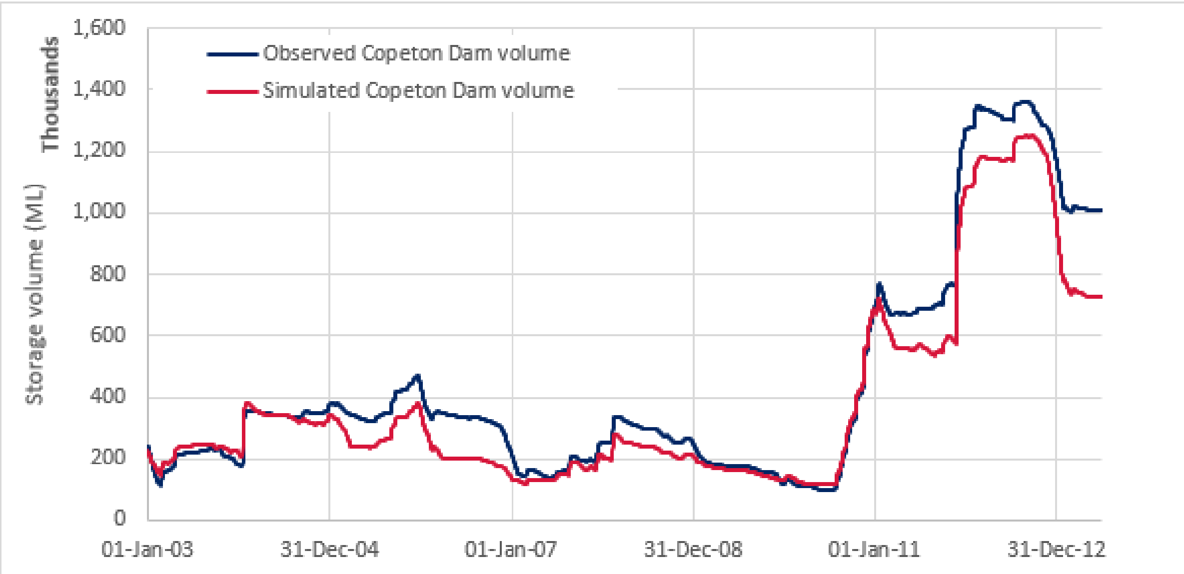

Figure 29 Time series of simulated and observed total storage volume at Copeton Dam for the years 1/1/2003 to 30/6/2013

The observed and modelled storage volumes compare reasonably well over the millennium drought period from 2003 to 2010, with the exception of 2005 to 2007. The increased drawdown of the modelled storage volume in 2005/06 appears to be related to over-estimation of general security water use in the model. Whilst the observed and modelled crop areas in 2005/06 are similar, potential reasons for lower observed diversions than modelled include variations between simulated and actual floodplain harvesting in that year, and variations in watering practices.

In 2006/07, the situation reverses, as the model commences the year with less water in storage and simulates lower diversions in that year, resulting in the observed volume in storage catching up to the modelled volumes in storage.

During the wetter period between 2010 and 2013, the modelled storage volumes are drawn down further than observed in 2010/11 and again in 2012/13 consistent with the model over-estimating **general security diversions** in those years as noted above. During 2012/13, the modelled crop areas were significantly higher than observed, and the model also simulated higher diversions than observed. Consistent with this, the modelled storage drawdown of Copeton Dam was larger than observed.

8.5 Long-term annual diversions

An indication of how these different diversion components vary based on long term climate conditions is illustrated using the model set up to do a long-term simulation at an approximation of the 2008/09 Scenario. The results shown at Figure 30 are purely indicative for illustration of the relative magnitude of the components and how they vary over time.

The results show the most significant diversions in terms of long-term averages are general security, followed by supplementary access, then overbank flow harvesting, and lastly on-farm rainfall runoff harvesting. The general security inter-annual variability reflects the impacts of climate and headwater storage. The supplementary diversions have lower inter-annual variability due in part to the annual limit on diversions, as well as other factors related to the inter-seasonal dynamics of water use and availability. Overbank flow harvesting has the greatest inter-annual variability and corresponds with the occurrence of flow breakout events as shown in Figure 30. Rainfall–runoff harvesting has a similar pattern, albeit at a reduced scale.

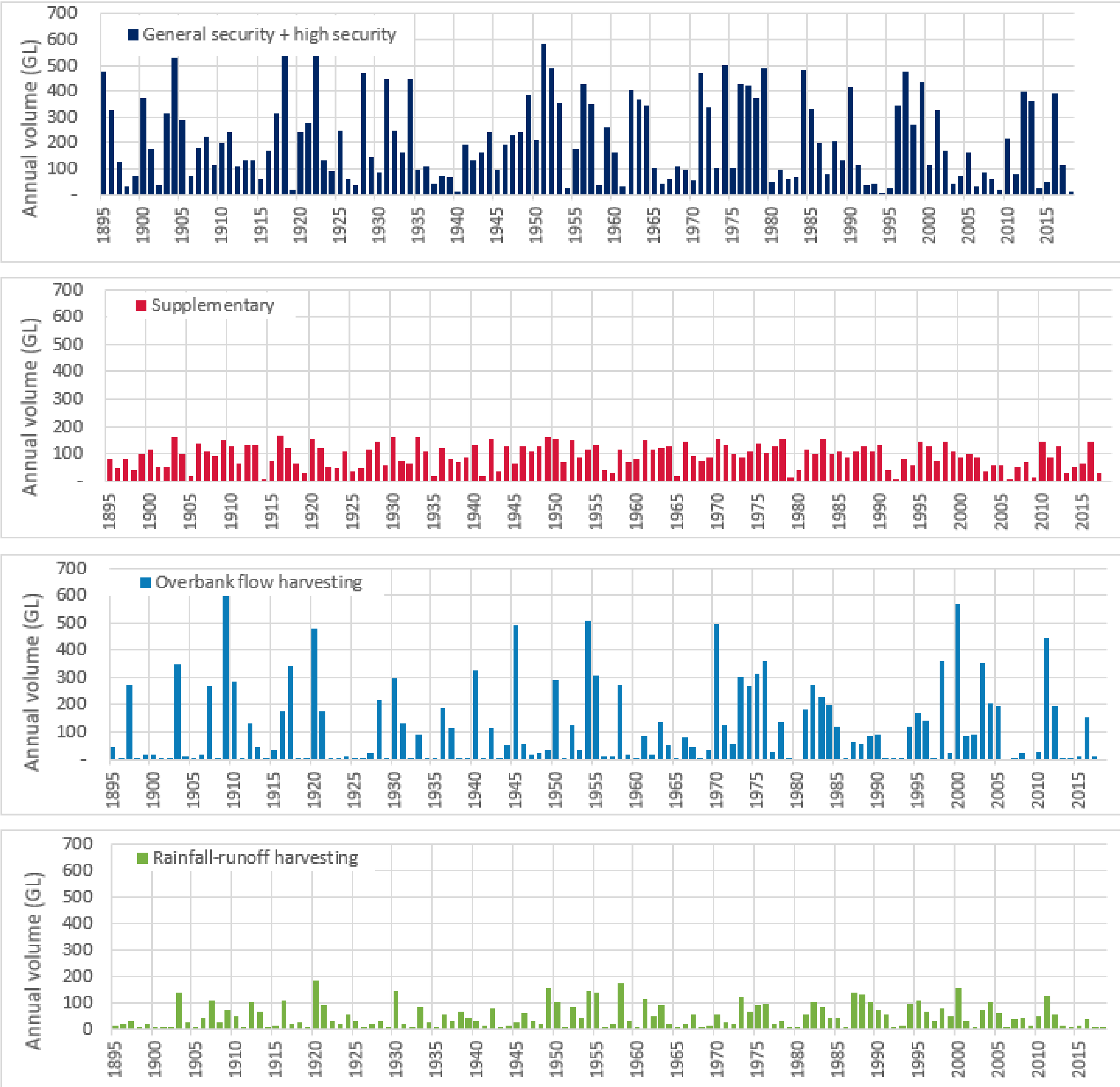

Figure 30 Simulated annual volumes of high and general security, supplementary, overbank flow harvesting and rainfall-runoff floodplain harvesting for the years 1895 to 2019

9 Sensitivity testing and uncertainty analysis

This section considers:

- key sources of uncertainty in the models
- measures put in place to reduce the uncertainty
- sensitivity of modelled floodplain harvesting outputs compared to the remaining significant uncertainty
- measures required to reduce uncertainty in the future.

Specifically, this section responds to recommendations from the *Independent Review of NSW Floodplain Harvesting Policy Implementation* (Alluvium 2019) for a qualitative assessment of uncertainty.

> “Document an assessment of model uncertainty and suitability for application, including where future improvements should be made to reduce that uncertainty, in the model.”
>
> “We believe that a more qualitative assessment of uncertainty is still required, combined with an analysis of parameter sensitivity, in order to document where the major uncertainties may lie and how they can be addressed through further model improvements.”

The two main model outputs (in terms of the policy) are the impacts of modelled floodplain harvesting outputs on:

- **total diversion limit**, as specified in a water sharing plan, and **annual compliance** with the limit
- the **distribution** of floodplain harvesting entitlements **between individual properties.**

These two criteria can be used to assess the impact of uncertainty on these modelled outputs.

Future refinements to models and adaptive management tools will enable changes to the total valley limits. However, these changes will not enable changes to the distribution of individual floodplain harvesting entitlements. In accordance with the policy, the distribution of entitlements is based on a capability assessment of eligible works capable of floodplain harvesting and access to water flowing across a floodplain. Further, the policy states that information relating to history of use will not be used to determine entitlement. Further information on the capability assessment, and how our methodology addresses this component of the policy, is discussed later in this section.

In summary, we consider the:

- key sources of uncertainty in the models
- measures we put in place to reduce the uncertainty
- sensitivity of modelled floodplain harvesting outputs compared to the remaining significant uncertainty
- measures we need to take to reduce uncertainty in the future.

9.1 Sources of uncertainty

During model development, these issues are considered, and a number of actions taken to minimise uncertainty, as described below. It is not possible to define total uncertainty in quantitative terms. Table 31 and Table 32 summarise the significance of a range of sources of uncertainty on the modelling of floodplain harvesting and the Plan Limit. The summary draws on sensitivity testing where possible.

The key sources of uncertainty in the models are as follows:

- input and calibration data
- model representation of processes including physical processes and management arrangements
- model parameter values.

We considered these issues during model development and took a number of actions to minimise uncertainty as described in Table 32 below. The following risk management approach has been used to consider uncertainty:

- If our confidence in the parameter or model component is high, model uncertainty has low significance
- If our confidence in the parameter or model component is not high, sensitivity testing is used, where possible, to assess the sensitivity of model results to the parameter or model component (i.e. how much it matters).

We have devised qualitative rating criteria to identify the largest impact on the ability of the model to accurately determine diversion limits and distribution of floodplain harvesting entitlements. The rating is for indicative purposes only.

Table 31 Qualitative uncertainty significance rating system, with sensitivity test results examples

Significance rating	Description	Example
Low	Either the uncertainty in the parameter is low or the impact of the uncertainty on floodplain harvesting outputs is low	Sensitivity test using a plausible scenario results in: less than or equal to 5% change, or the issue is not relevant, or the issue is well researched / analysed
Medium	Uncertainty in the parameter and impact on floodplain harvesting outputs is larger, but they are not considered as primary issues	Sensitivity test using a plausible scenario results in: change greater than 5% and less than or equal to 15%
High	Primary issues affecting the accuracy of floodplain harvesting outputs in a long-term model assessment	

Table 32 Sources of uncertainty and their significance for modelling floodplain harvesting estimates

Source of uncertainty	Comment	Significance rating
Climate and flow data		
Long term climate stations used in modelling are significant distances apart and may not match rainfall on an individual farm on specific days	Large rainfall events may make it difficult to calibrate for a specific area if it is not representative of rain on that day. However, the long term modelled results have low sensitivity to changes in assignment of climate station to each property (see Table 33, Test 1)	Low
Use of historical climate data means that climate change is not accounted for	Use of historical climate data is consistent with the data specified for the limit specified in water sharing plans (1895–2009)	Low
Data accuracy – error in measurement of historical climate data	We implement a suite of methods to review data to ensure that we identify and filter out poor quality climate stations or data at these stations, particularly those with missing data that has been infilled	Low
Data accuracy – availability of and error in flow data	Short periods of flow records, sparsity of flow gauges and data quality issues all contribute to uncertainty in flow behaviour and representation in river system models. We use mitigation measures, including ensuring inflow estimates are a plausible ratio of rainfall, avoiding poor quality gauges, having regard to periods of and ranges of flow record with higher uncertainty, and using supplementary information such as remote sensing and hydraulic modelling to understand flow behaviour	Medium
Diversion data		
Accuracy of river diversions	Meters used to measure regulated and supplementary diversions have known uncertainties of ±1–25%. A key consideration in our method was to assess the overall water balance to meet irrigation requirements for historical crop areas. Uncertainty in the measured component of the water balance would be offset through estimates for the other components, such as floodplain harvesting. Noting the significance of metered diversions, a systematic 5% underestimate or overestimate in metered diversions would result in a 10–20% compensatory overestimate or underestimate respectively in floodplain harvesting diversions. This uncertainty will be reduced in the future by further meter testing and validation data through the Metering Framework and on-farm storage monitoring data through the Floodplain Harvesting measurement requirements	High

Source of uncertainty	Comment	Significance rating
Sparsity of records on harvested volumes	There is a lack of reliable records on actual volumes harvested from overbank flow events or rainfall–runoff. Whilst other lines of evidence have been used, such as information gathered through farm surveys (Irrigator Behaviour Questionnaires), the lack of data makes it difficult to validate both the valley total and individual variability in floodplain harvesting. This is the principal cause of uncertainty in modelling floodplain harvesting. However, the data provided through the measurement requirements for floodplain harvesting properties will reduce this uncertainty over time	High
Model assumptions / simplifications		
Property scale rainfall–runoff model operating on a daily timestep does not account for rainfall intensity	Research indicates that the primary predictors of rainfall–runoff in areas with high water holding capacity are rainfall and soil moisture content. Our model continuously tracks soil moisture content. Therefore, in most areas, any limitations in accounting for rainfall intensity would not be a significant issue for a long-term simulation period	Low
Evaporation and seepage loss from storages is based on assumed sequential filling rather than simultaneous filling of storages	This assumption relies on this being the most efficient mode of operation to minimise losses. Long term results have low sensitivity to changes in this assumption (see Table 33, Test 2). We can further reduce this uncertainty in time through analysis of monitoring data and of multi-date satellite imagery	Low
Hydraulic characteristics of intake pipes are not represented	Intake pipe flow rates depend on the difference between intake and outlet water levels. This intake or environmental information is not available. However, in most situations this limitation is not an issue as the total rate of floodplain harvesting is limited by the on-farm storage pumps. Sensitivity testing for the intake rate shows that valley wide totals are not sensitive to our assumptions. The majority of individual results also have low sensitivity (see Table 33, test 3). The sensitivity may be higher when considered in conjunction with other issues, as is further discussed in Table 33. Reducing this uncertainty further would require significant new datasets and investment in model refinements (which we are not planning to undertake)	Low

Source of uncertainty	Comment	Significance rating
Model parameters		
On-farm storage capacity	We identified at an early stage of this work that the floodplain harvesting results were very sensitive to on-farm storage capacities. Significant effort has been put into improving the accuracy by using LIDAR or photogrammetry data with verification against a sample of surveyed storages (Morrison and Chu, 2018). These data indicate the results are reasonably reliable (generally around 2% difference in volume at a given level) but the assumptions around freeboard can have a larger impact on the assumed full supply capacity. Due to the latter, we have assigned Medium significance. Overall, we consider our approach to be robust due to a standardised approach for calculating freeboard (1m for constructed permanent storages which is in line with industry best practice)	Medium
On-farm storage seepage	Seepage rate estimates for on-farm storages are based on data published in Wigginton (2012a). Sensitivity testing indicates our floodplain harvesting outputs are not sensitive to seepage estimates (see Table 33, test 4)	Low
Crop model parameters	Uncertainty in total irrigation water use has a significant impact on the assessment of the diversion limit but has less of an impact on the distribution of individual floodplain harvesting entitlement. Irrigation water use is estimated using historical crop area data, and a crop model that is parameterised to match published crop water requirement information, including application rates. This assumption is important to the assessment of the valley total floodplain harvesting. We explicitly account for annual variation in irrigation water use due to climate, however, individual differences in application rates and efficiency cannot be verified and accounted for. We have managed this uncertainty by using multiple sources of information to represent floodplain harvesting access, rather than relying on highly accurate water balance at individual properties without data to validate harvested volumes. We have found, through sensitivity testing of irrigation efficiency post calibration, that the determination of entitlements is not highly sensitive to individual differences in water use (see Table 33, test 5). In the future, we will use data from the floodplain harvesting measurement requirements to review and verify our assumptions about application rates and reduce the uncertainty in total valley estimates	Medium for valley total Low for distribution

Source of uncertainty	Comment	Significance rating
Rainfall–runoff parameters for within farm runoff model	We have relied on best available data to characterise differences in runoff between undeveloped, developed and irrigated areas. However, this data are limited, and it is not possible to verify and account for individual variation in irrigation practice and runoff generation. In response to recommendations of the Independent Review (Alluvium 2019), we have also undertaken another independent review of the assumptions for runoff from irrigation areas (Barma Water Resources 2019). This found that: • the estimates were uncertain due to limited available data • the adopted approach represents a step forward compared to other approaches reviewed • harvesting of rainfall–runoff is likely to be a fairly small component of total valley diversions. In the future, data from the floodplain harvesting measurement requirements will be used to review and verify our assumptions.	generally Medium may be High for some properties where rainfall–runoff is the dominant form of take
Relationships between river flow and overbank flow and access to that flow	We have based overbank flow relationships where possible on hydraulic models of floodplain flow developed for floodplain management plans[18]. These models were calibrated to several flood events against gauged flows, remotely sensed flood inundation extents, and previous flow distribution calculations and estimates. Where this was not available, we have used other lines of evidence such as long-term flow records at upstream and downstream gauges, flood records, farm survey information and remote sensing. The relationships between river flow and overbank flow are important for determining the volume of water on the floodplain available to harvest. We have managed uncertainty in this by assessing the overall farm water balance at a reach scale. Individual property access to overbank flow has been assessed using a range of information such as irrigator behaviour questionnaire data and remote sensing analysis. In larger floods, the model is less sensitive to overbank flow and access assumptions as there is an excess of water compared to airspace in storages. However, in small to medium floods the actual volume harvested will be sensitive to the breakout relationship and access to this flow. This will be reviewed when information from the floodplain harvesting measurement becomes available.	Medium

[18] The floodplain management plan models are described in technical appendices for each valley. https://www.industry.nsw.gov.au/water/plans-programs/healthy-floodplains-project/plans

Source of uncertainty	Comment	Significance rating
Rate of take of floodplain water into permanent on-farm storages	All on-farm storage pump capacity values are based on expected flow rates from well-designed pump stations. Gravity fill of storages is only represented where this is the only eligible intake into the storage, or in exceptional circumstances, where high rates can be used to fill to a high level. Comparisons have been made between farm survey (IBQ) data, industry advice and pump charts to inform the expected flow rate for a given type and size pump, within a range of around 30%. This range was derived through discussion with field operators and industry consultants. Sensitivity testing shows that valley wide totals are not sensitive to these assumptions. The majority of individual results also have low sensitivity (see Table 33, test 3). Adopting a standard set of rates is considered to be the most equitable approach that also enables a robust review of eligible and historical works.	Low

9.1.1 Sensitivity testing

The 6 sensitivity tests referred to throughout Table 32 are described in Table 33.

Table 33 Sensitivity tests, results and discussion

Test	Test completed	Result and discussion
Choice of long-term climate stations used in modelling farm water balance	For all properties or groups of properties represented in the Gwydir regulated river system, we changed the climate station used in the irrigator component model to the second closest climate station.	The average change was 2% for FPH, and 0.3% for total diversions.
Assumptions around sequential filling of storages	Two tests have been completed for all properties or groups of properties represented in the Gwydir Valley model: 1) Assume that the storage losses are based on all storages being at maximum surface area at all times. This is not physically possible; however, it provides an indication of upper bounds of sensitivity. 2) Assume that least efficient storages are filled first.	1) The average change was 0.1% for FPH, and 1% for total diversions. Note that this scenario is not physically possible and therefore the actual impact will be less than this. 2) The average change was 0.7% for FPH, and 1.3% for total diversions.

Test	Test completed	Result and discussion
Change intake rate assumptions	30% increase in each of the following: • intake of FPH • on-farm storage pump rates • rate of release from the virtual storage This test was completed for all properties or groups of properties represented in the Gwydir Valley model.	The average change was 1.9% for FPH, and 0.5% for total diversions. The model has low sensitivity as the rate of release from the virtual storage is matched to the assumed take rates. If more detailed information were known about conveyance of water across the floodplain and represented in the model, then the assumed take rates would likely be more significant.
OFS seepage	On-farm storage seepage rate was doubled from 2mm/day to 4mm/day. This test was completed for all properties or groups of properties represented in the Gwydir Valley model.	The average change was 3.3% for FPH, and 1.8% for total diversions
Irrigation efficiency assumptions	Irrigation component model changed to assume less efficient operation; from 30% loss to 40% loss (i.e. 33% relative increase in loss). This test was completed for all properties or groups of properties represented in the Gwydir Valley model.	The average change was 1.1% for FPH, and 1.1% for total diversions

9.2 Total uncertainty estimates

There is an understandable interest in total uncertainty in a quantitative sense. This type of rigorous analysis has been tested for simple models where good quality observed data exist to be able to use automated calibration techniques. The complexity of the river system models, the large number of parameters and insufficient data mean that confidence intervals cannot be provided for floodplain harvesting model outputs.

Methods used to provide a quantitative analysis of uncertainty require good observed data to either undertake model error analysis (e.g. McInerney et al. 2018) or assess parameter, structure and data errors (e.g. Beven and Binley 1992; Kavetski et al. 2006). We do not have sufficient observed data for floodplain harvesting or knowledge of parameter distributions to undertake any of these approaches.

Simple sensitivity testing, where random combinations of parameters are assessed, is not suitable to quantify uncertainty in results. This is because it is entirely likely that many of the tests created in this way result in models that are not plausible.

Rather than attempting to quantify overall uncertainty, the purpose of this report is to communicate what we have done to manage (and minimise) uncertainty. We also take the opportunity to recommend the key data collection and future work needed to significantly improve confidence in floodplain harvesting estimates.

9.3 Impact of uncertainty on distribution of entitlements

The policy states that the determination of share components will not be based on any history of use information. Instead, a capability assessment is to inform the distribution of individual entitlement. This assessment is intended to allow consideration of both the physical infrastructure used for floodplain harvesting, and the opportunities that irrigators may have to access floodplain flows based on their location and climatic variability. The key components of the capability assessment are detailed in Table 34. The appropriateness of the adopted methodology in addressing each criteria relies on the conclusions made in Table 33.

Table 34 Capability assessment criteria and confidence to inform the distribution of individual entitlements

Capability assessment criteria	Confidence in modelled approach
Know with some confidence	
Capacity to store and use water	The use of independent and verified methods such as LIDAR and standard assumptions around freeboard result in a robust approach to determining storage capacity. However, there are a few examples of unusual storage construction where the method is less reliable. In these instances, it is assumed that the information supplied by the applicants in the submissions process will improve the confidence
Existing water access licences	Department database data as at 2008 has been used in determining individual shares
Know with less confidence. However, sensitivity testing indicates a minimal impact on distribution of individual floodplain harvesting entitlements	
Irrigation behaviour	Differences in irrigation efficiency have been shown to have little impact on individual estimates. Other aspects of behaviour such as planting decisions have been defined in line with information provided in irrigator behaviour questionnaires and historical cropping
Configuration of the works	Sensitivity testing was undertaken to examine different scenarios for the sequence of storage use. This shows that there is low sensitivity
Know with less confidence and distribution of individual floodplain harvesting entitlements is sensitive to assumptions	
Extraction capability and location specific frequency, magnitude and duration of flood events	Sensitivity testing has been undertaken which shows the model has low sensitivity to the assumed extraction rates. However, we propose that, in combination, these issues are a larger cause of uncertainty. Some of these issues are structural in nature such as routing and water depth on the floodplain, making it difficult to complete a sensitivity test. Sensitivity tests could be undertaken for other components, such as individual property access to overbank flow. We have already attempted to use multiple lines of evidence to inform the individual property access, such as farm survey data, remote sensing analysis and, in some cases, relevant information from floodplain management plan hydraulic models. A review of the modelled approach can be undertaken when sufficient data are obtained from the floodplain harvesting measurement requirements

In summary, uncertainty in the distribution of individual floodplain harvesting entitlements has been managed through the following:

- incorporating all aspects of the capability criteria into the modelling approach. Importantly, the modelling which informs the distribution of entitlements, is based on eligible works which have been identified by the Natural Resource Access Regulator (NRAR)
- undertaking checks on the relative distribution of the floodplain, such as comparisons with storage capacity, to check trends
- undertaking checks of farm water balances. Tests of farm water balance can be used as a check of modelled estimates. These checks have been completed, primarily at valley and reach scale. There can be large errors for individual properties, for example, if differences in irrigation behaviour and the accuracy of existing meters are not known and accounted for. Therefore, this test should be used with caution at an individual property scale. Initial assessments of water balance calculations have shown that, in some cases, results can become implausibly large and the distribution less reliable. This result is supported by previous work undertaken by the Murray-Darling Basin Authority which compared a farm water balance calculation to ground-truthed data and found a large scatter in estimates and some bias (Prasad, 2010).

9.4 Adaptive management approach

Adaptive management is a principle of the *Water Management Act 2000.*

There are two primary areas where adaptive management is used in modelling of floodplain harvesting:

- The first relates to the on-going improvements made to models in response to increased availability of data. These improvements allow for better calibration and understanding of processes on the floodplain.
- The second relates to the crucial role that modelling plays in assessing compliance with diversion limits specified in *Water Sharing Plans*. By bringing floodplain harvesting into the licensing framework, a targeted growth in use response can be undertaken for floodplain harvesting or other forms of licensed take. The use of models that are regularly updated and improved is crucial in assessing current conditions against diversion limits to determine if a growth in use response is required.

9.5 Summary

This Section has provided information on the sources of uncertainty and their significance on the modelling of floodplain harvesting, what we have done to reduce these uncertainties, and some recommendations for future work to further reduce these uncertainties. Where possible, sensitivity testing has been used to support the discussion.

The work undertaken as part of implementing *the Policy* has already substantively reduced uncertainty in the models. We have more confidence in the estimates due to updated detailed datasets, and we now established a framework to better understand causes of uncertainty and their impacts. Despite this substantive improvement, uncertainty remains in our estimates that we can improve with acquisition of better information.

What measures have we already put in place to reduce uncertainty?

We have reduced the uncertainty in the models by undertaking an extensive review of all datasets to ensure the best quality available data are used. We have used multiple lines of evidence where possible such as remote sensing and hydraulic modelling, as well as comparing datasets to published literature.

Where there is significant residual uncertainty, how sensitive is the modelling of floodplain harvesting outputs to this?

We have undertaken a number of sensitivity tests to show the relative sensitivity of different issues. The principal causes of uncertainty are the lack of records on actual volumes taken by floodplain harvesting and inaccurate measurement of regulated river diversions.

Where standard values are used rather than farm specific values, how sensitive are individual floodplain harvesting results to potential variability in these values?

We have assessed 5 cases where standardised values were used: the choice of long-term climate stations, on-farm storage seepage rates, crop model parameters, rainfall–runoff long term averages, and the rate of take of floodplain water into on-farm storages.

We found that our use of long-term climate stations, on-farm storage seepage rates and rate of take were of Low significance for total valley floodplain harvesting diversions and distribution of entitlements. Crop model parameters have a Medium significance to total valley diversions, with a Lower significance for the individual floodplain harvesting entitlement distribution.

Rainfall–runoff assumptions have been independently reviewed and concluded that harvesting of rainfall–runoff is likely to be a fairly small component of total valley diversions and that the department's approach represents a step forward compared to other approaches adopted. Proposed rainfall– runoff harvesting partial exemption should reduce the significance of uncertainty in these values. This should mean that these assumptions have Low to Medium significance to individual entitlements, however it may have Higher significance for some properties where rainfall–runoff is the dominant form of take.

What are the key actions required to improve floodplain harvesting modelling in future?

The key information required to make significant improvement in estimates of floodplain harvesting will be data obtained through the floodplain harvesting measurement requirements.

The models are under continuous improvement in response to availability of better data, information and lines of evidence. Modelling of floodplain harvesting will be reviewed and improved after sufficient floodplain harvesting measurement data are available following implementation of the policy.

10 Conclusions

Two modelling objectives and six design criteria were established in Section 2.1 for the model to be fit for the purposes of: informing water planning, establishing floodplain harvesting entitlements, and of compliance with statutory annual diversion limits. Section 10.1 provides a qualitative assessment of how well these were met.

The Gwydir Valley model is the primary tool that will be used for the NSW Government to provide the technical information about the regulated Gwydir river system. The model will be used for a range of purposes some of which are known and likely some that will emerge over time in response to future water management challenges. This model has known uncertainties that inform how fit it is for current purposes. Recommendations for addressing this are set out in Section 10.4.

10.1 Meeting objectives

The Gwydir Valley model represents the key physical and management processes that affect water availability and sharing within this managed river system. This model is proposed as the best available model to estimate flow and water use for water planning purposes and estimating floodplain harvesting entitlements. The two objectives were that it would:

- support traditional water policy, planning and compliance uses, such as implementing the Basin Plan and estimating Plan limits
- determine volumetric entitlements for floodplain harvesting.

We have reported on the enhancements to the model to meet the second objective, while not compromising the ability of the model to deliver against the first objective. Based on the model assessment results, we contend that the model is suitable to be used for entitlement estimation, with two caveats:

- the model is best suited to modelling at whole-of-valley and river reach scale, and increasing the spatial resolution to farm-scale requires very detailed understanding and characterisation of flow pathways and farm management at that scale
- that the lack of actual harvested volumes data reduced our ability to minimise uncertainty in the model and thus our ability to verify the accuracy of the modelling.

10.2 Meeting design criteria

Six (6) design criteria to serve the dual role of informing the model development and evaluating the resultant model, set in Section 2.1 (and paraphrased below), were that the model must:

1. represent key processes affecting water availability and sharing
2. use a sufficiently long period of climate data to capture the climate variability
3. have detailed spatial resolution to allow system analysis and reporting at multiple spatial scales
4. use a daily time step to enable flow variability assessment and reporting at multiple time scales
5. represent historical usage on a seasonal basis
6. provide a pathway to update and improve accuracy (i.e. be update-able and extensible).

A qualitative assessment of how well these modelling objectives and criteria have been met is discussed in the following sections. Meeting the design criteria was a critical requirement to be able to meet the objectives. The 6 criteria, and how they were met is discussed below.

Criteria 1: key physical and management processes represented

The processes that have the greatest effect on water availability at a valley scale and are represented explicitly in the model can be characterised as either a physical or management process.

In summary, the physical processes represented in the model are described primarily in Section 4 and include:

- climate (rainfall and potential evapotranspiration)
- inflow generation
- flow aggregation
- flow routing
- transmission losses
- flow outbreaks
- on-farm evapotranspiration
- evaporation from and rainfall on water surfaces.

The management processes are those that relate to the storage, regulation and diversion of water, and are a combination of infrastructure and policy. These are described in Section 5 Modelling water access and *licensing*, Section 5.6 *Access to groundwater* has been configured in the model for those individually modelled properties that are eligible for floodplain harvesting licences with existing groundwater access. Groundwater volumetric entitlements and historical usage were sourced from the farm surveys, while the pattern of use was developed based on landholder's advice combined with diversion calibration at some properties with reliable records. Groundwater use in the model is linked to volume of water available in the on-farm storage during the irrigation season: that is extractions are triggered when volume in the on-farm storage drops below a certain level. In general, groundwater use is more prevalent in dry periods.

Modelling water users and Section 7 *Modelling water management rules*, and include:

- headwater storages
- instream storages
- irrigation farms, including developed areas, infrastructure, and pump capacity
- water access entitlements
- resource assessment
- irrigation crop planting decisions
- interstate water sharing
- diversions, both metered and unmetered
- water accounting
- environmental watering.

Criteria 2: period of data sufficient to capture climate variability

The reference climate period over which statutory diversion limits are calculated is water years 01/07/1895 to 30/06/2009. These limits are used to calculate entitlements. The period of climate data in the model extends from 01/01/1890 to 30/06/2019 and includes this period.

The calibration period varies depending on the component. The flow calibration uses the period of flow record. Most of the calibration for diversions and on-farm harvesting is more recent, with floodplain harvesting based on a 10-year period with wet and dry periods, the adequacy of which was discussed in Section 8.2.

The inclusion of climate records to represent climate change has been raised. This is not necessary for the purposes of estimating Sustainable Diversion Limits under the 2012 *Basin Plan*, nor for estimating entitlements which use the same reference climate period for calculations.

Climate change is of broader interest and will be addressed in other departmental programs such as the Regional Water Strategies, and later for the 2026 Basin Plan review. The Gwydir Valley Model has been designed to enable use of different climate data. A climate risk dataset has been developed for that purpose which includes: a stochastic element derived from historical climate observations, and a paleo-logical climate signal; and combines this with future climate projections from dynamically downscaled climate models.

Criteria 3: spatial resolution sufficient for multi-scale analysis

The model was developed with high spatial detail. Where possible a physical representation of processes was implemented (rather than a statistical approach), allowing for better managing uncertainties by revealing the link between cause and effect which allows for diagnostics of behaviour.

The spatial detail in the Gwydir Valley model is best illustrated by the node-link diagram (Figure 5 in Section 2), indicating several hundred computational points. The highest number of points represent where water:

- enters (inflows)
- leaves (diversions, breakouts, and transmission loss)
- is measured (gauging stations).

For inflows and measurements, the spatial resolution makes the use of all available gauged flow data of reasonable quality. This combined with the large number of rainfall stations allow for coverage of the spatiotemporal variability of water availability from climate, upstream and downstream of the major headwater storages. The resultant flow variability enables representation of regulated water access, as well as for Supplementary Access and Floodplain harvesting. The checking of flow variability as both inflows and mainstream flow was covered in detail in Section 8.2.

The detail reporting and assessment of diversions was with reference to available data. These models have previously been used primarily to report aggregated diversion at a valley scale. In contrast, this model needs to provide results at a farm scale. Hence the model includes a separate calculation point for each and every farm that was assessed as eligible for a floodplain harvesting entitlement. The detailed data collected from farm surveys and other sources for each farm was used to undertake a capability assessment of each farm.

The model configuration of river network, breakout relationships, and individual farm detailed representation allows for the type of calculations that enable individual farm water balance to be estimated under different scenarios, and from that, entitlements that fairly reflect their share of the total based on policy detail.

The model includes all significant breakouts based on multiple lines of evidence, and the flow rates down these breakouts based on local knowledge including farm surveys, flow change analysis and hydraulic modelling, as well as a high level of physical detail for each farm.

The uncertainty in this regard still remains significant. This is not necessarily because of spatial detail. What is missing in fully meeting this potential of equitable distribution of entitlements is lack of information on actual volumes harvested as either rainfall runoff, or from overbank flow, as well as incomplete management detail on each farm, including application rates specific to that farm, and on-farm water management.

The model uncertainty is much better resolved where there is data to help parameterise the model. For this reason, the uncertainty around volumes harvested is lower at a reach scale, where flow gauges, breakout volumes, and reach water balance can be assessed.

Criteria 4: report at multiple time scales (daily to annual)

The standard time step for calculation in the IQQM is **daily**, as is the climate data and inflow data used for these models. This enabled the replication of flow variability as discussed in Section 8.2, with results shown in detail in Appendix J.

The model was configured with the hydrology, infrastructure and management arrangements to simulate climatically dependent inflows at multiple points in the river system, as well as the development and management conditions at defined points in time that affect the interannual water use. The ability to aggregate to **annual use** was demonstrated in the results of the calibration in Sections 8.3 and 8.4 and in the long term simulation results in Section 8.5. This capability will be further tested in the annual diversion compliance for the *Basin Plan*.

Criteria 5: supports replication of historical usage

The fully assembled model with simulated crop areas generates General Security diversions which are close to metered diversions as discussed in Section 8.3.3. Overall bias was 0.4%, with under-estimation during the earlier drier periods. Some potential reasons for the under-estimation in the earlier period include variations in planted area and application rates and limitations in rainfall data.

Supplementary Access diversions simulated by the model were higher than metered diversions, and this was attributed to difficulties representing the periods of access announced by river operators. The annual patterns of access were well replicated.

The balance of diversions from unmetered sources, i.e. **floodplain harvesting**, was inferred from farm infrastructure and management combined with known crop areas and industry standardised crop application rates. Given there was a severe paucity of data to validate these results directly, they could only be assessed on water balance considerations as discussed in Section 8.3.1.

Criteria 6: pathway for upgrades

Water resource models in the department have been and will continue to be used as ongoing tools to inform water management in NSW. The previous models are about two decades old, and it is foreseeable that the Gwydir Valley models will likewise be around for at least a generation.

Good modelling practice requires that the models are continuously improved, both in terms of their accuracy and their capability. Improved accuracy increases confidence for existing purposes, and improved capability provides for broader application and increased confidence. These improvements arise from the inclusion of additional data, particularly where previously sparse, better methods, and more time.

In the case of the Gwydir Valley model, additional on farm water harvesting and use data will allow the department the greatest scope to improve the models, as the on-farm water balance is where there is the greatest uncertainty. These data should be provided as an output from implementing the Floodplain Harvesting Monitoring Policy. The additional data can be used within the existing model framework to better parameterise components of the farm models.

The other significant limitation of the Gwydir Valley model is the estimation of the proportion of overbank flows that return to the river. This will require additional data collection and method development, and additional detail in the model.

We are planning to rebuild the Gwydir Valley model in the Source software, and the upgrades described here will be implemented as part of the rebuilding process where feasible.

10.3 Conclusion

The updated Gwydir Valley model represents floodplain harvesting much better than previous models and can provide more detailed results at a finer spatial resolution. Significant effort has gone into detailed data collection and model conceptualisation under the Healthy Floodplains Project. The model has been developed using multiple lines of evidence and best available industry data to ensure that the assessment of floodplain harvesting capability at each farm is realistic. We also used a water balance assessment given historical crops grown and the estimated water requirements. This assessment focuses on the reach and valley scale to ensure that the total volume of water including historical metered use and estimated floodplain harvesting is representative of the estimated historical water use.

In brief we would argue there is enough evidence to conclude with low uncertainty that the model meets design criteria 1–4. Meeting these is important for the model to meet the remaining design criteria and objectives. We acknowledge that further work to improve the modelling of river flows would reduce uncertainty and ensure the model is suitable for a wider range of purposes.

With respect to criteria 5, we can reasonably conclude that the model produces sufficiently accurate results where we have accurate direct observations to compare against, for example metered diversions. The calibrated model provides a good representation of the area planted in each season in response to water availability, and a good representation of both total and monthly average metered diversions.

There are some significant differences in simulated monthly and annual time series of diversions. These differences are considered acceptable as they can largely be attributed to yearly differences in irrigation behaviour. It may be possible to better capture some of this behaviour in future refinements, however, some issues such as the influence of markets are not able to be captured in river system modelling.

in conjunction with more accurate infrastructure data, the model is now able to provide a more robust estimate of floodplain and rainfall harvesting diversions. However, for components with only surrogate data such as on farm water balance, we can only conclude that we have made the best available estimate given the data available. Despite the improvements to our models, there is still uncertainty in the estimates for floodplain harvesting. However, we are better able to understand the sources of uncertainty, and their impact on both total valley diversions and individual shares. We intend to make further improvements to reduce the impacts of these sources of uncertainty.

Another known limitation is in estimating the location of and extent to which floodplain flows return to the downstream channel system. This could be concluded to be implicit as part of the flow calibration but presents a limitation when estimating the flow impacts of changes to diversions, e.g., as part of the entitlement derivation. This limitation is picked up in the recommendations' section.

With respect to criteria 6, we conclude that through the model we have made the best available estimate based on the available data. However, the important data needed to confirm accuracy was simply not available, and as a result there is greater uncertainty than there would be if we had data on actual harvested volumes.

The model has sufficiently demonstrated its ability to estimate annual water use over the long-term, meeting design criteria 7.

We would argue that the model is suitable to upgrade for accuracy and capability (design criteria 8). The model has sufficient process and spatial description, however, has been constrained by availability of data. As these data become available, methods can be refined and models re-parameterised to improve the accuracy and capability. Over the course of this model build, we have gone to great lengths to develop methods and datasets, for example, the hydraulic models and satellite data. Additional analysis of this data, as well as the consideration of data from the floodplain harvesting monitoring program, will improve accuracy and capability of the model.

10.4 Recommendations for future work

This modelling work has benefitted greatly from the feedback from stakeholders and especially the Independent Reviewers. While we contend that the model as described in this report meets the objectives and design criteria, models are under continuous evolution as better data and methods become available. We propose the 10 recommendations listed in Table 35 as priorities to evolve the model to increase its functionality and improve model results. These recommendations reflect external feedback and the insights of the modelling team.

Table 35 Recommendations for future work to improve model results

	Recommendation
1	Comparison to data that will be obtained through the floodplain harvesting monitoring program. Revise rainfall–runoff and overbank flow take assumptions if required, noting that several years of data will be required before this can be done with any confidence
2	Improved recording of diversions, entitlements and account balances to enable future calibrations of the model to be undertaken more efficiently and accurately, including: recording diversions separately for each pump through a unique ESID, rather than sharing ESID across multiple pumps changes to WLS structure and maintenance to ensure historical entitlements and temporary trades can be more readily generated for each property
3	Better representation of return flows from floodplains to river channels. This will require further research to develop a methodology for addressing this limitation in the models
4	Investigate reasons and solutions for over-estimating supplementary access
5	Determine the impacts of future climate on diversion and flows for consideration during 5 yearly reviews of Water Sharing Plans and the development of the department’s Regional Water Strategies
6	Review and refine the account management transfer functions
7	Including stock and domestic entitlements and usage within the model (where significant)
8	Determine whether any refinement in either the planting decision or under-irrigation behaviour during wet and dry periods can be quantified by the available data. In particular this may be required to update the Current Conditions Scenario

These priorities recognise that there is already work underway to improve aspects of the Gwydir Valley model in other programs such as the Regional Water Strategies. This work includes improving the representation of environmental water use, and the development of enhanced climate datasets to better understand climate variability and climate change.

11 References

Legislation

(NSW) *Water Management Act 2000* No 92. Last updated 2020. https://legislation.nsw.gov.au/~/view/act/2000/92/

Water Sharing Plan for the Lower Gwydir Groundwater Source 2019. https://www.legislation.nsw.gov.au/regulations/2019-300.pdf

Water Sharing Plan for the Gwydir Alluvial Groundwater Sources 2019. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0017/192320/Draft-water-sharing-plan-for-the-Gwydir-alluvial-groundwater-sources-2019.pdf

Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0003/315480/final-wsp-gwydir-unregulated-river-water-sources-2012.pdf

Floodplain Management Plan for the Gwydir Valley Floodplain 2016. http://www.water.nsw.gov.au/__data/assets/pdf_file/0009/668637/floodplain-management-plan-for-the-gwydir-valley.pdf

NSW Floodplain Harvesting Policy. First published May 2013, updated September 2018. http://www.water.nsw.gov.au/__data/assets/pdf_file/0012/548499/floodplain_harvesting_policy.pdf. Referred to in this report as the policy

Natural Resources Access Regulator Act 2017. https://legislation.nsw.gov.au/#/view/act/2017/64

Water Sharing Plan for the Gwydir Alluvial Groundwater Sources 2020. 2020-342.pdf (nsw.gov.au)

Water Sharing Plan for the Gwydir Regulated River Water Sources 2020. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0010/315478/final-wsp-gwydir-regulated-river-water-source-2020.pdf. Referred to in this report as the Gwydir WSP

Reports and journal articles

Allen RG, Pereira LS, Raes D, Martin M (1998) Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations, Rome. ISBN 92-5-104219-5. http://www.fao.org/docrep/X0490E/X0490E00.htm

Alluvium (2019) Independent Review of NSW Floodplain Harvesting Policy Implementation – Final Report – July 2019, A report prepared for the NSW Department of Planning and Environment. https://www.industryIGA.nsw.gov.au/__data/assets/pdf_file/0004/272146/Final-floodplain-harvesting-independent-review.pdf

Barma Water Resources (2019) Assessment of the additional cropped area rainfall–runoff occurring due to irrigation, Final Report October 2019, unpublished report prepared for the NSW Department of Planning and Environment.

Beven KJ, Binley AM (1992) The future of distributed models: Model calibration and uncertainty prediction, Hydrol. Processes 6, 279–298.

Connolly RD, Kennedy IR, Silburn DM, Simpson BW, Freebairn DM (2001) Simulating endosulfan transport in runoff from cotton fields in Australia using the GLEAMS model. Journal of Environmental Quality 30, 702–713.

DECCW (2011) IQQM Wetland modelling for the Gwydir Valley.

DLWC (2000) Regional crop factors derived in consultation with Department of Agriculture for the purposes of area based license conversion, unpublished data.

DPEDPE (2020) Guideline for the implementation of the NSW Floodplain Harvesting Policy. March 2020. NSW Department of Planning and Environment. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0007/272338/floodplain-harvesting-implementation-guidelines.pdf

DPEDPE Water (2021a) Harvesting entitlements for Gwydir Valley regulated river system: model scenarios. NSW Department of Planning and Environment.

DPEDPE Water (2021b) Environmental Outcomes of implementing the Floodplain Harvesting Policy in the Gwydir Valley. NSW Department of Planning and Environment.

eWater Ltd (2016) Source Scientific Reference Guide (v4.1) [Online]. https://wiki.ewater.org.au/display/SD41

Freebairn DM, Wockner GH, Hamilton NA, Rowland P (2009) Impact of soil conditions on hydrology and water quality for a brown clay in the north-eastern cereal zone of Australia. Australian Journal of Soil Research 47, 389–402.

FSA Consulting and Aquatech Consulting (2011) Estimating Land Surface Diversions: Stage 2, Final Report (August 2011), Murray Darling Basin Authority, Canberra. https://www.researchgate.net/publication/277004542_Assessment_of_Land_Surface_Diversions_from_water_balance_and_remote_sensing_data

Haghnazari F (2015) 'Factors affecting the infiltration of agricultural soils: review', International Journal of Agronomy and Agricultural Research (IJAAR) 6 (5), 21–35.

Harris GA (2012) A decade of change in water productivity in the Australian cotton water story: a decade of Research and Development 2002-2012. In: Wiggington, David (ed) (2012b).

Kavetski D, Kuczera G, Franks SW (2006) Bayesian analysis of input uncertainty in hydrological modeling: 1. Theory, Water Resources Research 42, W03407. https://doi.org/10.1029/2005WR004368

Kisters Pty Ltd (2010) Hydstra. http://kisters.com.au/hydstra.html

Larsen D, Weir D (2012) Managing soils for irrigation. In: Wiggington, David (2012b) 188–195.

McInerney D, Thyer M, Kavetski D, Bennett B, Lerat J, Gibbs M et al (2018) A simplified approach to produce probabilistic hydrological model predictions. Environmental Modelling & Software 109, 306–314. DOI: 10.1016/j.envsoft.2018.07.001

MDBA (2018) Irrigation demands on the Murray and Lower Darling rivers. Murray Darling Basin Authority. https://www.mdba.gov.au/sites/default/files/pubs/crop-water-model-murray-lower-darling-2018.pdf

MDBA (2017-2019) Hydrologic modelling practice notes. https://www.mdba.gov.au/publications/mdba-reports/hydrologic-modelling-practice-notes

Morrison T, Chu Cat-Tuong (2018) Storage Bathymetry Model Update and Application (Gwydir Valley), report prepared by Hydrospatial Pty Ltd for Department of Industry. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0010/271936/Storage-bathymetry-model-update-and-application-gwydir.pdf

Neumann L, Brown A, Zhang L, Zheng H, Davidson A, Egan C, Korn A (2017) Assessing residual inflow and loss estimates methods in river reach calibration using the Budyko Framework. In Syme G, Hatton MacDonald D, Fulton B, Piantadosi J (eds) MODSIM2017 International Congress. MSSANZ. 1649–1655.

NSW Department of Industry (2019) Modelling and data collection for implementing floodplain harvesting, PUB18/640. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0003/179931/Floodplain-harvesting-water-modelling-overview.PDF

NSW Department of Planning and Environment (DPEDPE) (2019) Fact sheet: Estimating rainfall run-off and harvesting in the NSW Murray–Darling Basin, INT19/141340. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0008/272726/Estimating-rainfall-run-off-and-harvesting-in-the-NSW-Murray-Darling-Basin-Fact-Sheet.pdf

NSW Office of Water (NOW) (2016) Irrigator Behaviour Questionnaire, Irrigator survey as part of application for floodplain harvesting entitlement.

Prasad A (2010) Use of modern technologies in estimating unaccounted water uses in the Murray-Darling Basin, Australia. In: Hydrocomplexity: New Tools for Solving Wicked Water Problems. Kovacs Colloquium, July 2010 (IAHS Publ. 338, 2010). https://iahs.info/uploads/dms/15035.11-43-45-Prasad1.pdf

Silburn M, Montgomery J, McGarry D, Gunawardena T, Foley J Ringrose-Voase A, Nadelko T (2012) Deep drainage under irrigated cotton in Australia: a review. In: Wiggington, David (ed) (2012b) 40–58.

Simons M, Podger G, Cooke R (1996) IQQM—A hydrologic modelling tool for water resource and salinity management, Environmental Software Volume 11, Issues 1–3, 1996, Pages 185-192. https://www.sciencedirect.com/science/article/pii/S0266983896000196

Tennakoon S, Richards D, Milroy S, Harris G (2012) Water use efficiency in the Australian cotton industry, In: Wiggington, David (ed) (2012b). 22–27.

Vleeshouwer J, Car NJ, Hornbuckle J (2015) A Cotton Irrigator's Decision Support System and Benchmarking Tool Using National, Regional and Local Data. In: Denzer R, Argent RM, Schimak G, Hřebíček J (eds) Environmental Software Systems. Infrastructures, Services and Applications. ISESS 2015. IFIP Advances in Information and Communication Technology, vol 448. Springer, Cham.

Wigginton D (2012a) Measuring to improve water storage efficiency, in Australian Cotton Research Institute & Cotton Catchment Communities Cooperative Research Centre (Australia) 2012, The Australian cotton water story : a decade of research & development 2002–2012, Cotton Catchment Communities CRC Limited : Australian Cotton Research Institute, Narrabri, NSW. pp13-15 http://www.crdc.com.au/publications/australian-cotton-water-story

Wigginton David (ed) (2012b) WATERpak — a guide for irrigation management in cotton and grain systems. Cotton Research and Development Corporation. Third edition. November 2012. http://www.cottoninfo.com.au/sites/default/files/documents/WATERpak.pdf

Appendix A Quality assurance

A.1 Quality assurance practices

The department maintains a set of in-house modelling practice guidelines for the development of river system models. These are based on the collective application of modelling over many decades and the broader modelling community of practice across the Murray-Darling Basin and internationally. These guidelines cover recommended data sources, extraction, validation and preparation techniques. They are regularly reviewed to capture new learnings including those circumstances which deviate from the expected, and to improve departmental modelling practice. As they are a 'living' document, i.e. they continue to evolve, they are not published in report form. However, many of the principles and practices are published through contributions to other initiatives, most recently with eWater[19] and MDBA (2017–2019).

The department's approach to selection and review of data is further detailed below.

Another important part of our quality assurance process is to undertake peer review of our final work. This includes both internal and external reviews. The department together with the Murray Darling Basin Authority (MDBA) commissioned an independent peer review of implementation of the Floodplain Harvesting Policy in northern NSW. The key objective of the review is to provide transparency around the technical information and to provide stakeholders with confidence that the technical rigour and supporting processes are suitable to support policy implementation. Further information on this review and our action plan to respond to the recommendations is available from the department's website[20].

One of the recommendations of the independent peer review was that we undertake a farm scale validation process. This was to ensure "that the chosen parameters relating to particular farms or enterprises are realistic in relation to farm activity and are discussed with landholders". This review has been conducted and is described in Section A.3.

A.2 Data review and prioritisation of data sources

Selection of data source is informed by its:

- completeness
- consistency
- accreditation, e.g. official sources with quality assured processes
- verifiability.

Available data are first reviewed and checked for completeness, and to ensure that the quality of the data is understood and acceptable for the intended use. Much of the flow and climate data used in these river system models are collected using procedures that are documented and well understood. These procedures provide a basis for assessing the accuracy of the data and are taken into account when undertaking calibration and validation

A typical review process for a set of data are to search for any gaps or missing records, for example, when a flow gauging station malfunctions or a rainfall gauge was discontinued for some time. Where possible we check data against independent information or with data for nearby sites. We check for consistency in the data and to identify anomalies or changes in the statistical properties of the dataset over time.

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[19] https://wiki.ewater.org.au/display/SC/Australian+Modelling+Practice

[20] https://www.industry.nsw.gov.au/water/plans-programs/healthy-floodplains-project/harvesting

A body of practice has developed for techniques to infill missing data for many data sources. The techniques can include establishing relationships between climate (rainfall and evaporation) at one site (where there is a gap in the data) and other sites nearby (where there is no gap in the data), either directly, or via models. Where these techniques have been used to improve data for this model, relevant sections of the report describe the approach and results.

To adequately model floodplain harvesting, we required more detailed information about on-farm processes than was previously available. We have collected data from several new sources, including an extensive survey of irrigators, site inspections, remote sensing, and advice from research and industry bodies. We, therefore, needed to prioritise between the use of different data sources.

We applied the following rationale when making data choices:

1. Follow the department’s guidelines where possible. These have been developed based on the collective body of knowledge through the development and application of models over many years, including from other agencies within NSW and interstate.
2. Base modelling on Natural Resources Access Regulator (NRAR) datasets.
    - In particular, NRAR site inspection data helped to review assumptions around the rate of floodplain harvesting. Their knowledge and data of farm operations and data on infrastructure such as pipes and pumps were used to estimate rates of take.
    - NRAR also determined on-farm storage capacities using a combination of LIDAR and survey data
    - When using the models to determine floodplain harvesting licences, some existing infrastructure is excluded as it has been deemed ineligible by NRAR for entitlement determination. Conversely, some proposed future works were deemed eligible and need to be accounted for in the entitlement determination process. Further information will be contained in the companion floodplain harvesting scenario report
3. Prioritise verifiable data sources. For example, official government records, published data or data derived from appropriate use of remote sensing technology.

A ‘multiple lines of evidence’ approach is embedded throughout river system modelling. It is considered in initial data reviews as well as throughout the calibration process from flow calibration through to the final model. For example, we undertook comparisons between the farm survey information as well as other supplementary material such as gauged flows and remote sensing data.

A.3 Farm scale validation and review

The floodplain harvesting program has a number of data collection and review steps which are completed prior to finalisation of entitlements. One of these steps is referred to as the farm scale validation process. We sent letters to all eligible properties in the Gwydir Valley, outlining some key information that we would use to determine floodplain harvesting entitlements for their property. This includes a letter from NRAR with details on their works that are eligible for consideration in determining the floodplain harvesting entitlement. Landholders were able to make a submission, with supporting evidence, to the Floodplain Harvesting Review Committee. Further information on the function of the review committee, and the overall implementation of the policy, can be found in *Guideline for the implementation of the NSW Floodplain Harvesting Policy* (DPEDPE 2020).

A.4 Report review process

This report has gone through an extensive review and editorial process. A key finding of the Alluvium (July 2019) *Independent Review of the NSW Floodplain Harvesting Implementation* was the lack of documentation of the model development process, in particular in respect to:

- the rainfall–runoff component
- how matters raised in the Independent review were responded to
- compliance with good modelling practice
- documentation of assessment of model uncertainty and suitability for application.

In response, the department prepared the first draft of this report for review (again by Alluvium). Comments were received from the reviewers, together with a marked-up copy of the report (using MS Word Comments). Overall, the review team indicated that the report was well written and provided sufficient justification and transparency of the modelling process, while drawing attention to areas where more detail was required. This report includes responses to those review comments, either through adding more explanatory material to this report, or through adding material to the companion Scenarios report (DPEDPE Water 2021a).

An external editor was engaged in June 2020 to work with the model development team to prepare the final report.

Appendix B Climate stations

Table 36 Rainfall stations used in headwater inflow calibration, their station numbers, location (latitude/longitude) and mean annual rainfall

Station #	Station name	Lat (°S)	Long (°E)	Mean annual rainfall (mm)
54004	Bingara Post Office	29.8673	150.5715	730
54014	Bingara (Derra Derra)	29.9198	150.3744	708
54017	Gravesend Post Office	29.5836	150.3362	661
54021	Barraba (Mount Lindsay)	30.3209	150.2734	983
54029	Warialda Post Office	29.5416	150.5754	684
54039	Bingara (Keera)	29.9943	150.7812	706
56006	Bundarra Post Office	30.1711	151.0757	761
56018	Inverell Research Centre	29.7752	151.0819	791

Table 37 Evapotranspiration stations used in headwater inflow calibration, their station numbers, location (lat/long), mean potential evapotranspiration (PET)(Mwet) and mean lake evaporation (MLake)

Station #	Station name	Lat (°S)	Long (°E)	Mean PET (Mwet) (mm/y)	Mean lake evap (MLake) (mm/y)
054004	Bingara Post Office	29.8673	150.5715	1515	1540
054014	Bingara (Derra Derra)	29.9198	150.3744	1521	1547
054017	Gravesend Post Office	29.5836	150.3362	1544	1570
054021	Barraba (Mount Lindsay)	30.3209	150.2734	1335	1359
054029	Warialda Post Office	29.5416	150.5754	1503	1530
054039	Bingara (Keera)	29.9943	150.7812	1459	1486
056006	Bundarra Post Office	30.1711	151.0757	1394	1418
056016	Guyra Post Office	30.2204	151.6714	1223	1241
056028	Uralla (Salisbury Court)	30.7338	151.5105	1218	1236

Appendix C Streamflow gauges

Table 38 Inflow headwater gauges used in the Gwydir Valley river system model, their station number and name, catchment area (CA), start and end dates of gauge, highest recorded and highest gauged flows

Station #	Station name	CA (km^2)	Start date	End date	Highest recorded flow (m^3/s)	Highest gauged flow (m^3/s)
418005	Copes Creek at Kimberley	259	18/04/1929	Current	115	178
418014	Gwydir River at Yarrowyck					
418015	Horton River at Rider (Killara)	1970	11/01/1957	Current	1,814	1,088
418016	Warialda Creek at Warialda No.3	544	8/02/1972	5/01/2005	318	343
418017	Myall Creek at Molroy	842	10/05/1964	Current	686	1,104
418018	Keera Creek at Keera	562	11/05/1964	16/03/1989	148	34
418021	Laura Creek at Laura	311	4/06/1965	Current	145	297
418022	Georges Creek at Clerkness	518	7/06/1965	20/04/1989	153	26
418023	Moredun Creek at Bundarra	656	9/06/1965	13/05/1988	305	68
418025	Halls Creek at Bingara	156	15/06/1965	Current	172	113
418029	Gwydir River at Stonybatter	1940	9/06/1967	28/02/1989	1,107	113
418032	Tycannah Creek at Horseshoe Lagoon	866	2/06/1971	Current	443	326
418033	Bakers Creek at Bundarra					
416054	Gil Gil Creek at Boolataroo		5/12/1996	Current	333	163

Table 39 Stream gauges used for reach calibration in the Gwydir Valley model, their station number and name, catchment area (CA), start and end dates of gauge, and highest recorded and highest gauged flows

Station #	Station name	Start date	End date	Highest recorded flow (m^3/s)	Highest gauged flow (m^3/s)
418001	Gwydir River at Pallamallawa	17/12/1891	Current	2,631	1,468
418002	Mehi River at Moree	18/03/1937	Current	859	708
418004	Gwydir River at Yarraman Bridge	1/08/1929	Current	1,333	1,039
418011	Carole Creek at Downstream Regulator(Bells Crossing)	28/06/1939	Current	218	161

Station #	Station name	Start date	End date	Highest recorded flow (m^3/s)	Highest gauged flow (m^3/s)
418013	Gwydir River at Gravesend Road Bridge	12/12/1936	Current	2,861	3,536
418036	Gwydir River D/S Boolooroo Weir	26/07/1972	Current	859	596
418037	Mehi River at D/S Combadello Weir	27/07/1972	Current	335	139
418042	Gwydir River at D/S Tareelaroi Weir	20/10/1976	Current	1,334	1,308
418044	Mehi River D/S Tareelaroi Regulator	5/05/1976	Current	187	61
418048	Moomin Creek at Combadello Cutting	27/07/1972	Current	87	70
418052	Carole Creek at Near Garah	9/07/1980	Current	117	118
418053	Gwydir River at Brageen Crossing	7/05/1980	Current	110	87
418055	Mehi River at Near Collarenebri	11/06/1980	Current	191	155
418058	Mehi River at Bronte	21/11/1978	Current	125	63
418060	Moomin Creek at Glendello	23/03/1984	Current	135	120
418061	Moomin Creek at Alma Bridge (Derra Road)	16/11/1978	Current	319	209
418063	Gwydir River (South Arm) at D/S Tyreel Offtake Regulator	10/09/1985	Current	66	45
418066	Gwydir River at Millewa	2/06/1988	Current	19	8
418067	Moomin Creek at Clarendon Bridge (Heathfield)	2/06/1988	Current	299	190
418068	Mehi River at U/S Ballin Boora Creek	2/06/1988	Current	300	199
418070	Moomin Creek at Moomin Plains	21/03/1994	Current	52	3
418074	Gingham Channel at Teralba	9/04/1997	Current	140	59
418076	Gingham Channel at Tillaloo Bridge	8/05/1997	Current	283	10
418078	Gwydir River at Allambie Bridge	8/04/1997	Current	186	162
418079	Gingham Channel at Gingham Bridge	6/05/1997	Current	309	221
418085	Mehi River D/S Gundare Regulator #2	21/11/2002	Current	38	28
418086	Carole Creek at Midkin Crossing (Ds Marshalls Ponds)	6/10/2005	Current	287	107
418087	Mehi River at Chinook	23/05/2006	Current	89	40
416027	Gil Gil Creek at Weemelah	30/03/1968	Current	488	361
416052	Gil Gil Creek at Galloway	27/05/1987	Current	104	70
416054	Gil Gil Creek at Boolataroo	5/12/1996	Current	333	163

Appendix D Major storage characteristics

Table 40 Copeton storage curves (level, volume, surface area relationships)

Level	Volume (ML)	Surface area (km^2)
467.194	16	0.01
470.242	78	0.03
473.290	251	0.08
476.338	515	0.10
479.386	845	0.12
482.434	1,255	0.16
485.482	1,868	0.25
488.530	2,873	0.42
491.578	4,501	0.65
494.626	6,833	0.89
497.674	9980	1.17
500.722	13,880	1.40
503.770	18,487	1.66
506.818	24,304	2.15
509.866	31,545	2.61
512.914	40,223	3.12
515.962	50,730	3.82
519.010	63,608	4.75
522.058	80,519	6.36
525.106	102,288	8.02
528.154	130,109	10.22
531.202	164,491	12.34
534.25	205,255	14.44
537.298	252,587	16.67
540.346	307,294	19.22
543.394	369,765	21.74
546.442	439,475	24.07
549.490	517,089	26.82
552.538	602,767	29.38
555.586	696,047	31.85
558.634	797,137	34.46
561.682	905,975	36.97

Level	Volume (ML)	Surface area (km^2)
564.730	1,022,718	39.58
567.778	1,146,713	41.87
570.826	1,278,634	44.66
573.874	1,418,679	47.23
576.992	1,566,439	49.76
579.970	1,722,447	52.51
583.018	1,885,905	54.65

Appendix E Irrigation farm runoff: data review

E.1 Background

The irrigator nodes in the IQQM include runoff from rain falling on developed areas, irrigated and un-irrigated, as well as undeveloped areas. The model continuously tracks the soil moisture based on rainfall, irrigation, and evapotranspiration, allowing for antecedent conditions when calculating runoff following rainfall. Quantifying this runoff is important for the farm water balance. Data to quantify this was collected and reviewed as part of our modelling.

Long term monitoring data are available for natural catchments in the region. However, there is not as yet a comparable dataset for farmed irrigated areas. An analysis of data from all calibrated gauged rainfall–runoff models in northern river systems shows runoff rates increasing with rainfall, with 2–4% of long-term average rainfall becoming runoff for catchments with less than 600 mm/year average annual rainfall, the range most representative of irrigated areas. The comparative rates for higher rainfalls are 4–8% for average annual rainfall from 600 – 800 mm/year, and 8–16% for average annual rainfall from 800–1100 mm/year.

As part of earlier model evaluation, two gauged catchments in the Border Rivers Valley have been evaluated to understand how much the rainfall–runoff coefficient might vary from year to year; this is shown as an exceedance graph in Figure 31. While runoff from individual rainfall events may be very high, especially for high rainfall events on a wet soil, the long-term average will be much lower. For example, annual runoff from these gauged inflows can be up to 18% of annual rainfall volume with a long-term average of about 4%. Similar results were also found for several catchments that were evaluated in the mid-Macquarie Valley.

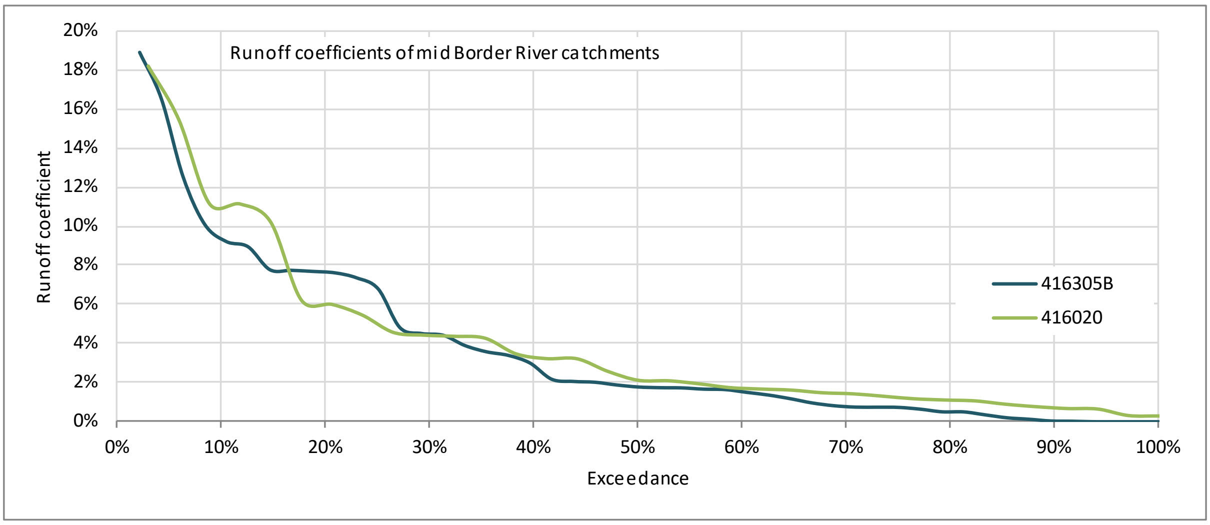

Figure 31 Comparison of mid system gauged inflow annual runoff coefficients

Long term mean annual rainfall–runoff rates are useful to develop trends for different climate zones. The Budyko framework is one such assessment method that can be used to estimate lower and upper bounds for runoff coefficients. These bounds can be used to test that inflow estimates are within the expected range at the mean annual timescale given the climate characteristics for the site. This is the recommended approach adopted by the good modelling practice guideline[1] developed by modellers across the Murray-Darling Basin jurisdictions. Neumann et al. (2017) have demonstrated the approach using 213 catchments in the basin over the 1965 to 2009 period. Their results have been used to characterise the expected and range of runoff values for a given climate.

The expected runoff rates derived by Neumann et al. (2017) in the more arid regions is also consistent with property level runoff data and modelling for several cotton properties as is detailed in the following section. This gives us some confidence that the farm scale runoff results for fallow and undeveloped land should be within the bounds suggested by Neumann et al. (2017).

Runoff rates for irrigated land are expected to be higher than the fallow and undeveloped rates due to elevated soil moisture. In response to recommendations of the Independent Review, we have undertaken another independent review of the assumptions for runoff from irrigation areas (Barma Water Resources, 2019). This found that:

- the estimates were uncertain due to limited available data
- the adopted approach represents a step forward compared to other approaches reviewed
- harvesting of rainfall–runoff is likely to be a fairly small component of total valley diversions.

A small amount of relevant farm scale data was available and is summarised below.

- In field data for furrow-irrigated cotton fields was collected by Connolly et al. (2001) to calibrate a daily water balance model (GLEAMS). This has been used to assess runoff values from both un-irrigated and irrigated areas over a relatively long period (e.g. 30-year simulation in Connolly et al. (2001). They measured 16 mm runoff for a dryland cotton site on black vertisols in Emerald, Queensland with 600 mm rainfall (~3% of rainfall), whereas an irrigated field with the same rainfall generated 42 mm of runoff (as quoted in Silburn et al. 2012). Their results indicate for a site near Warren in NSW with 625 mm of rainfall, that rainfall–runoff under conventional irrigation is around 8.5% of rainfall and that under dryland conditions it is approximately half this rate.
- The farm survey data indicated a large range of rainfall–runoff values, however the quality of the reported data (in particular the separation from other forms of floodplain harvesting) is uncertain. Only a few farms provided estimates of runoff volumes harvested. These estimates were analysed to estimate what percent of annual rainfall these volumes represented. There was uncertainty in these estimates as to what area of land this runoff was from, and whether these separated out rainfall runoff from outside of the farm. The average and median value across all properties and all years for the Gwydir was 13% and 11%. There was no discernible positive trend with increasing rainfall as would be expected. We assumed that the reported rainfall harvesting was from developed areas. If some of the harvesting were also from undeveloped areas, then the runoff coefficient would be lower.
- MDBA commissioned a study (FSA Consulting and Aquatech Consulting 2011) which included field data collection over a three-year period from 2008 to 2011 from six representative sites in the northern basin (three in NSW). These data were used to inform calibration of farm water balance models, including rainfall–runoff harvesting from within the irrigation property. This included runoff from both fallow and irrigated areas. The study period was relatively short but covered both dry and wet periods. An average and median rainfall–runoff of 2.5% and 1.3% respectively were reported across all properties and across both the calibration and verification period; however, some correction to these rates has now been proposed by one of the authors, which would make the results closer to around 10% runoff.

E.2 Further information on Gwydir Valley model development

The parameters for the rainfall–runoff model at irrigator nodes in the Gwydir Valley model were developed so that final developed and undeveloped area runoff rates appear to be reasonable compared to the median values in the Budyko framework (Figure 32). The developed area runoff rates include runoff from both cropped and irrigated areas, and it is reasonable to expect that runoff from irrigated areas will produce higher runoff rates than would naturally occur.

The parameters were defined such that runoff from fallow areas were greater than undeveloped areas. The undeveloped runoff rates were assumed to be lower than fallow runoff rates, in part as the efficiency of harvesting runoff from these areas is not known. The models have adopted the undeveloped farm catchment areas claimed in the farm surveys generally without review, which in most instances was considered acceptable as the runoff volumes are relatively small. The adopted approach is that, where these areas become more significant, or there is evidence of significant unaccounted for volumes, the assumptions for undeveloped areas would be reviewed.

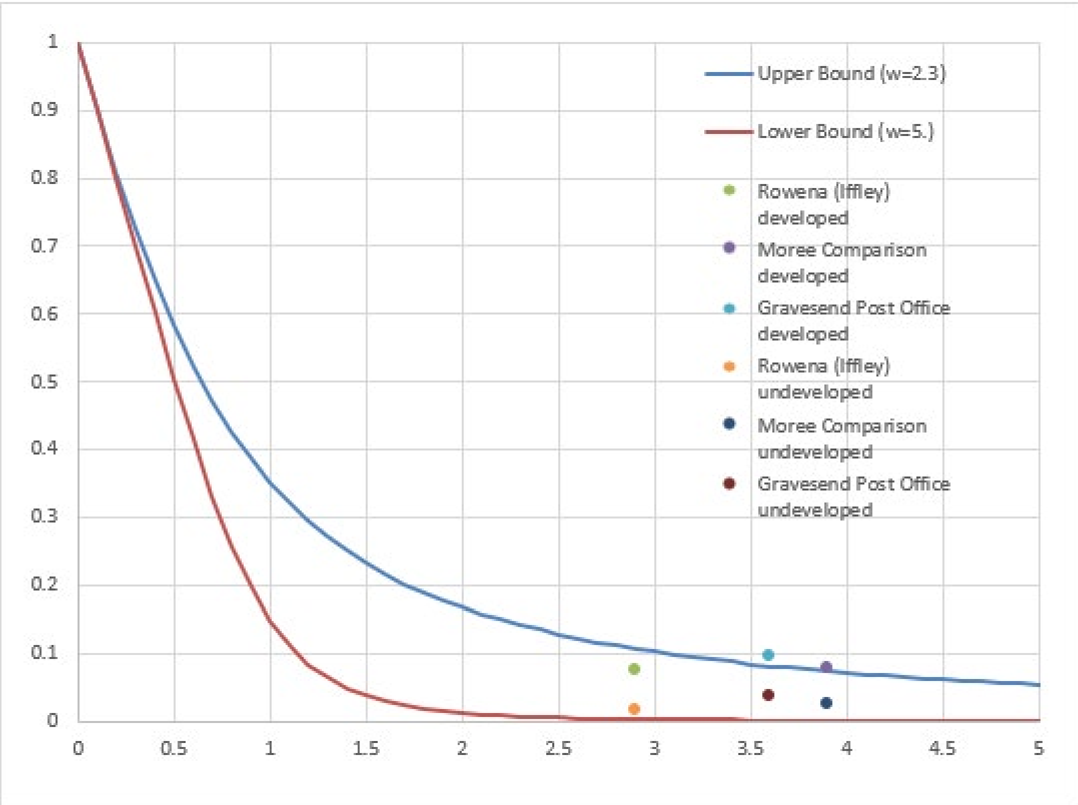

Figure 32 Runoff and aridity results for Gwydir Valley (1965–2009 as per Neumann et al. (2017))

Appendix F On-farm storage and pump rate verification and worked examples

As part of implementing the policy, there has been increased investment in data and modelling to improve modelled estimates of floodplain harvesting. The farm surveys collected a range of data, including information on permanent and temporary on-farm storages. The model was initially developed using the permanent storage and pump information in the farm survey. Because of the sensitivity of model results to this infrastructure, we further validated this information from a combination of remote sensed data and detailed surveys.

F.1 Storage volume and surface area

While indicative information of storage volume(s) and height(s) was provided as part of the farm surveys, more accurate information was needed. Only a few properties provided storage geometry data from a qualified surveyor and these datasets were also of variable quality.

Storage capacities have been reviewed using LIDAR data. In a few instances where these data were not available, photogrammetry has been used.

LIDAR is a remote sensing method that can be used to measure relative elevations of the land surface. LIDAR was used to provide a detailed survey of significant areas in the five northern valleys for the Healthy Floodplains Project. The elevation data were used to generate a high-resolution digital elevation model. This was accurate enough to develop water level versus volume curves for on-farm storages that were empty during the time of survey.

The LIDAR survey cannot penetrate below water in partially full storages. This limitation was overcome by synthesising the area below water level using a storage bathymetry model (SBM) and computing the volume vs level relationship from this synthesis. An initial storage bathymetry model was based on five empty storages with a range of volumes and surface areas. The storage bathymetry model was validated using an additional six on-farm storages for which a conventional land survey was available.

The average difference in volume between the storage curves derived from the land survey and the SBM survey was less than 2% at full supply level. However, the accuracy is lower for on-farm storages with small surface areas and high bank heights. The SBM model was then refined using information from an additional 27 empty storages. Further information on the method and verification can be found on the department’s website[21]. A 1m freeboard has been assumed for all permanent storages.

The spatial maps of storages were combined with Landsat data to confirm the date on-farm storages were built, which was used to estimate levels of development for scenarios.

F.2 Verification of temporary storages

As part of the detailed survey data collected from all farms, many landholders indicated significant historical use of irrigation fields, surge areas, and supply channels, as temporary water storages. The extent of this was verified using the past 30+ years of Landsat data to assess instances of temporary water storage within property boundaries after a number of flood events using the following process:

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[21] https://www.industry.nsw.gov.au/__data/assets/pdf_file/0010/271936/Storage-bathymetry-model-update-and-application-gwydir.pdf

- the archive of Landsat data was downloaded as Natural Colour images[22]
- flood events during this period were identified based on gauged flow data and breakout relationships
- the first usable Landsat image after the flood event was selected
- farm boundaries and permanent on farm storage areas were overlayed over the Landsat data
- areas of temporary storage of water were manually detected and polygons drawn to estimate area.

Temporary storages have only been accounted for in the model where NRAR advise that they should be included. The policy position is that temporary storages are not to be included in the storage capacity assessment for the farm. However, where temporary storages such as surge areas and sacrificial fields allow for a fast intake of water and then transfer to permanent storages (within 14 days), this buffering effect can be accounted for. It is only the water transferred to permanent storage which counts as eligible floodplain harvesting. All temporary storages deemed by NRAR to be eligible for floodplain harvesting were included in the model.

F.3 On-farm storage pump rate

NRAR have undertaken a comparison of IBQ data, industry advice and pump charts to provide information to the modelling team on the expected flow rate for a given type and size pump. A flow range has also been provided.

The actual flow rate can vary for a number of reasons:

- capacities can change by 20–30% depending on head
- all values are based on expected flows from reasonably designed pump stations. Variations in design may affect flow rates.
- some irrigators run pumps harder (higher speed / higher tolerances) than others for greater output. In particular this may occur for short periods when floodplain harvesting.

We have adopted the expected flow rate; however, sensitivity testing has also been undertaken to assess the impact of variable pump rates on the floodplain harvesting estimate.

Pump rate analysis

The adopted flow rate and expected range are illustrated in Figure 33 and Figure 34. The adopted flow rates have also been compared to check for reasonably consistency (Figure 35).

The adopted flow rate has good consistency with average flow rate information obtained from a combination of IBQ and other industry advice.

[22] https://earthexplorer.usgs.gov/

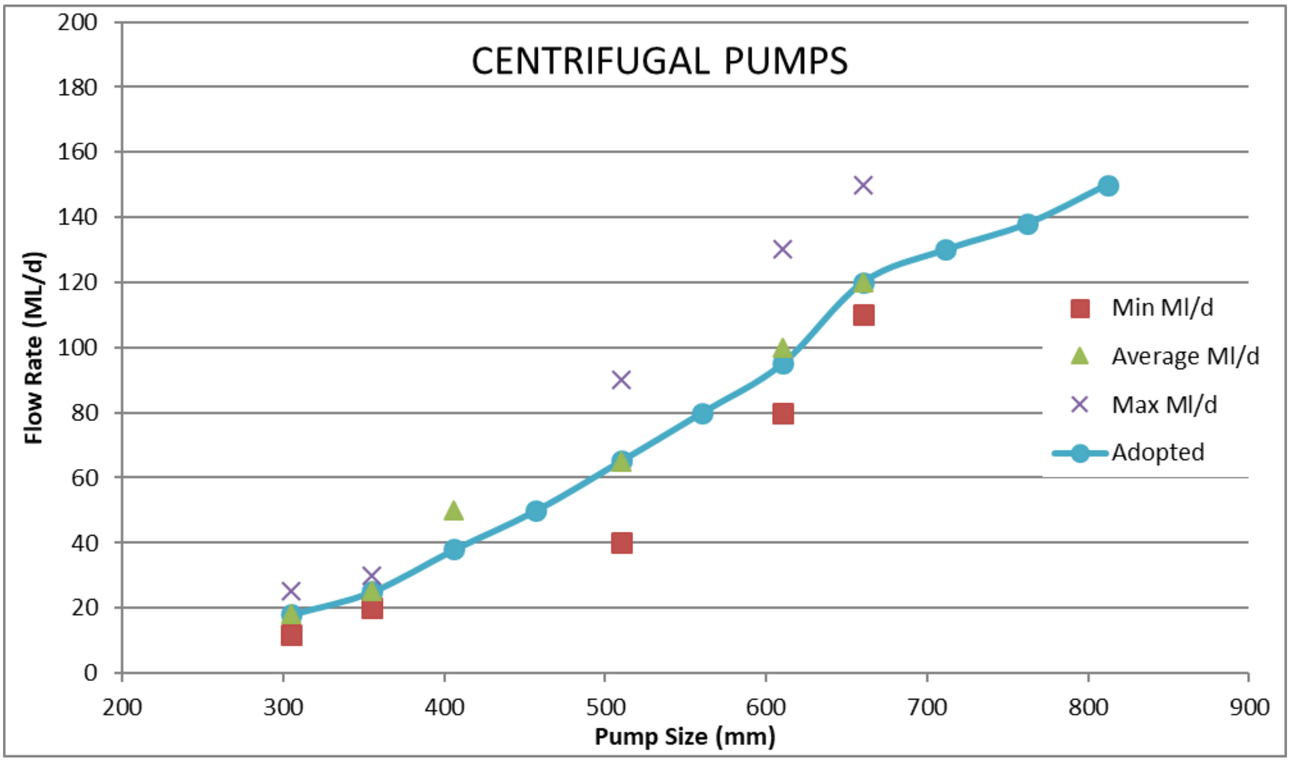

Figure 33 Centrifugal pumps flow rate analysis for a range of pump sizes

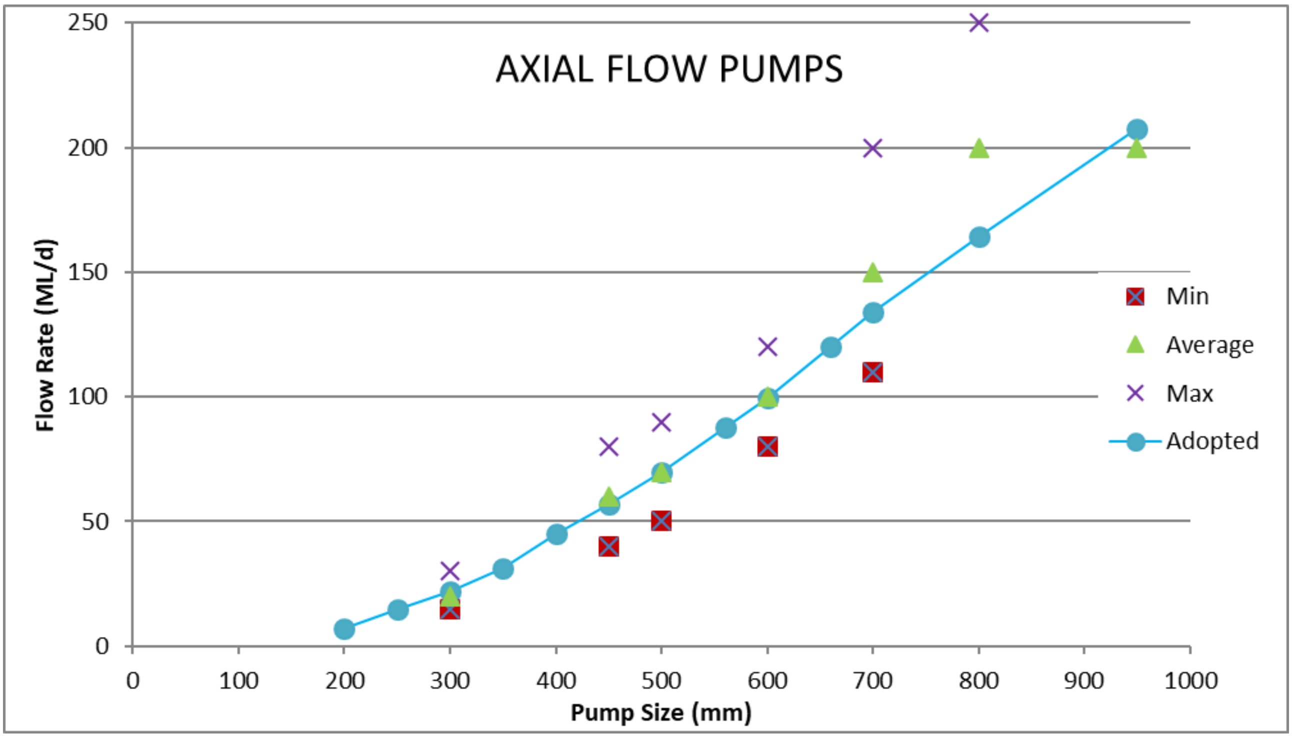

Figure 34 Axial flow pumps flow rate analysis for a range of pump sizes

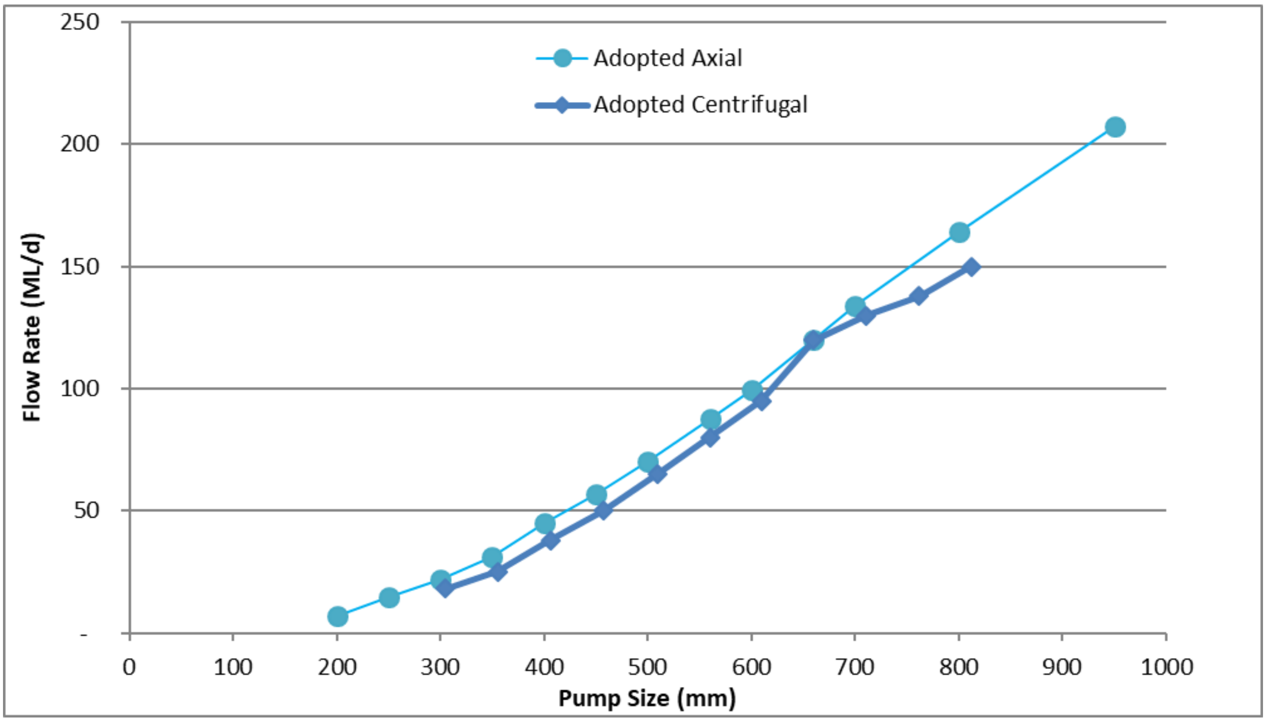

Figure 35 Comparison of adopted centrifugal and axial flow rates for a range of pump sizes

F.4 Intake infrastructure

There are typically a number of pipes which bring water in from the floodplain to the area developed for irrigation. In some cases, regulators and pumps also serve this function. These were all assessed to estimate the capacity of 'intake' into the property. In general, the total 'intake capacity' was more than the total on-farm storage pump capacity. This means that in most cases the on-farm storage pumps were considered to be the limiting factor and the capacity of the pipes were used in the modelling only when the pipes were considered to be limiting factor. The capacity of both pumps and pipes were used in modelling for properties with eligible temporary storages as discussed in Section 6.2.2.

The flow rates assumed in the review of pipes are set out in Table 41.

Table 41 Pipe diameter and estimated flow rate at 0.2m head

Diameter (m)	Flow rate (ML/day)
1.80	264
1.50	183
1.20	117
1.05	92
0.90	66
0.75	48
0.60	29
0.50	20

F.5 Example of representing floodplain harvesting works which includes temporary storage

For the purposes of illustrating the modelling methodology we added an example of a hypothetical farm where temporary storage has been included in the modelling.

Farm's floodplain harvesting infrastructure:

- one permanent eligible storage of 3,950 ML
- total storage lift pump capacity is 240 ML/d
- one temporary storage of 770 ML
- total pipe capacity of 813 ML/d

Model representation of farm's overbank flow harvesting:

Floodplain harvesting events begin in the model on the next day following a flood breakout event. The flood water becomes available in the virtual floodplain storage at the start of day two of a multi-day flood event, and at the finalisation of a one-day flood event. Water available in the virtual floodplain storage is first released into the flood runner for harvesting by properties with access to this virtual storage. Configuration and parameterisation of the virtual floodplain storages are discussed in Section 6.2.2.

To represent overbank flow harvesting at this farm we use the following configuration:

- Flood water is harvested from the flood runner at a rate of up to 813 ML/day[23] and placed into the temporary storage, noting that each temporary storage is modelled with its specific characteristics such as depth and volume/area relationship[24].
- The water available in the temporary storage is transferred into the permanent storage at a total lift pump capacity of 240 ML/day on the following day. However, if like in this example the capacity of temporary storage is smaller than the total pipe take, temporary storage would be spilling on the same day, and flood harvesting would commence a day earlier. Water available for harvesting on that day, however, is limited by the smaller of the volume spilled and the total pump/lift capacity.

Water availability in the virtual floodplain storage and airspace in the permanent on-farm storage are other major factors determining flood water that is actually harvested, i.e. captured in the permanent on-farm storage. Any unharvested volume of flood water that is available for harvesting due to unavailability of space in the permanent on-farm storage is returned to the flood runner[25]. Evaporation and/or seepage losses from the temporary storages which also impact on harvested flood water are also modelled.

Table 42 demonstrates calculations in this example. For simplicity we assumed a large one-day overbank flow event, and no other type of diversions, water use, and losses from any of the storages are taking place.

As demonstrated in Table 42, the total overbank flow harvested in the 18-days floodplain harvesting event is 3,993 ML, noting the same floodplain harvesting event would be shorter and smaller in volume if we were considering evaporation and/or seepage losses from the temporary storage in our calculation.

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[23] The daily take is limited by volume of water available on the floodplain if that is lesser than the pipe take rate.

[24] Relevant estimates and assumptions may be used in absence of reliable data.

[25] Returned unharvested flood water is modelled accordingly, e.g. harvested by downstream users, merges with another flood breakout, becomes a loss.

Under the same assumption, but without the temporary storage, the calculated take would be 3,360 ML (14 days multiplied by 240 ML/day). This means that maximum hypothetical impact of temporary storage in this example is 633 ML in an assumed event.

However, in the model we consider all the factors which impact on the volume of actually harvested water and which are discussed above in this section. Consequently, the increase in **modelled** floodplain harvesting at this property would be significantly smaller. The impact of modelling temporary storage generally is a function of several factors including but not limited to access to floodplain harvesting source/s, on-farm infrastructure and other water sources such as regulated river licences and other entitlements.

Table 42 Simplified example of overbank flow harvesting at a farm with temporary storage

Floodplain harvesting event day	Virtual storage volume (ML)	Temporary storage volume (ML)	Permanent storage volume (ML)	Comment
1	0	0	0	Overbank flow event day
2	11,382	0	0	11,382 ML is calculated as 14 days times 813 ML/d
3	10,586	770	43	43 ML is calculated as 813 ML (i.e. maximum daily take at the same daily take rate) minus 770 ML. This is a spill from temporary on-farm storage
4	9,756	770	283	
5	8,943	770	523	
6	8,130	770	763	
7	7,317	770	1,003	
8	6,504	770	1,243	
9	5,691	770	1,483	
10	4,878	770	1,723	
11	4,065	770	1,963	
12	3,252	770	2,203	
13	2,439	770	2,443	
14	1,626	770	2,683	
15	813	770	2,923	
16	0	770	3,163	
17	0	530	3,403	
18	0	290	3,643	
19	0	50	3,883	
20	0	0	3,933	

Figure 36 demonstrates this example.

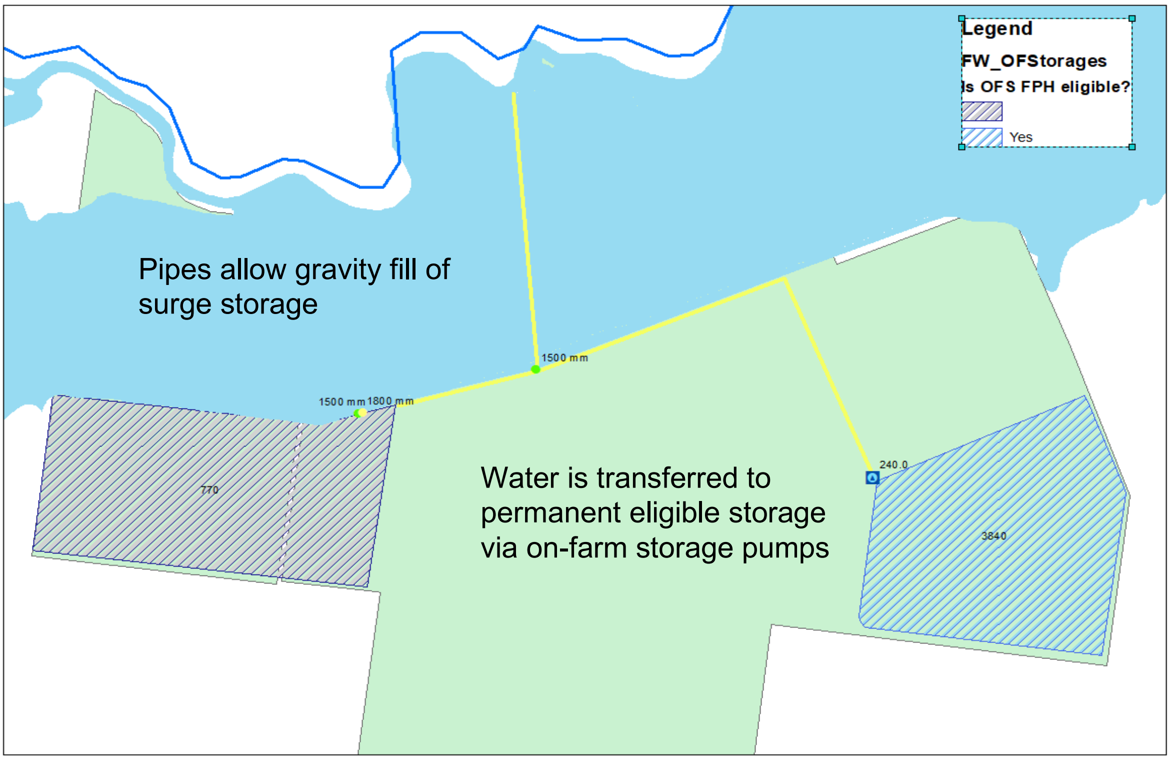

Figure 36 Example property with temporary storage

F.6 Example of representing floodplain harvesting works with multiple storages and floodplain harvesting sources

Most properties in the valley have multiple permanent storages. Many of them also can access overbank flow from multiple breakouts and from different streams. This section describes an example of a property with multiple permanent storages, and two sources of overbank flow harvesting. For the purposes of illustrating the modelling methodology we will be using a worked example of a farm in the Border Rives but using hypothetical development data.

Farm layout:

The property can access overland flow in the following way:

- Overbank flow from the Macintyre River is intercepted by below ground channels. The upstream properties have first access to overbank flow from this region and the model represents this order of access.
- Overbank flow from Tarpaulin Creek. The channel crossing the creek requires modification and is not included in the water supply work approval. The within bank flow in Tarpaulin Creek is not to be included in the floodplain harvesting entitlement, while estimated overbank flow in this region is.

Farm's floodplain harvesting infrastructure:

The property has multiple works:

- two eligible permanent storages with 2,500 ML and 1,200 ML of capacity for storage 1 and 2 respectively
- one lift pump at each of the storages with 360 ML/d take rate at storage 1 and 240 ML/day take rate at storage 2

- one ineligible storage. This storage is not included in the assessment of eligible floodplain harvesting.
- no eligible temporary storage
- multiple pipes which bring water in from the channels into the developed part of the farm and allow delivery to the storages. The total capacity of the pipes intercepting overbank flow from the Macintyre River is 720 ML/d while total pipe capacity intercepting overbank from Tarpaulin Creek is 480 ML/day.

Figure 37 demonstrates this example.

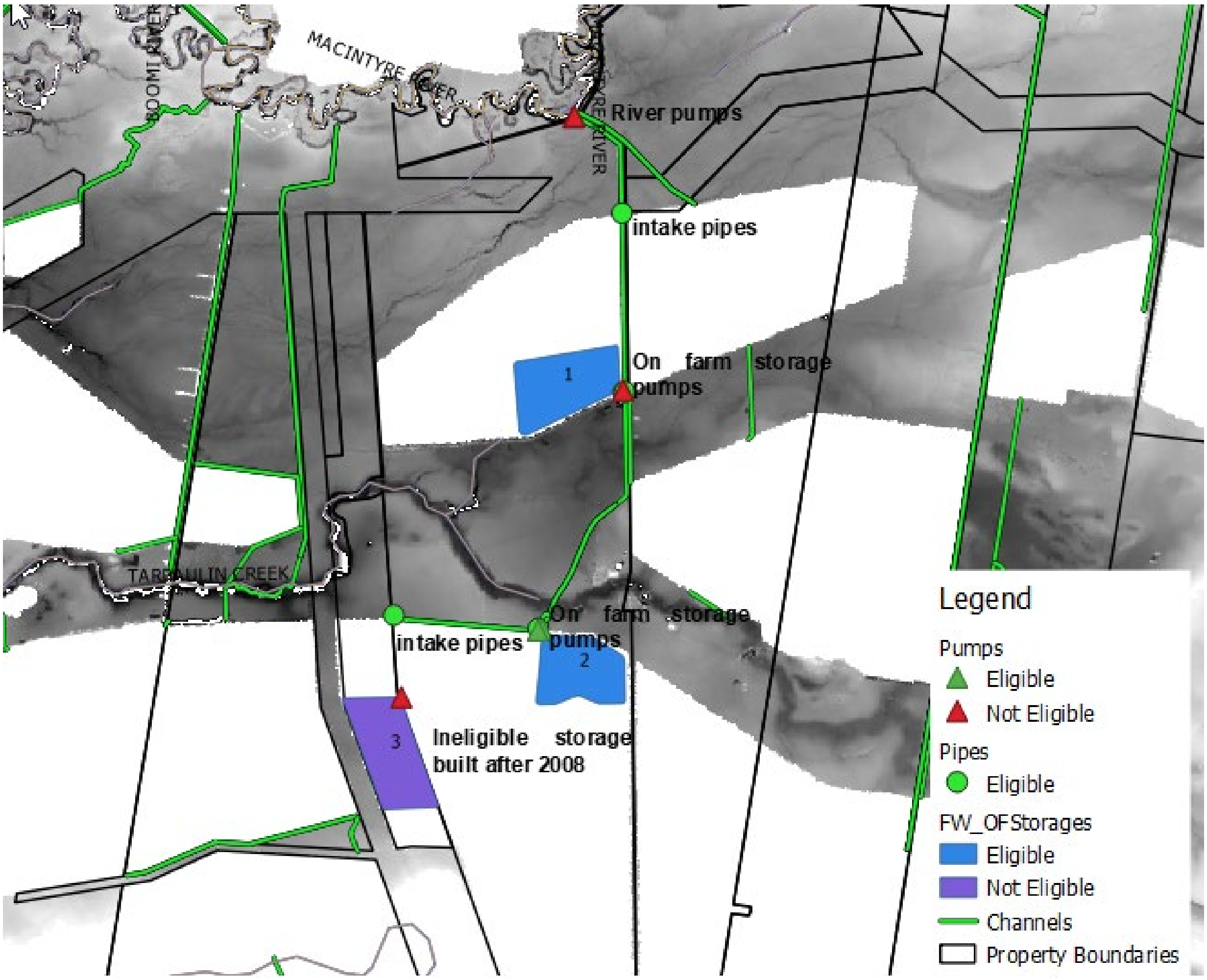

Figure 37 Example property with multiple storages and intakes

Model representation of farm's overbank flow harvesting:

If we were to configure the above example in the Gwydir Valley model, we would use the following configuration:

- single permanent on-farm storage with total capacity of 3,700 ML and pump take rate of 600 ML/d would be configured as discussed in Section 6.2.2
- total pipe take rate capacity at this property is 1,200 ML/day, which is double the lift capacity on combined permanent storage. Hence the on-farm storage pumps would be considered the limiting factor. The rate of floodplain harvesting is therefore set to the same as the total on-farm storage pumps rate; this means for the eligible scenario the rate is 600 ML/day.

Appendix G Crop area verification

G.1 Completeness of survey crop area data

Farm survey data on crop area and crop type were supplied by most floodplain harvesting properties. However, some properties supplied no data, and others did not provide crop areas starting from 2003/04. In some cases, this may be due to no crops being planted; however, there will be cases where crops were planted but no records were available. As there was a substantial proportion of properties and years with missing crop area information, the IrriSAT remote sensing described in Appendix G.2 was used to fill gaps in the farm survey data. A limited amount of checking of farm survey data against IrriSAT was also undertaken during gap filling, with IrriSAT data used where there was a difference in data. The results of the gap-filling and checking are shown in Figure 38.

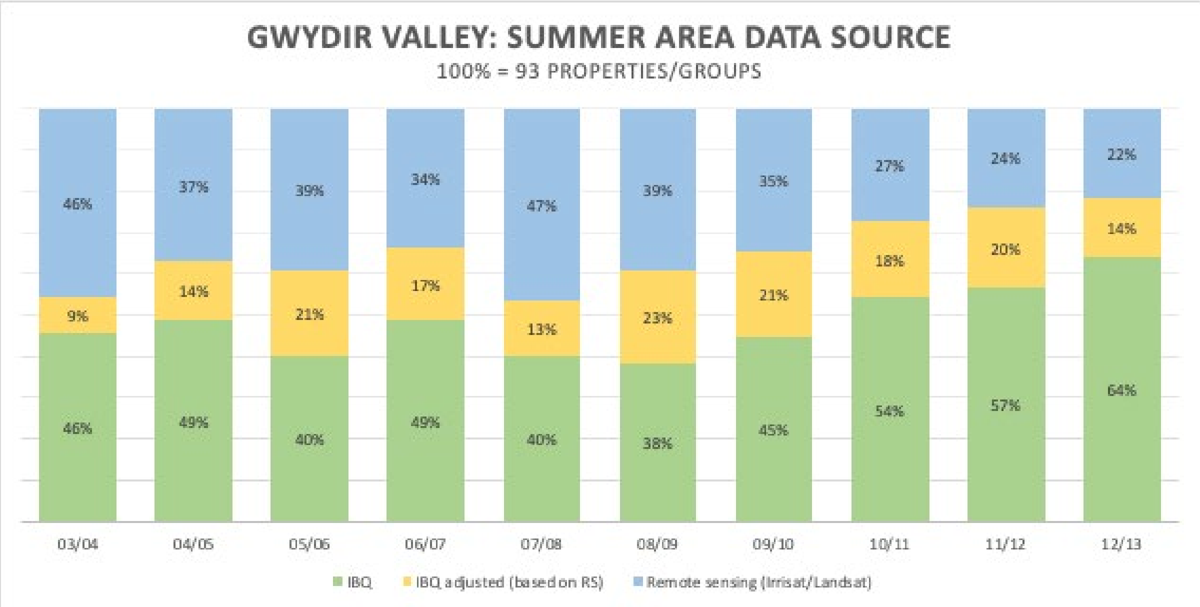

Figure 38 Completeness of reported summer crop area records from 2003/04 to 2012/13

G.2 Remote sensing of crop areas

Remote sensing of irrigated crop areas using MODIS and satellite imagery sourced via IrriSAT was undertaken for the Gwydir Valley to validate the information provided in the farm surveys.

The farm survey reported summer crop areas were compared against both IrriSAT and MODIS data. Winter crop areas have not analysed as remote sensing data is less reliable during these periods. Irrigation in the Gwydir Valley is also dominated by summer irrigation.

The IrriSAT and MODIS remote sensing data was obtained for the model validation period from 2003/04 to 2012/13.

- MODIS analysis uses a time series analysis to look for spectral response which approximates the expected crop behaviour. It has lower resolution, but more frequent imagery.
- IrriSAT analysis also uses a time series analysis to look for spectral response, but offers higher spatial resolution, and was used in conjunction with paddock-scale area measurements using IrriSAT online.

The IrriSAT analysis provides a robust independent measure of the irrigated crop areas. It also shows the intensity of irrigation, as shown in Figure 39, which can indicate whether alternative irrigation practices such as skip-row watering are occurring. Multiple images across the growing season have been examined to remove the effects of cloud cover obscuring particular images. However, this process currently requires significant manual manipulation of the information, and this analysis has been limited to those farms where the Farm Surveys did not provide complete information, and as part of addressing submissions made by individual farms as part of the farm-scale validation process.

Clear cases of non-cotton or under-irrigated cotton crops, and cases where there was a known practice of alternative planting practices (based on Farm Surveys) were considered when estimating the areas. The IQQM does not simulate these alternative practices. To provide a more consistent comparison between modelled and observed crop areas in these cases, the irrigated crop areas from the remote sensing were scaled back to represent an equivalent fully irrigated area.

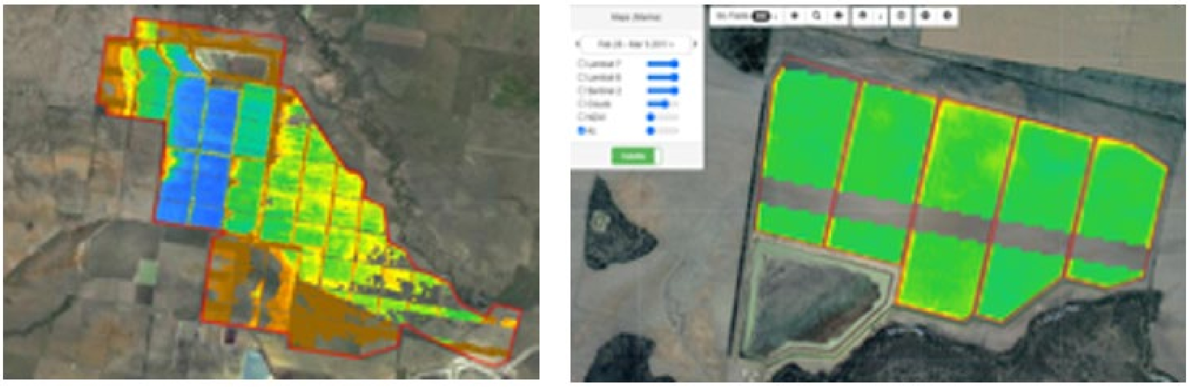

Figure 39 Examples of variable irrigation (left image) and single skip irrigation (farm survey response) (right image) [Source: IrriSAT imagery]

The combined farm survey and remote sensing data was also compared against other sources of information, including irrigated crop areas reported by the Australian Bureau of Statistics (ABS), and the Australian Cotton Foundation (ACF) as shown in Figure 40. The combined remote sensed/farm survey crop areas compare well with these other sources or are higher in some years.

Overall, comparisons of the MODIS remote sensing planted areas with farm survey information for individual properties were inconclusive. For some, generally larger, properties the areas between the two sets match reasonably well, but for others there was more variability between the datasets. In addition, remote sensing for winter areas generally produced a poor match with the survey results, and remote sensed winter areas were not used.

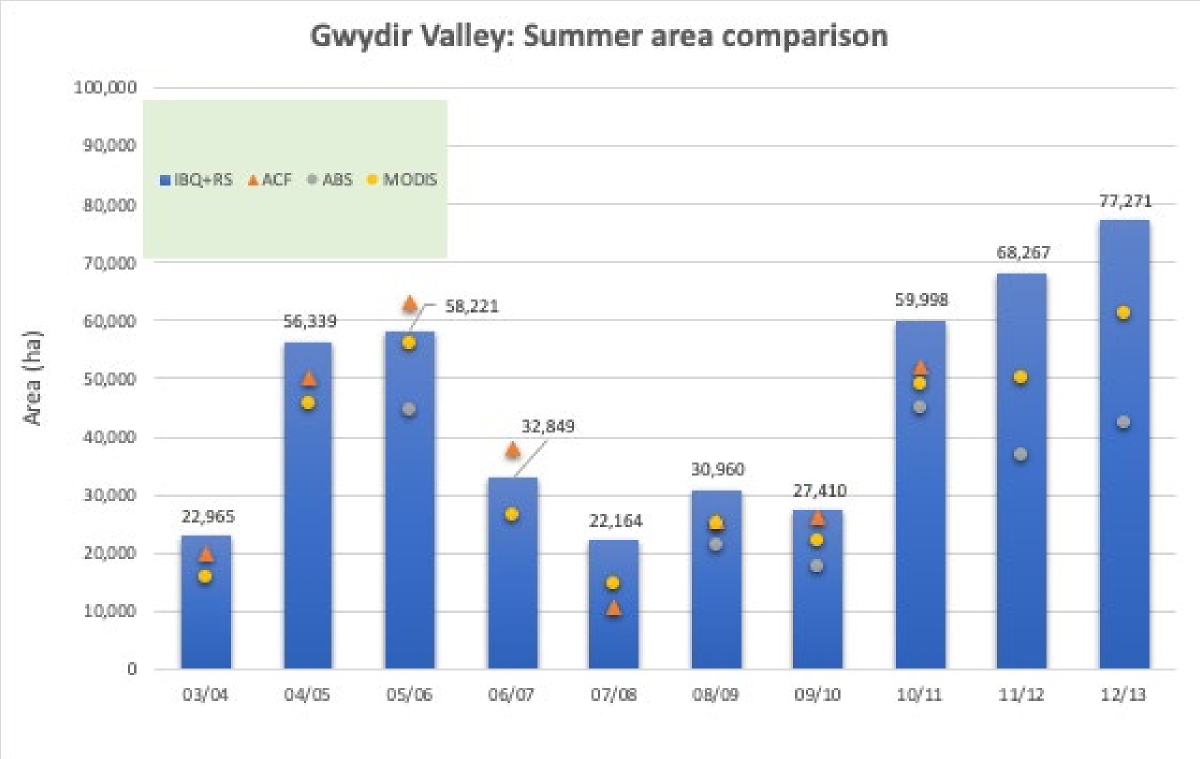

Figure 40 Irrigated summer crop area comparison across the four sources (farm survey, Australian Cotton Foundation, Australian Bureau of Statistics, MODIS) from 2003/04 to 2012/13

Appendix H Irrigation demands

To provide confidence in the water demands generated by the crop modelling, the modelled application rates were compared to published data. The following review focuses on cotton as this represents the majority of irrigation water use. This analysis used two types of modelled results:

- full irrigation application rates (no water availability restrictions)[26]
- modelled irrigation application rates as used in the Gwydir Valley model and the Border Rivers model.

The first test allows for comparison of the theoretical irrigation water use to other estimates such as WaterSched Pro. In practice, full irrigation may not be occurring during dry years. Hence the second test is designed so that comparisons can be made to published data on actual application rates (e.g. ABS and IrriSAT).

In both cases, the modelled results are assessed in terms of water applied to the field (ML/ha). The application rates are defined as follows:

- includes application losses
- excludes rainfall, on-farm storage losses and tailwater returns.

Available literature on average irrigation requirements is not consistent or clear on whether the requirements include some or all losses, making comparison difficult. It is also difficult to compare published data for large areas and/or for short periods as different climatic conditions in each season need to be taken into account.

H.1 Farm surveys

The farm surveys we undertook to collect information for assessing floodplain harvesting included questions on water application rates, pre-watering rates, and tailwater returns. After adjusting for tailwater returns, analysis of the survey results showed a range of application rates from 3.6–11.5 ML/ha, with an average of 7.9 ML/ha. There is no geographical relationship or other physical factor that explains this range. It is likely the variability can be attributed in part to averaging over different periods. Given the range, this information was referred to when assessing results, but not otherwise used directly in the model parameterisations.

H.2 IrriSAT

The IrriSAT methodology uses satellite images to determine the Normalized Difference Vegetation Index (NDVI) for each field, from which the plant canopy size can be determined and a specific crop coefficient (Kc) can be estimated. By combining Kc with daily reference Evapotranspiration (ET_o) observations from a nearby weather station, the crop water usage can be determined.

The method to estimate Kc and crop water use has been published internationally (Vleeshouwer et al 2015), however verification for the IrriSAT method has not been published for Australian cotton. We note that the IrriSAT method uses a different reference evapotranspiration dataset, hence new verification is required. Until the uncertainty in evapotranspiration estimates is established, the IrriSAT dataset will only be used by the department as a secondary information source.

[26] A simple test model was used with a notional unit crop area over a long term period with an unrestricted water supply. This model has been used to calculate the simulated water use per hectare for cotton.

The IrriSAT website[27] publishes estimates of crop factors and actual evapotranspiration. These data can be assessed at paddock scale and compared to modelled data. The IrriSAT website contains downloadable data from 2000 onwards, and estimates of crop areas and total crop water use at the paddock scale have been made across an extended period for 4 individual properties to check against the total crop water use produced by the Gwydir Valley model. A number of other properties were also checked for particular years. A comparison of total crop water use estimated by IrriSAT compared to the unrestricted crop demand simulated by the Gwydir Valley model is shown in Figure 41. Across the four farms analysed, the crop water use estimated by IrriSAT was within 10% of that simulated by the model.

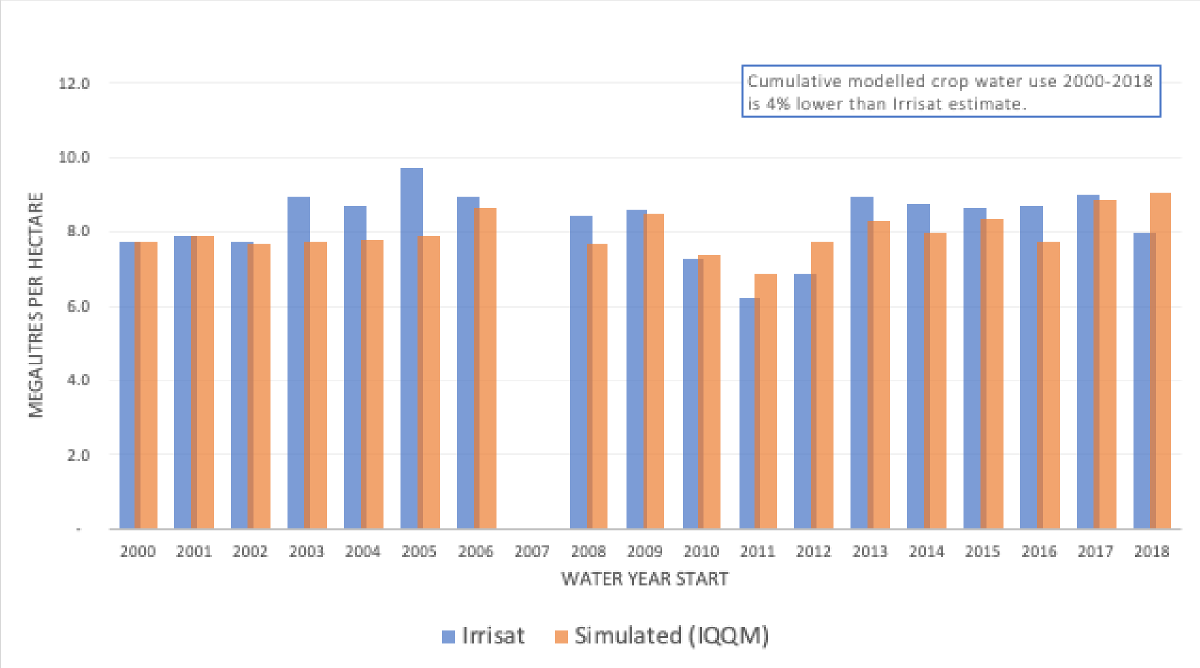

Figure 41 Comparison of simulated crop water use (Simulated IQQM) to IrriSAT data for an individual farm for the years 2000 to 2018

This analysis indicates that the Gwydir Valley model total crop water use is consistent for the growing season with those from IrriSAT, taking into account the current uncertainty regarding IrriSAT crop water use estimates.

Future work to more systematically compare and analyse IrriSAT and modelled results is needed to assess uncertainty in this method to develop confidence as to the best available estimate of actual crop water use.

H.3 WaterSched Pro

WaterSched Pro is an irrigation management tool that informs irrigation scheduling and crop water use[28] developed in Queensland, with comparable conditions to northern Murray Darling Basin. WaterSched Pro provides an estimate of long-term average crop water use using FAO56

[27] https://IrriSAT-cloud.appspot.com/

[28] https://waterschedpro.net.au/

crop coefficients assuming an unrestricted water supply. This utility does not account for any pre-watering, whereas the Source model parameterisation includes this[29].

The WaterSched Pro results are compared to the modelled cotton irrigation results in Figure 42. The following assumptions were used in WaterSched Pro for cotton:

- 70% efficiency[30]
- 70 mm soil water deficit at15 October plant date, 180-day, typical water use.

WaterSched Pro does not account for any pre-watering, whereas the Gwydir Valley model includes this. This largely accounts for differences in modelled values being 1.1 ML/ha higher, which is about the averaged modelled fallow soil depletion of at the beginning of the modelled irrigation season of 15 October.

Pre-watering requirements would be larger in the northern valleys where there is less spring rainfall preceding the irrigation season.

H.4 Australian Bureau of Statistics data

The Australian Bureau of Statistics (ABS) collects data on irrigation application rates for various crop types and regions. These data appears to represent water applied to field, including application loss, and is assumed to include data from unregulated cropping areas.

The ABS reports application rates over a large region covering both the Gwydir and Border Rivers. The ABS data has been compared to WaterSched Pro results in Figure 42. The data are reasonably close during the wetter years, but ABS data are significantly lower during dry years, and may indicate under-irrigation during dry years in this area.

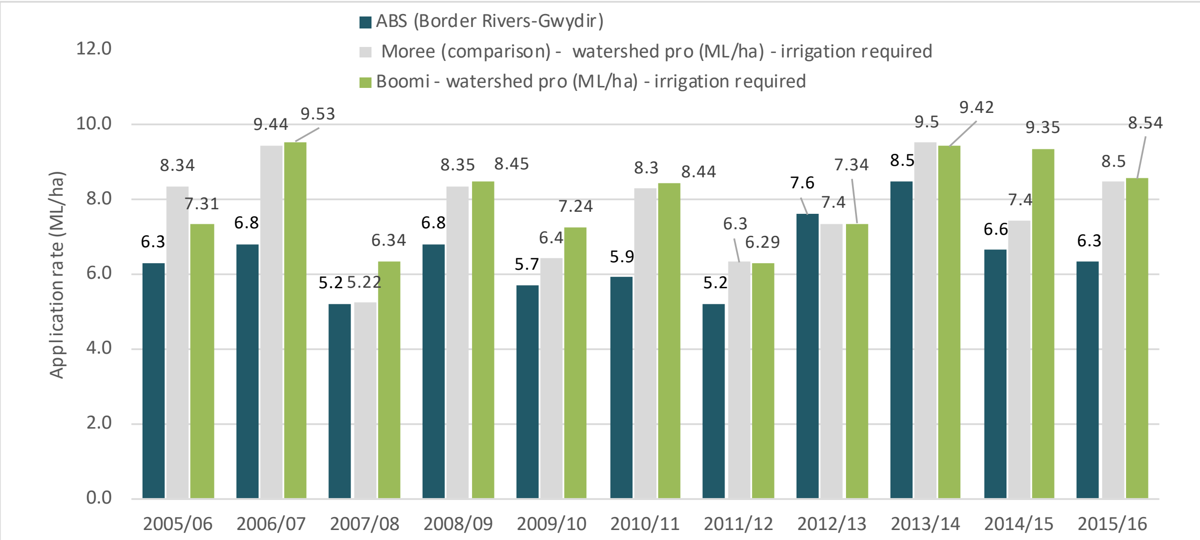

Figure 42 Comparison of ABS data and WaterSched Pro estimates for Border Rivers and Gwydir

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[29] WaterSched Pro assumes a full soil moisture profile at planting whereas Source modelling assumes soil moisture based on simulation of water balance in a fallowed area. The extent to which pre-watering is required will vary depending on fallow and soil management practises (e.g. Harris 2012).

[30] Gillies (2012) analysed 542 surface irrigation performance evaluations from the past decade. The average application efficiency with tail water recycling was 76.3% (cited in Tennakoon et al. 2012). The assumption of 30% loss allows for channel losses not modelled explicitly. On-farm storage losses are modelled separately.

Appendix I River reaches in the river system model

Table 43 Gwydir Valley reach division

Reach name	Upstream gauge	Downstream gauge
Gwydir1a-1	Copeton Dam	Pinegrove (418012)
Gwydir1a-2	Pinegrove (418012)	Gravesend (418013)
Gwydir1b	Gravesend (418013)	Pallamallawa (418001)
Gwydir2a-1	Pallamallawa (418001)	Boolooroo Weir (418051)
Gwydir2a-2	D/S Boolooroo Weir (418036)	Yarraman Bridge (418004)
Gwydir2b	Yarraman Bridge (418004)	Tyreel Weir (418065)
Gwydir3a	South Arm D/S Regulator (418063)	Brageen Crossing (418053)
Gwydir3b	Brageen Crossing (418053)	Millewa (418066)
Gwydir3c	Millewa (418066)	Collymongle (418031)
Gingham1	D/S Tyreel Weir Pool	Teralba (418074)
Gingham2	Teralba (418074)	Tillaloo Bridge (418076)
Gingham3	Tillaloo Bridge (418076)	Gingham Bridge (418079)
Carole1a	Bells Crossing (418011)	Midkin Crossing (416086)
Carole1b	Midkin Crossing (416086)	near Garah (418052)
Carole2a	near Garah (418052)	Carole-Gil Gil Junction
GilGil1	Carole-Gil Gil Junction	Weemelah (416027)
GilGil2	Weemelah (416027)	Galloway (416052)
Mehi1a-1	Mehi Offtake (418044)	Chinook (418087)
Mehi1a-2	Chinook (418087)	Moree (418002)
Mehi1b	Moree (418002)	D/S Combadello Weir (418037)
Mehi2	D/S Combadello Weir (418037)	D/S Gundare Regulator (418041)
Mehi3	D/S Gundare Regulator 18041)	U/S Ballin Boora Ck (418068)
Mehi4	U/S Ballin Boora Ck (418068)	Bronte (418058)
Mehi5	Bronte (418058)	near Collarenebri (418055)
Mallowa1	Regulator (418049)	Kamilaroi West (418046)
Moomin1a-1	Mehi offtake	Combadello Cutting (418048)
Moomin1a-2	Combadello Cutting (418048)	Glendello (418060)
Moomin1b	Glendello (418060)	Clarendon Bridge (418067)
Moomin2	Clarendon Bridge (418067)	Alma Bridge (418061)
Moomin3	Alma Bridge (418061)	Iffley (418054)
Moomin 4	Iffley (418054)	Mehi Junction

Appendix J Flow calibration tables and graphs

For headwater gauges, the Sacramento model results are compared to recorded flows.

For main river gauges, the results are generally based on using the final flow data inputs, which are a combination of gauged flows and Sacramento flows to extend (to meet the modelling period) and fill gaps.

Table 44 Headwater inflow flow calibration statistics, showing full, low, medium and high flow biases (%) for mean annual flow at selected stations

Station	Mean annual flow (GL)	Daily Nash-Sutcliffe	Full flow bias (%)	Low flow bias (%)	Medium flow bias (%)	High flow bias (%)	Graph reference
418005	21.5	0.62	0.1	9.5	-0.8	-0.6	Figure 44
418014	53.3	0.56	0.4	8.4	-0.2	-0.1	Figure 45
418015	175.6	0.72	0.0	11.30	0.50	-0.1	Figure 46
418016	25.9	0.65	-0.5	9.4	0.7	-0.9	Figure 47
418017	31.0	0.74	0.8	21.0	0.8	0.4	Figure 48
418018	38.0	0.63	-1.8	-1.6	-2.4	-1.4	Figure 49
418021	28.8	0.49	0.2	16.4	-1.4	0.1	Figure 50
418022	52.2	0.53	0.0	7.6	-1.8	0.4	Figure 51
418023	87.2	0.59	0.0	6.5	0.60	-0.80	Figure 52
418025	7.3	0.62	-2.1	11.4	6.4	-8.9	Figure 53
418032	26.6	0.83	-1.9	35.6	-3.9	-2.1	Figure 54
418033	9.5	0.85	0.0	3.5	0.30	-0.50	Figure 55
416054	55.4	0.85	0.0	0.1	4.1	-0.1	Figure 56

Sacramento model results have also been compared to expected values in the Murray-Darling Basin using the Budyko framework, and the results are shown in Figure 43.

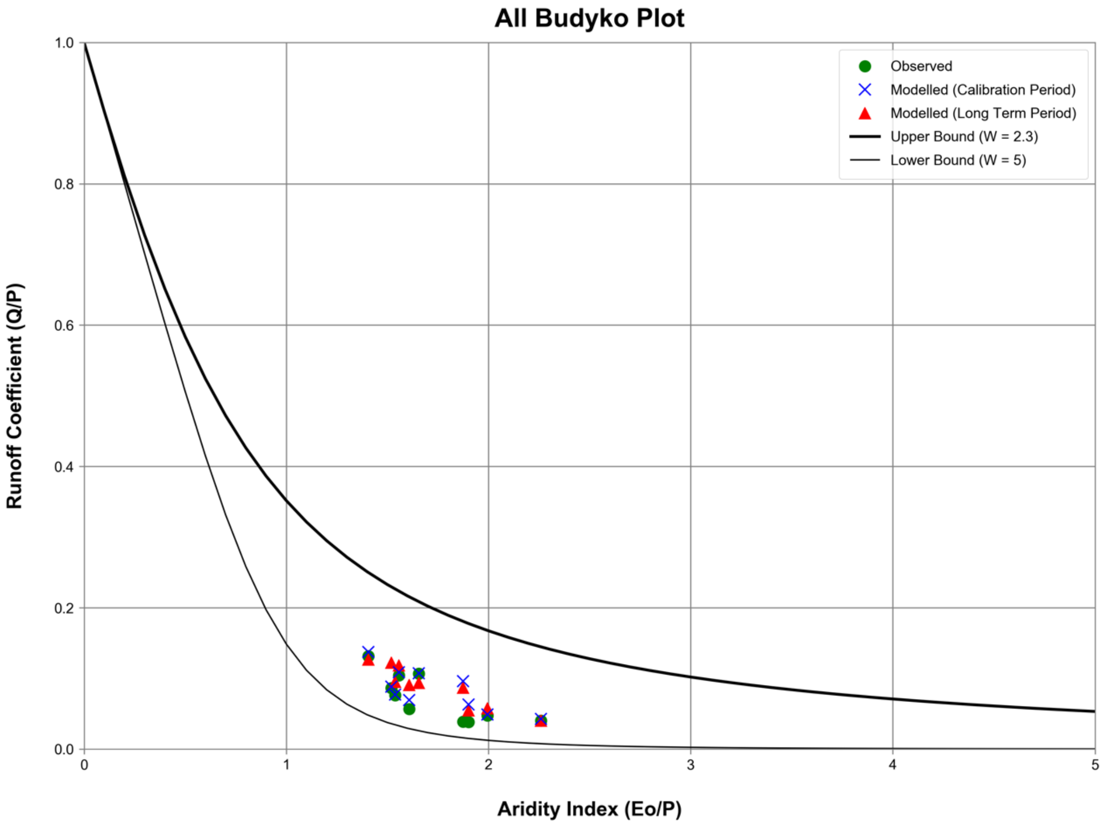


Figure 43 Sacramento modelling results compared to aridity index

Table 45 Reach flow calibration statistics, showing full, low, medium and high flow biases (%) for mean annual flow at selected stations

Station	Daily Nash-Sutcliffe	Full flow bias (%)	Low flow bias (%)	Medium flow bias (%)	High flow bias (%)	Graph reference
418001	0.91	6.03	11.2	3.29	6.66	Figure 57
418002	-0.07	6.87	48.17	-8.85	13.95	Figure 58
418004	0.79	17.55	166.27	26.38	17.51	Figure 59
418011	0.17	-2.37	-1.99	-2.19	-23.69	Figure 60
418012	0.76	3.76	35.48	11.09	-1.44	Figure 61
418013	0.95	1.58	8.22	6.08	-0.37	Figure 62
418037	0.63	12.08	249.47	-3.45	11.82	Figure 63
418041	0.18	16.12	378.2	-5.79	19.94	Figure 64
418042	0.74	9.46	67.99	16.34	7.17	Figure 65
418044	-4.4	14.42	-8.99	-7.37	45.06	Figure 66
418048	0.84	7.66	-28.86	-8.12	9.67	Figure 67
418049	0.32	9.67	-3.97	17.1	55.59	Figure 68
418052	0.53	2.19	-18.58	-1.74	-6.31	Figure 69

Station	Daily Nash-Sutcliffe	Full flow bias (%)	Low flow bias (%)	Medium flow bias (%)	High flow bias (%)	Graph reference
418053	0.79	-12.7	-97.34	-26.72	-1.63	Figure 70
418055	0.66	-8.7	79.84	11.29	-14.03	Figure 71
418058	0.66	1.31	-24.3	-20.12	-3.34	Figure 72
418060	0.62	1.03	-42.49	-12.48	2.2	Figure 73
418061	0.59	-9.31	-83.61	-24.8	-16.83	Figure 74
418063	-2.21	-1.52	-89.19	-25.05	23.82	Figure 75
418066	0.52	-17.92	-88.28	-31.04	-10.62	Figure 76
418067	0.73	-3.04	-65.79	-32.4	0.58	Figure 77
418068	0.79	-4.69	-15.24	-14.49	-6.09	Figure 78
418074	0.74	13.78	-100	63.78	5.93	Figure 79
418087	0.69	-2.73	8.96	-7.16	-10.17	Figure 80
416052	0.47	4.41	-15.91	-3.17	-1.19	Figure 81

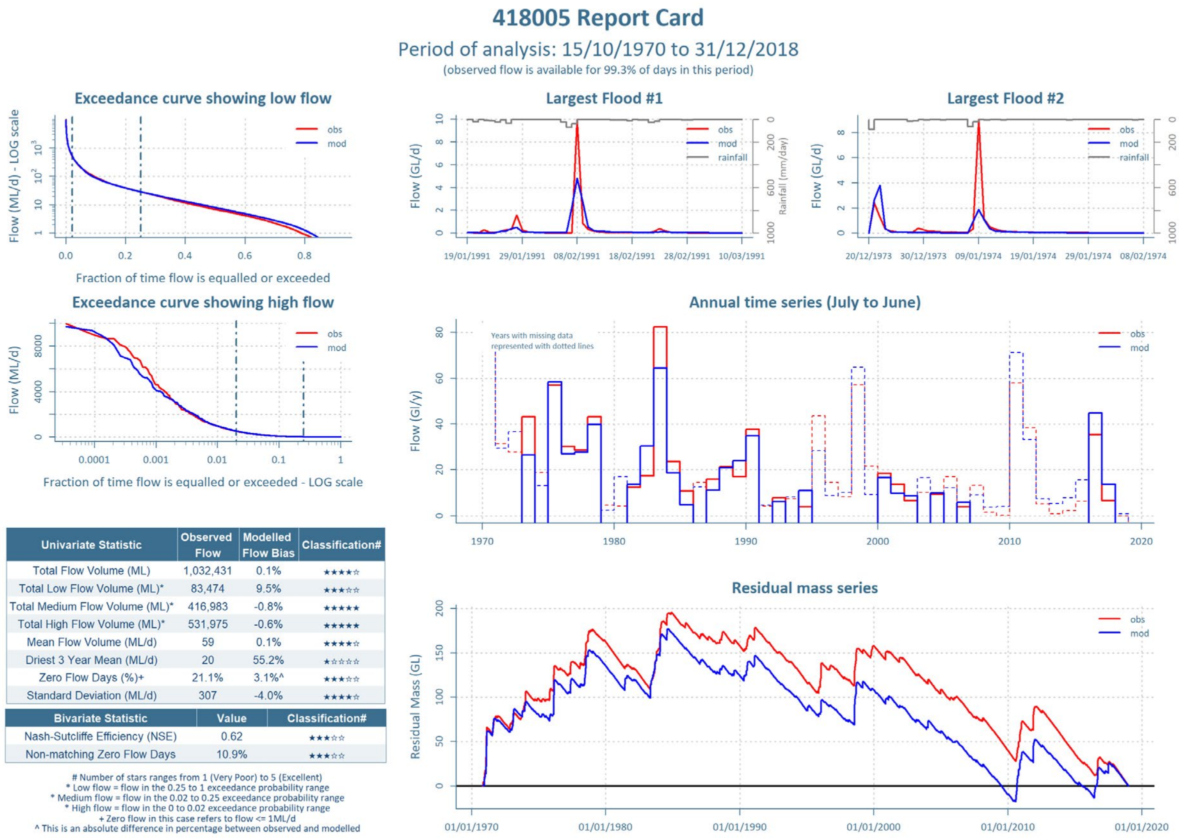
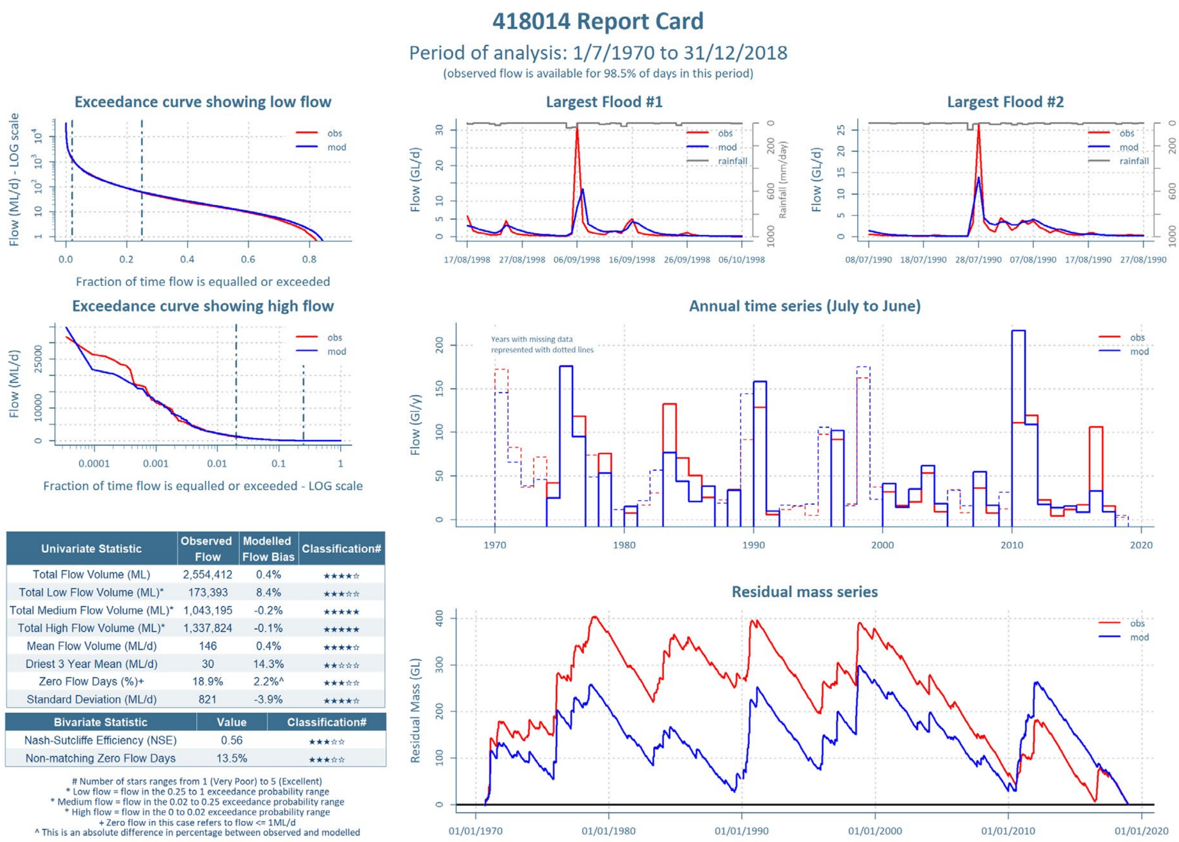


Figure 44 Flow calibration graphs for gauging station 418005 Copes Creek at Kimberley

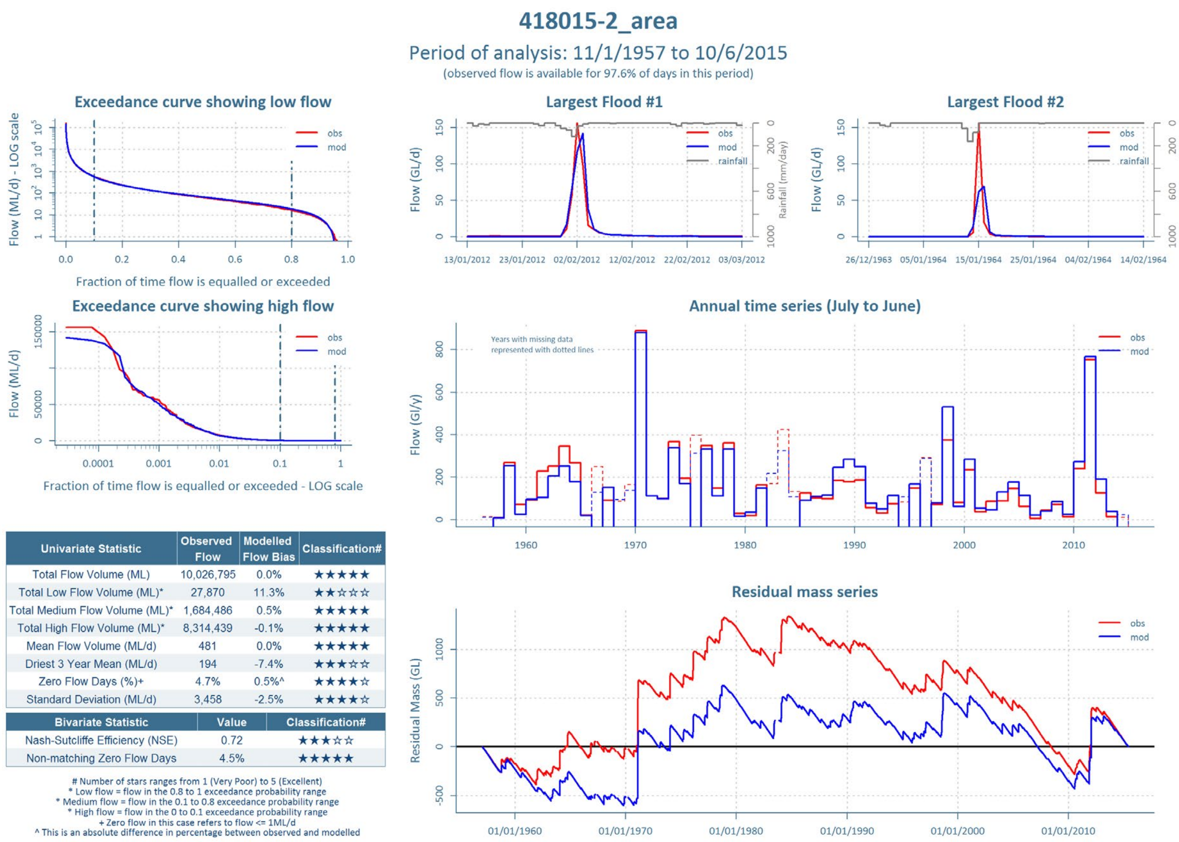


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	2,554,412	0.4%	★★★★☆
Total Low Flow Volume (ML)*	173,393	8.4%	★★★☆☆
Total Medium Flow Volume (ML)*	1,043,195	-0.2%	★★★★★
Total High Flow Volume (ML)*	1,337,824	-0.1%	★★★★★
Mean Flow Volume (ML/d)	146	0.4%	★★★★☆
Driest 3 Year Mean (ML/d)	30	14.3%	★★☆☆☆
Zero Flow Days (%)+	18.9%	2.2%^	★★★☆☆
Standard Deviation (ML/d)	821	-3.9%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.56	★★★☆☆
Non-matching Zero Flow Days	13.5%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.25 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.25 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 45 Flow calibration graphs for gauging station 418014 Gwydir River at Yarrowyck



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	10,026,795	0.0%	★★★★★
Total Low Flow Volume (ML)*	27,870	11.3%	★★☆☆☆
Total Medium Flow Volume (ML)*	1,684,486	0.5%	★★★★★
Total High Flow Volume (ML)*	8,314,439	-0.1%	★★★★★
Mean Flow Volume (ML/d)	481	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	194	-7.4%	★★★☆☆
Zero Flow Days (%)+	4.7%	0.5%^	★★★★☆
Standard Deviation (ML/d)	3,458	-2.5%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.72	★★★☆☆
Non-matching Zero Flow Days	4.5%	★★★★★

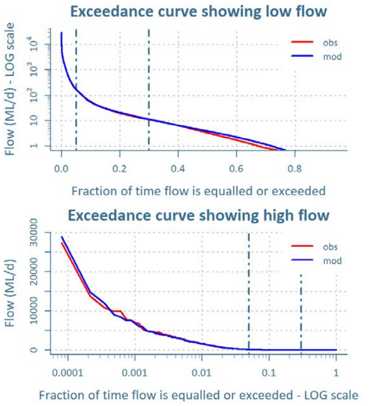
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.8 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.8 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

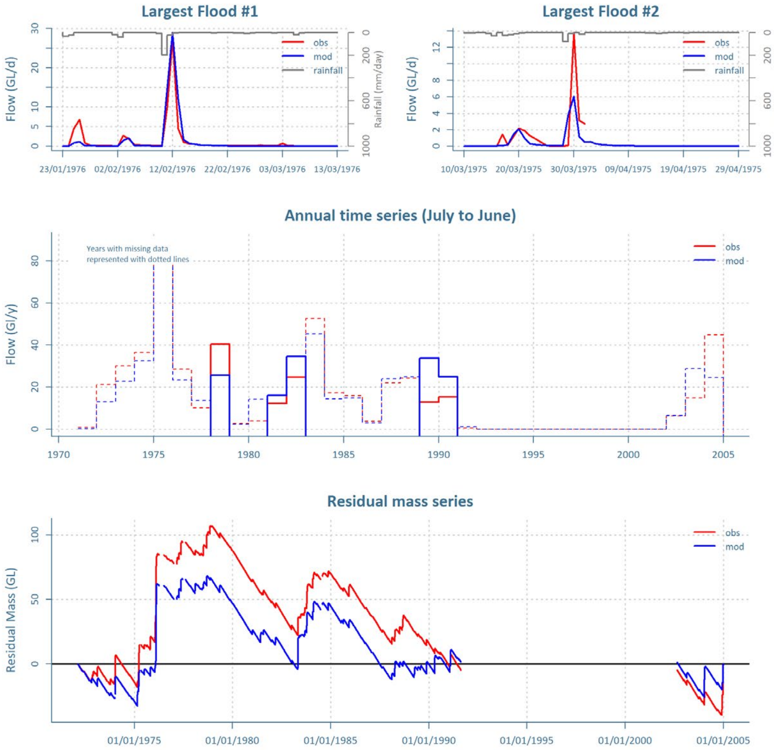
Figure 46 Flow calibration graphs for gauging station 418015 Horton River at Rider

418016 Report Card

Period of analysis: 10/2/1972 to 5/1/2005

(observed flow is available for 62.1% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	531,721	-0.5%	★★★★☆
Total Low Flow Volume (ML)*	13,309	9.4%	★★★☆☆
Total Medium Flow Volume (ML)*	71,729	0.7%	★★★★★
Total High Flow Volume (ML)*	446,683	-0.9%	★★★★★
Mean Flow Volume (ML/d)	71	-0.5%	★★★★☆
Driest 3 Year Mean (ML/d)	17	71.8%	★☆☆☆☆
Zero Flow Days (%)+	32.4%	4.5%^	★★★☆☆
Standard Deviation (ML/d)	541	1.3%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.65	★★★☆☆
Non-matching Zero Flow Days	12.6%	★★★☆☆

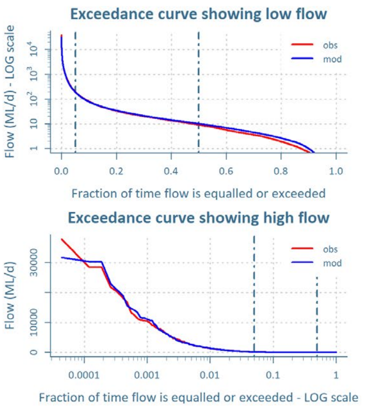
\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.3 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.3 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

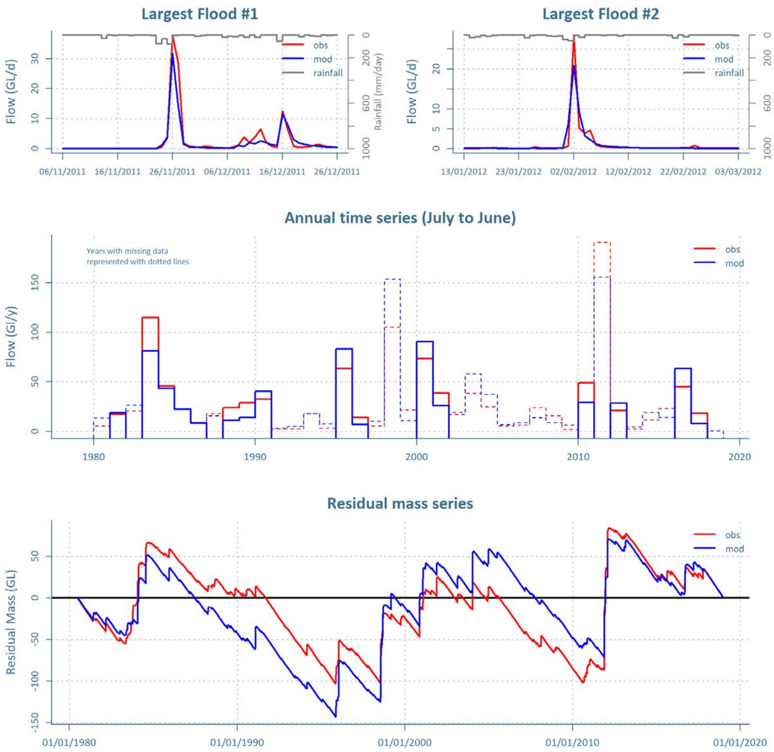
Figure 47 Flow calibration graphs for gauging station 418016 Warialda Creek at Warialda No 3

418017 Report Card

Period of analysis: 1/7/1980 to 31/12/2018

(observed flow is available for 98.4% of days in this period)



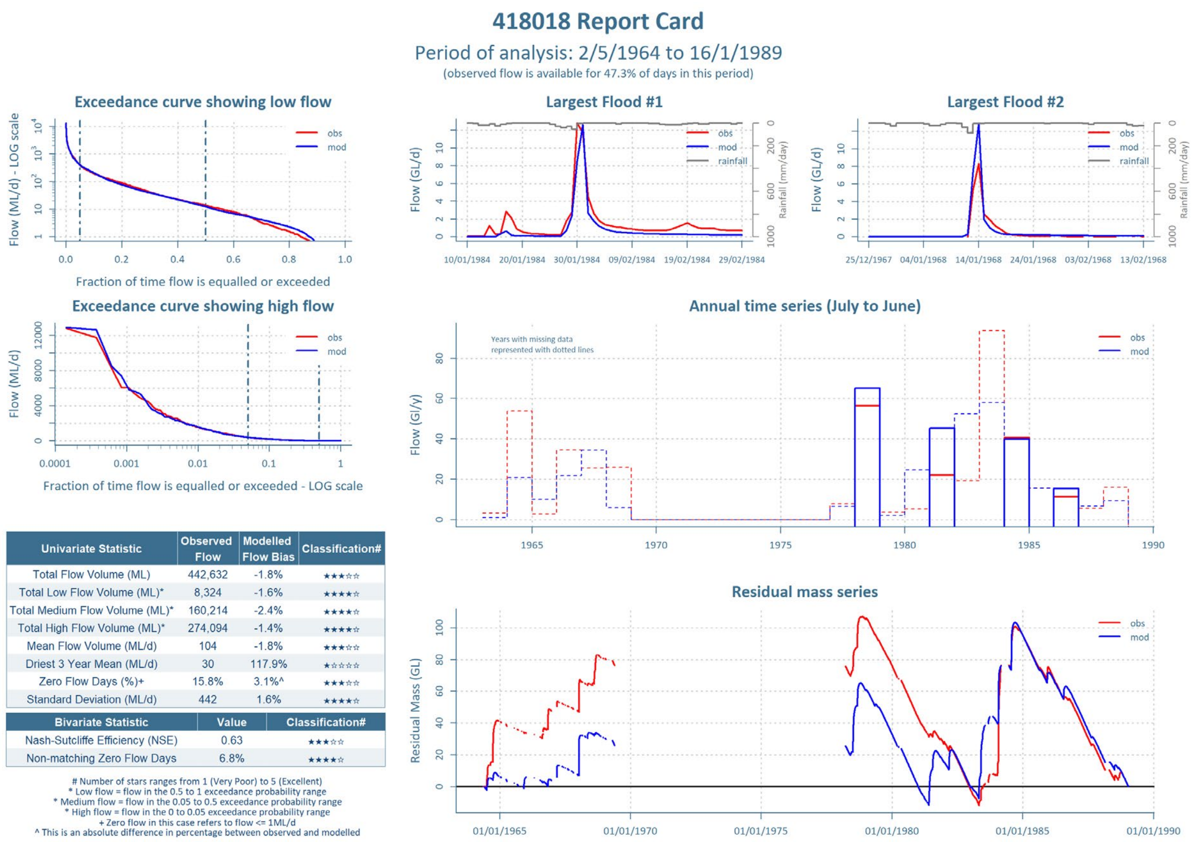


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,177,090	0.8%	★★★★☆
Total Low Flow Volume (ML)*	22,493	21.0%	★★☆☆☆
Total Medium Flow Volume (ML)*	227,468	0.8%	★★★★★
Total High Flow Volume (ML)*	927,129	0.4%	★★★★★
Mean Flow Volume (ML/d)	85	0.8%	★★★★☆
Driest 3 Year Mean (ML/d)	21	10.3%	★★☆☆☆
Zero Flow Days (%)+	12.8%	2.8%^	★★★☆☆
Standard Deviation (ML/d)	732	0.7%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.74	★★★☆☆
Non-matching Zero Flow Days	2.7%	★★★★★

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.5 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.5 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 48 Flow calibration graphs for gauging station 418017 Myall Creek at Molroy

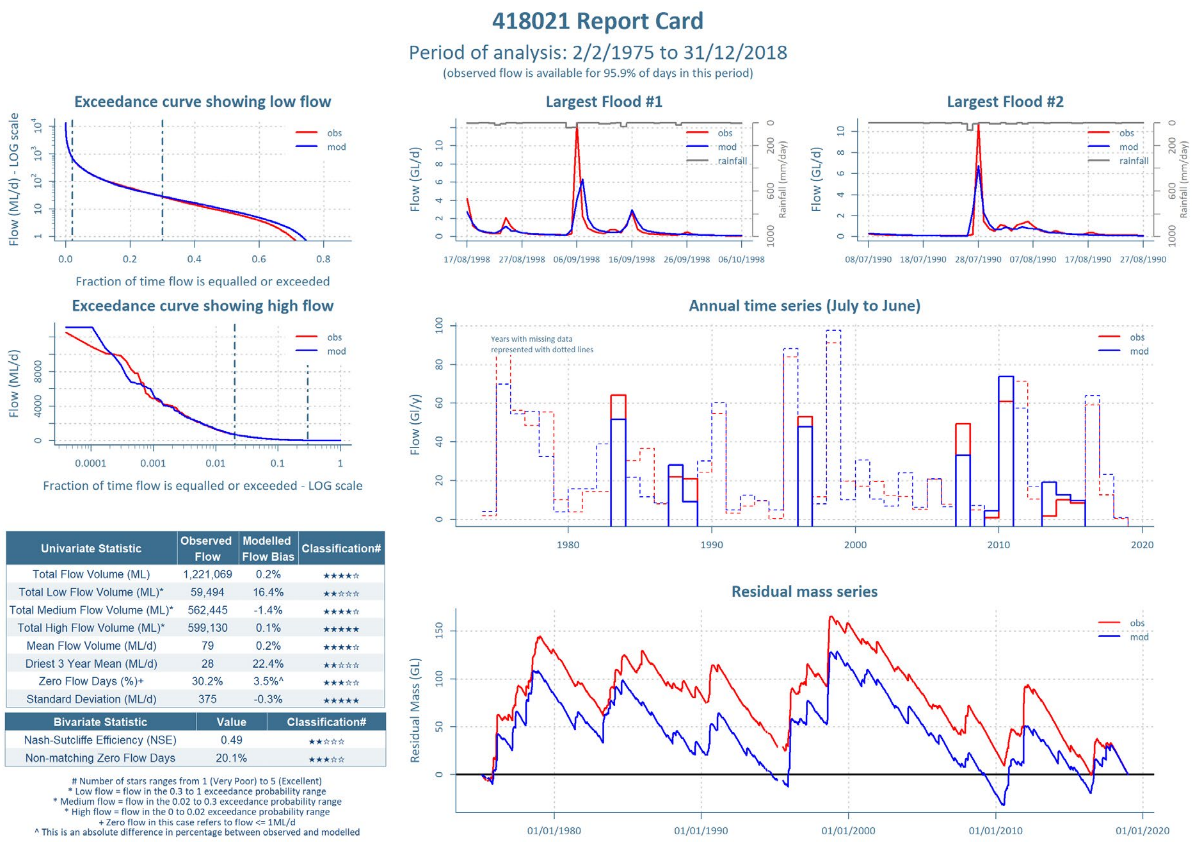


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	442,632	-1.8%	★★★☆☆
Total Low Flow Volume (ML)*	8,324	-1.6%	★★★★☆
Total Medium Flow Volume (ML)*	160,214	-2.4%	★★★★☆
Total High Flow Volume (ML)*	274,094	-1.4%	★★★★☆
Mean Flow Volume (ML/d)	104	-1.8%	★★★☆☆
Driest 3 Year Mean (ML/d)	30	117.9%	★☆☆☆☆
Zero Flow Days (%)+	15.8%	3.1%^	★★★☆☆
Standard Deviation (ML/d)	442	1.6%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.63	★★★☆☆
Non-matching Zero Flow Days	6.8%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.5 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.5 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 49 Flow calibration graphs for gauging station 418018 Keera Ck at Keera

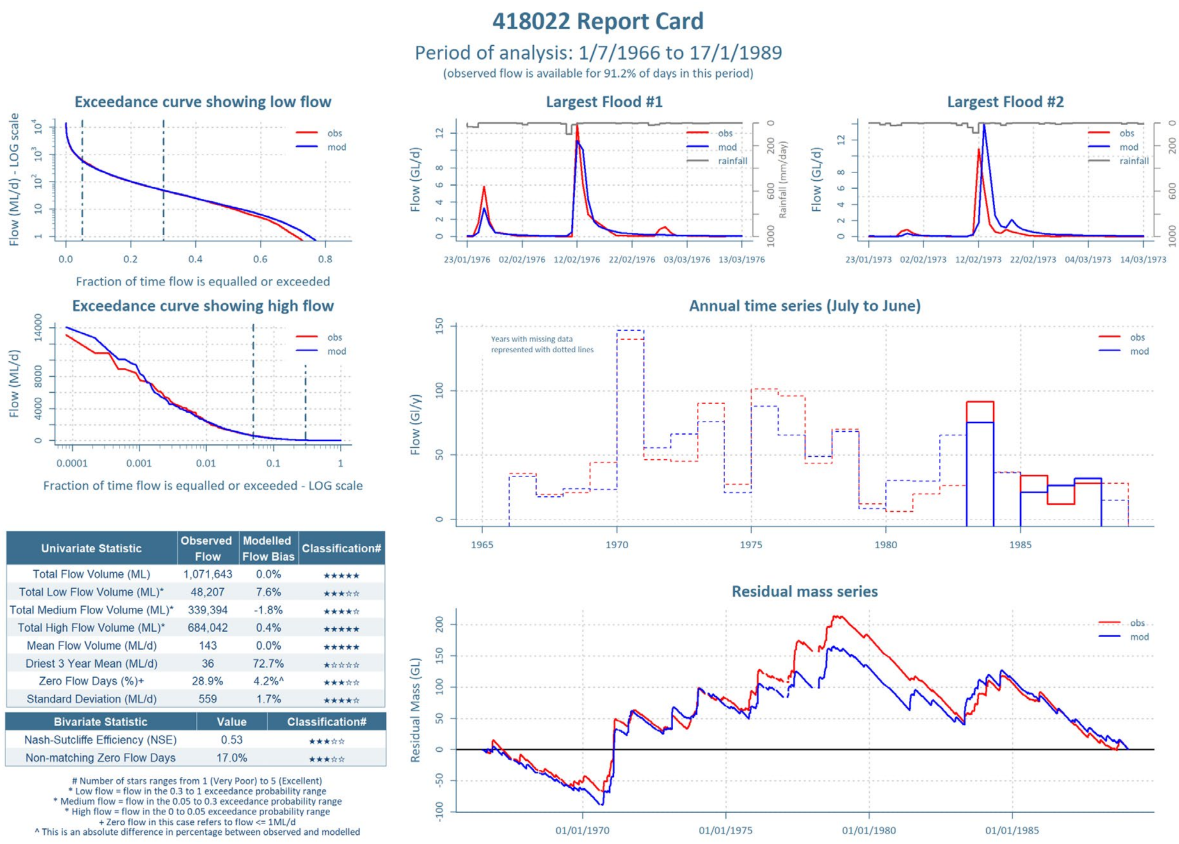


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,221,069	0.2%	★★★★☆
Total Low Flow Volume (ML)*	59,494	16.4%	★★☆☆☆
Total Medium Flow Volume (ML)*	562,445	-1.4%	★★★★☆
Total High Flow Volume (ML)*	599,130	0.1%	★★★★★
Mean Flow Volume (ML/d)	79	0.2%	★★★★☆
Driest 3 Year Mean (ML/d)	28	22.4%	★★☆☆☆
Zero Flow Days (%)+	30.2%	3.5%^	★★★☆☆
Standard Deviation (ML/d)	375	-0.3%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.49	★★☆☆☆
Non-matching Zero Flow Days	20.1%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.3 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.3 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 50 Flow calibration graphs for gauging station 418021 Laura Ck at Laura

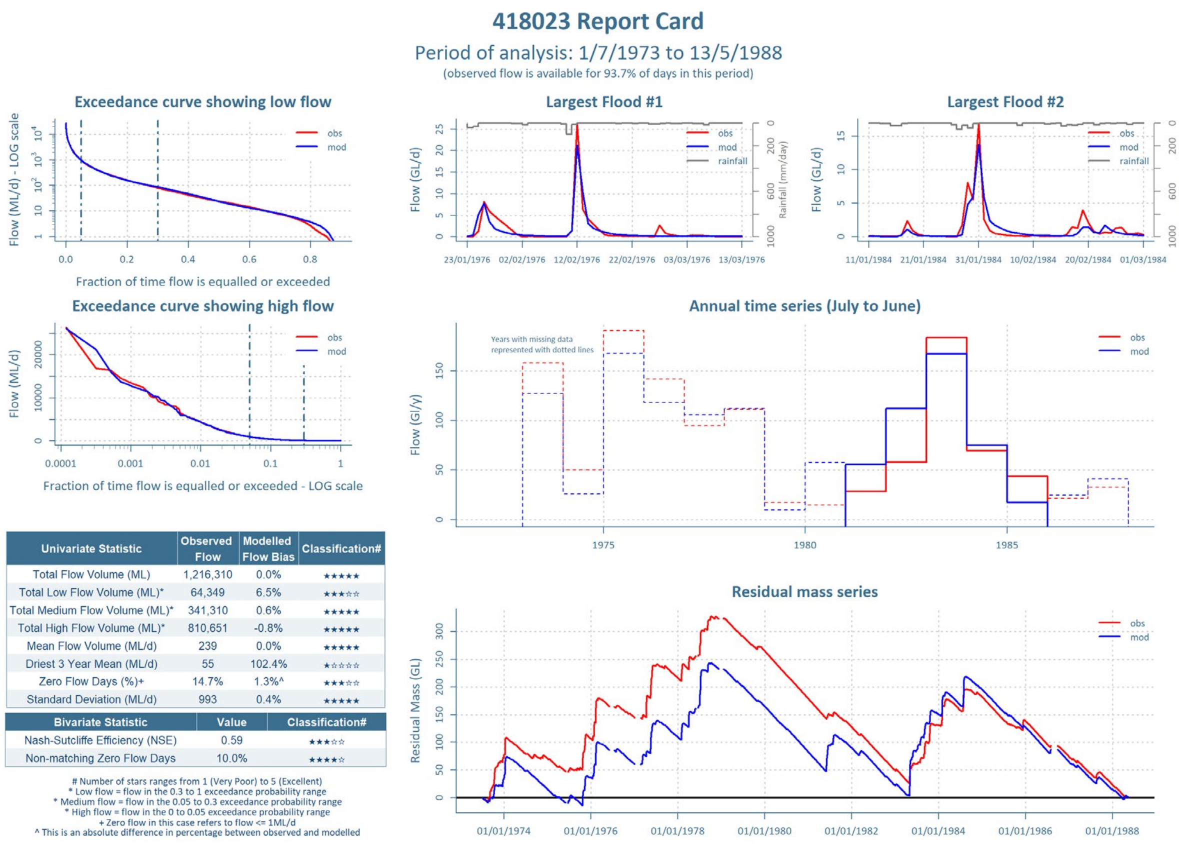


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,071,643	0.0%	★★★★★
Total Low Flow Volume (ML)*	48,207	7.6%	★★★☆☆
Total Medium Flow Volume (ML)*	339,394	-1.8%	★★★★☆
Total High Flow Volume (ML)*	684,042	0.4%	★★★★★
Mean Flow Volume (ML/d)	143	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	36	72.7%	★☆☆☆☆
Zero Flow Days (%)+	28.9%	4.2%^	★★★☆☆
Standard Deviation (ML/d)	559	1.7%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.53	★★★☆☆
Non-matching Zero Flow Days	17.0%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.3 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.3 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 51 Flow calibration graphs for gauging station 418022 Georges Creek at Clerkness

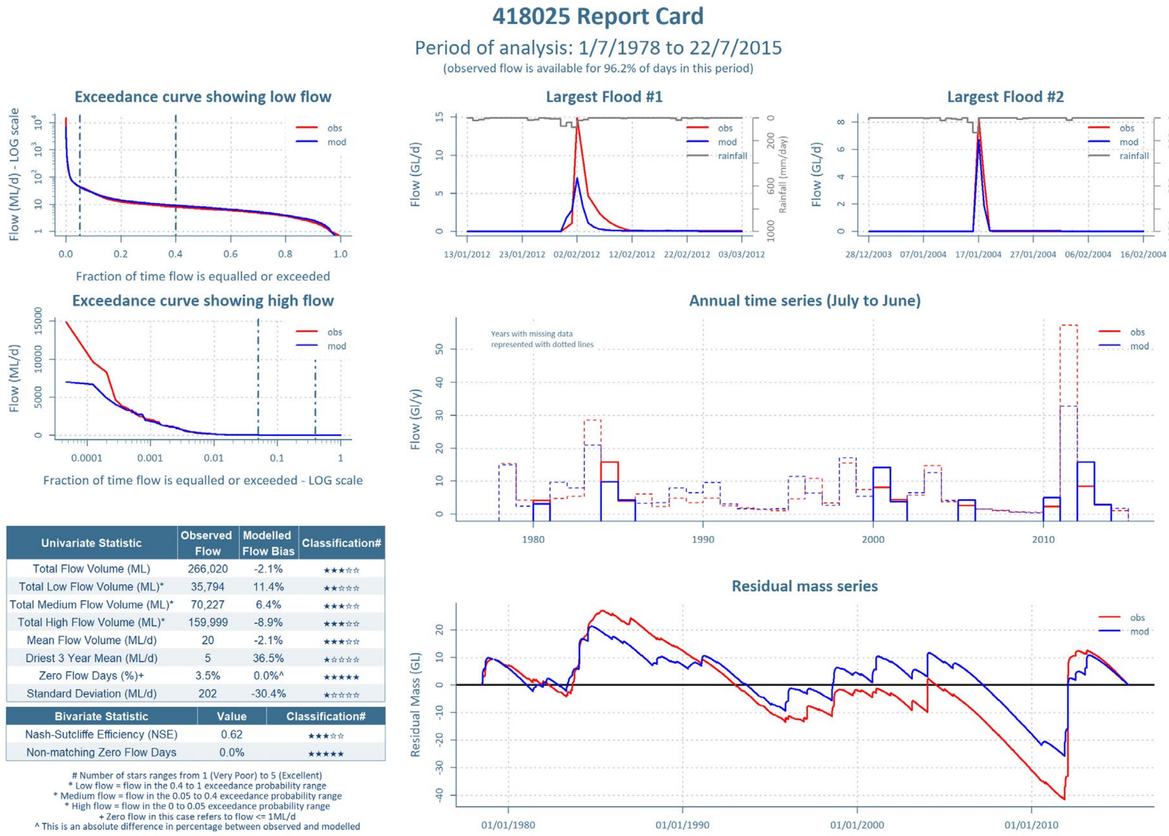


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,216,310	0.0%	★★★★★
Total Low Flow Volume (ML)*	64,349	6.5%	★★★☆☆
Total Medium Flow Volume (ML)*	341,310	0.6%	★★★★★
Total High Flow Volume (ML)*	810,651	-0.8%	★★★★★
Mean Flow Volume (ML/d)	239	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	55	102.4%	★☆☆☆☆
Zero Flow Days (%)+	14.7%	1.3%^	★★★☆☆
Standard Deviation (ML/d)	993	0.4%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.59	★★★☆☆
Non-matching Zero Flow Days	10.0%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.3 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.3 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 52 Flow calibration graphs for gauging station 418023 Moredun Creek at Bundarra

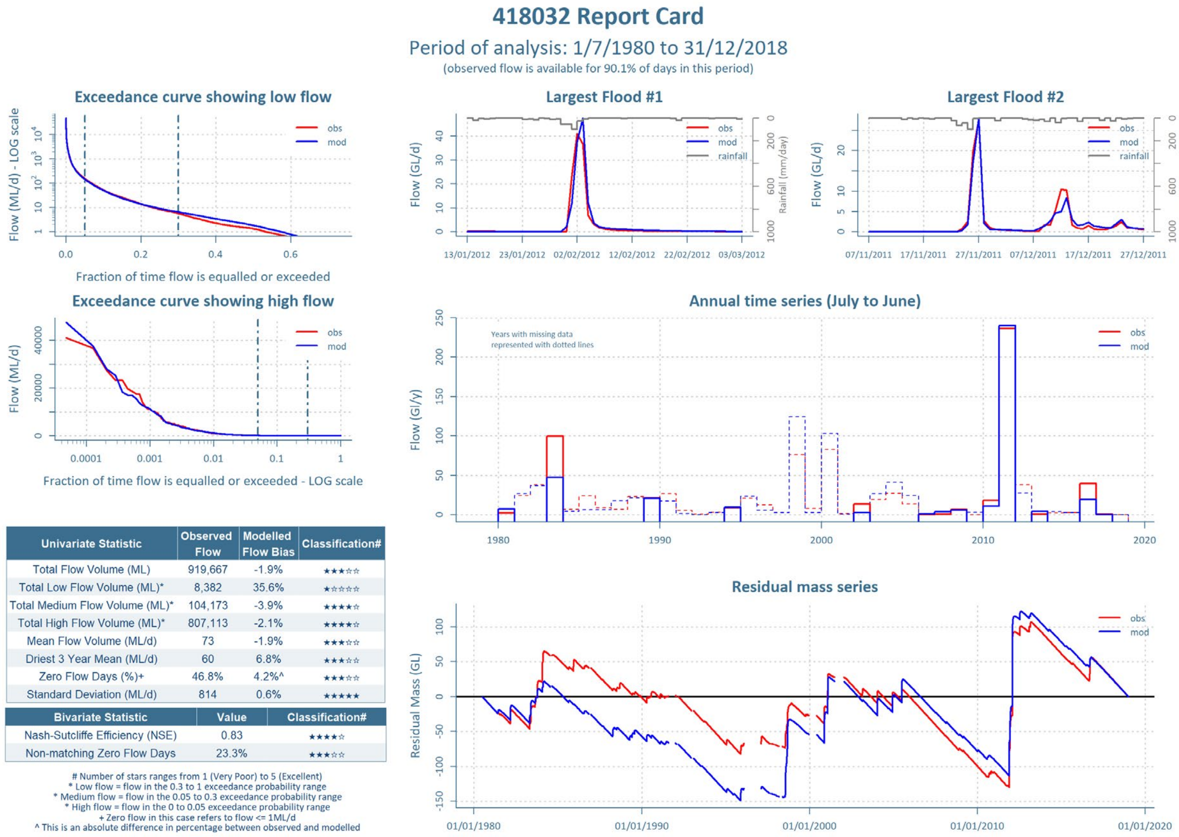


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	266,020	-2.1%	★★★☆☆
Total Low Flow Volume (ML)*	35,794	11.4%	★★☆☆☆
Total Medium Flow Volume (ML)*	70,227	6.4%	★★★☆☆
Total High Flow Volume (ML)*	159,999	-8.9%	★★★☆☆
Mean Flow Volume (ML/d)	20	-2.1%	★★★☆☆
Driest 3 Year Mean (ML/d)	5	36.5%	★☆☆☆☆
Zero Flow Days (%)+	3.5%	0.0%^	★★★★★
Standard Deviation (ML/d)	202	-30.4%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.62	★★★☆☆
Non-matching Zero Flow Days	0.0%	★★★★★

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.4 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.4 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 53 Flow calibration graphs for gauging station 418025 Halls Creek at Bingara



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	919,667	-1.9%	★★★☆☆
Total Low Flow Volume (ML)*	8,382	35.6%	★☆☆☆☆
Total Medium Flow Volume (ML)*	104,173	-3.9%	★★★★☆
Total High Flow Volume (ML)*	807,113	-2.1%	★★★★☆
Mean Flow Volume (ML/d)	73	-1.9%	★★★☆☆
Driest 3 Year Mean (ML/d)	60	6.8%	★★★☆☆
Zero Flow Days (%)+	46.8%	4.2%^	★★★☆☆
Standard Deviation (ML/d)	814	0.6%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.83	★★★★☆
Non-matching Zero Flow Days	23.3%	★★★☆☆

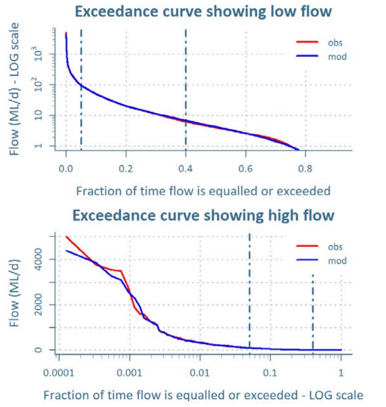
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.3 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.3 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

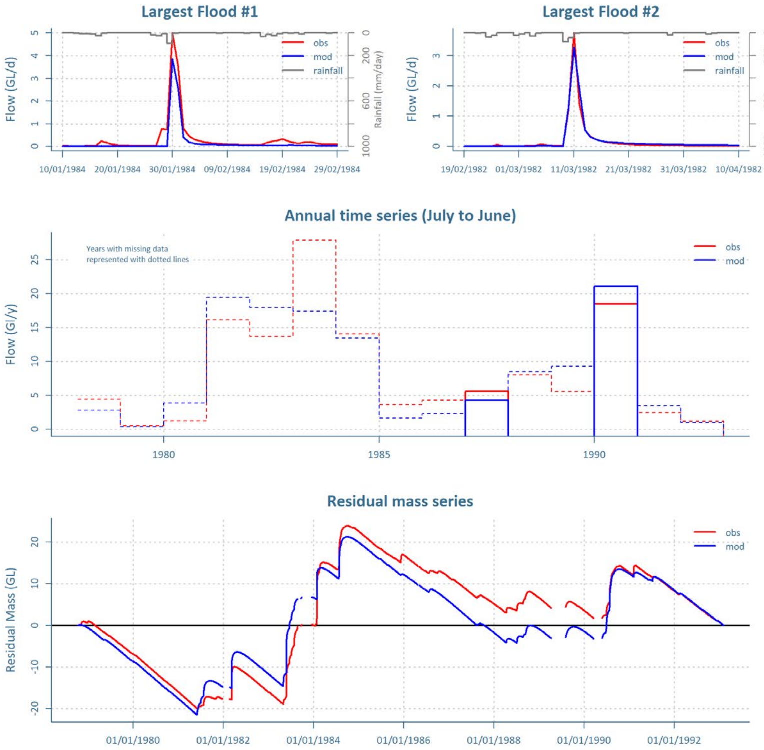
Figure 54 Flow calibration for gauging station 418032 Tycannah Creek at Horseshoe Lagoon

418033 Report Card

Period of analysis: 8/10/1978 to 5/2/1993

(observed flow is available for 91.7% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	126,783	0.0%	★★★★★
Total Low Flow Volume (ML)*	5,576	3.5%	★★★★☆
Total Medium Flow Volume (ML)*	43,426	0.3%	★★★★★
Total High Flow Volume (ML)*	77,782	-0.5%	★★★★★
Mean Flow Volume (ML/d)	26	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	18	23.2%	★★☆☆☆
Zero Flow Days (%)+	25.1%	0.3%^	★★★★☆
Standard Deviation (ML/d)	144	-4.2%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.85	★★★★☆
Non-matching Zero Flow Days	6.6%	★★★★☆

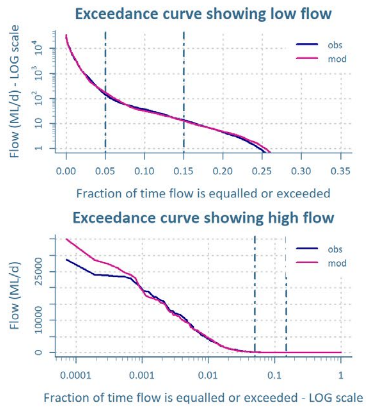
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.4 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.4 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

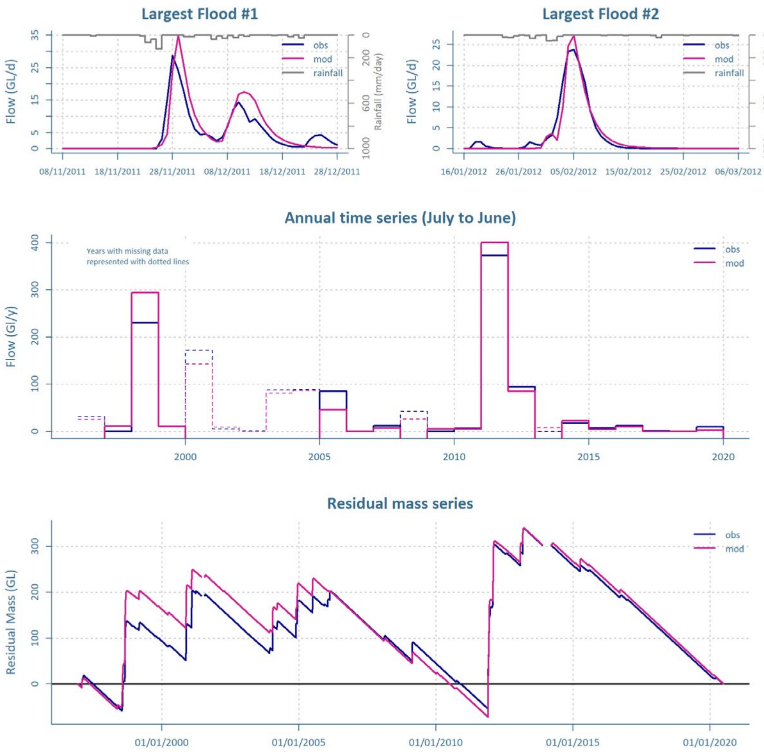
Figure 55 Flow calibration graphs for gauging station 418033 Bakers Creek at Bundarra

416054 Report Card

Period of analysis: 7/12/1996 to 30/6/2020

(observed flow is available for 98% of days in this period)



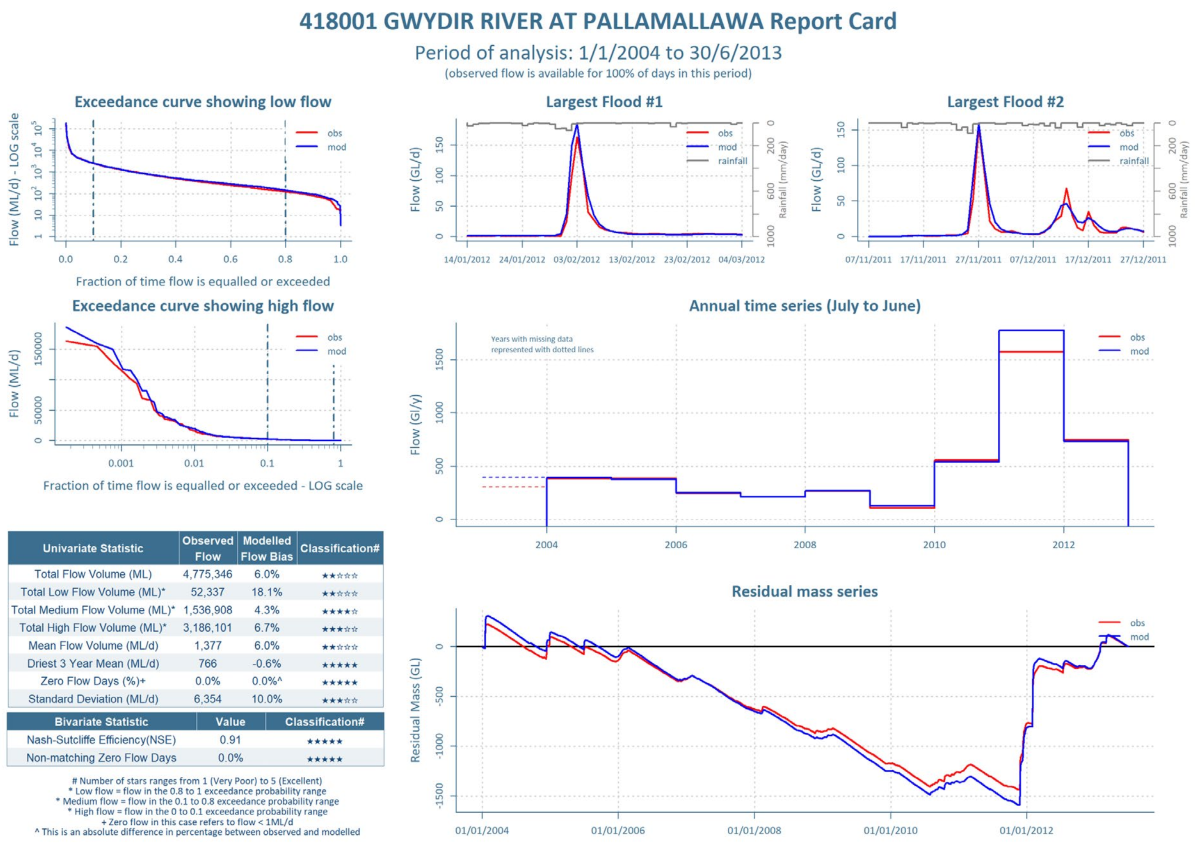


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,282,826	0.0%	★★★★★
Total Low Flow Volume (ML)*	4,686	0.1%	★★★★★
Total Medium Flow Volume (ML)*	38,070	4.1%	★★★★☆
Total High Flow Volume (ML)*	1,240,071	-0.1%	★★★★★
Mean Flow Volume (ML/d)	152	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	9	-75.1%	★☆☆☆☆
Zero Flow Days (%)+	75.4%	0.8%^	★★★★☆
Standard Deviation (ML/d)	1,245	2.0%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.85	★★★★☆
Non-matching Zero Flow Days	24.6%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.15 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.15 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 56 Flow calibration graphs for gauging station 416054 Gil Gil Creek at Boolataroo

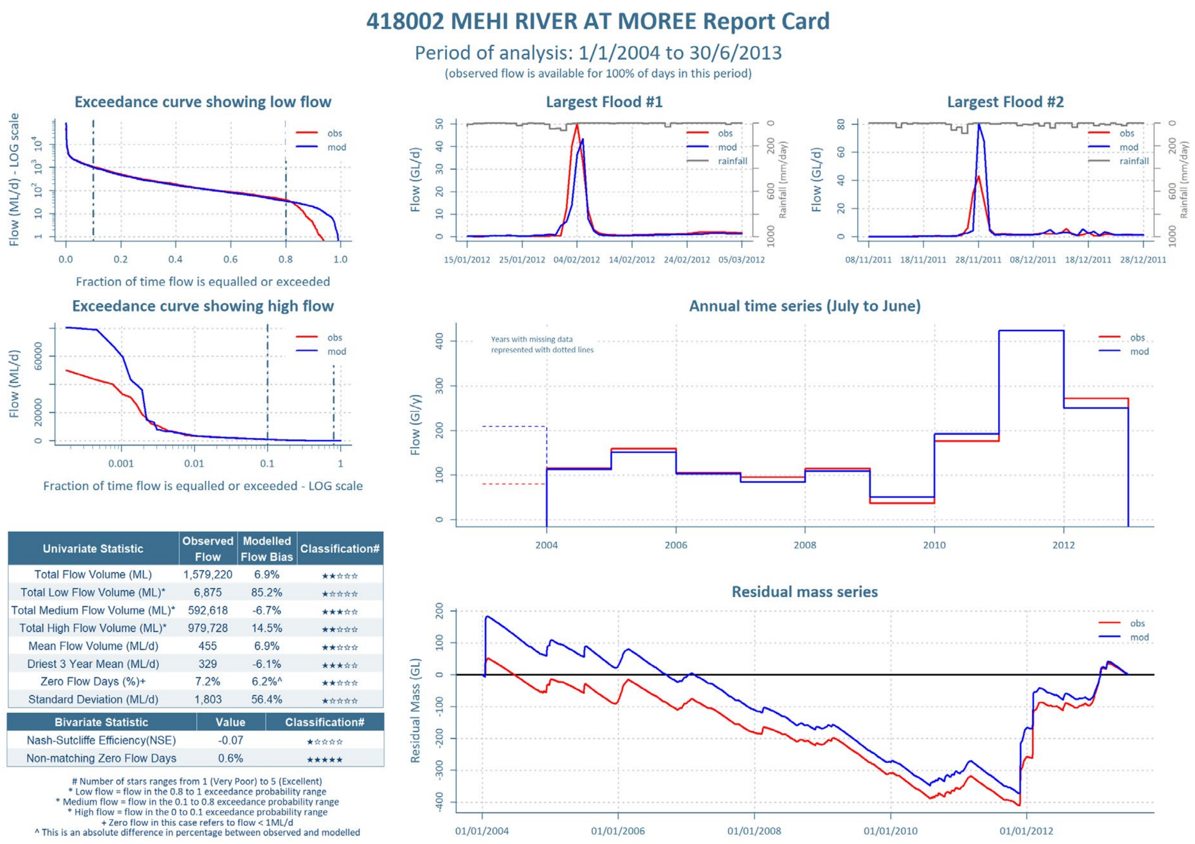


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	4,775,346	6.0%	★★☆☆☆
Total Low Flow Volume (ML)*	52,337	18.1%	★★☆☆☆
Total Medium Flow Volume (ML)*	1,536,908	4.3%	★★★★☆
Total High Flow Volume (ML)*	3,186,101	6.7%	★★★☆☆
Mean Flow Volume (ML/d)	1,377	6.0%	★★☆☆☆
Driest 3 Year Mean (ML/d)	766	-0.6%	★★★★★
Zero Flow Days (%)+	0.0%	0.0%^	★★★★★
Standard Deviation (ML/d)	6,354	10.0%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.91	★★★★★
Non-matching Zero Flow Days	0.0%	★★★★★

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.8 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.8 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
\+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 57 Flow calibration graphs for gauging station 418001



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,579,220	6.9%	★★☆☆☆
Total Low Flow Volume (ML)*	6,875	85.2%	★☆☆☆☆
Total Medium Flow Volume (ML)*	592,618	-6.7%	★★★☆☆
Total High Flow Volume (ML)*	979,728	14.5%	★★☆☆☆
Mean Flow Volume (ML/d)	455	6.9%	★★☆☆☆
Driest 3 Year Mean (ML/d)	329	-6.1%	★★★☆☆
Zero Flow Days (%)+	7.2%	6.2%^	★★☆☆☆
Standard Deviation (ML/d)	1,803	56.4%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	-0.07	★☆☆☆☆
Non-matching Zero Flow Days	0.6%	★★★★★

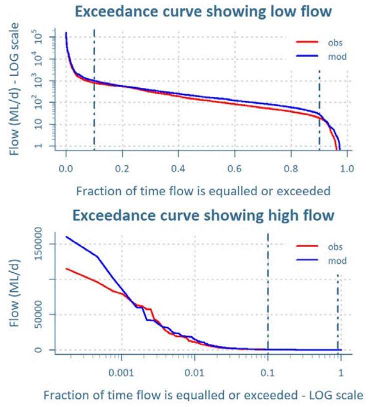
\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.8 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.8 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
\+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

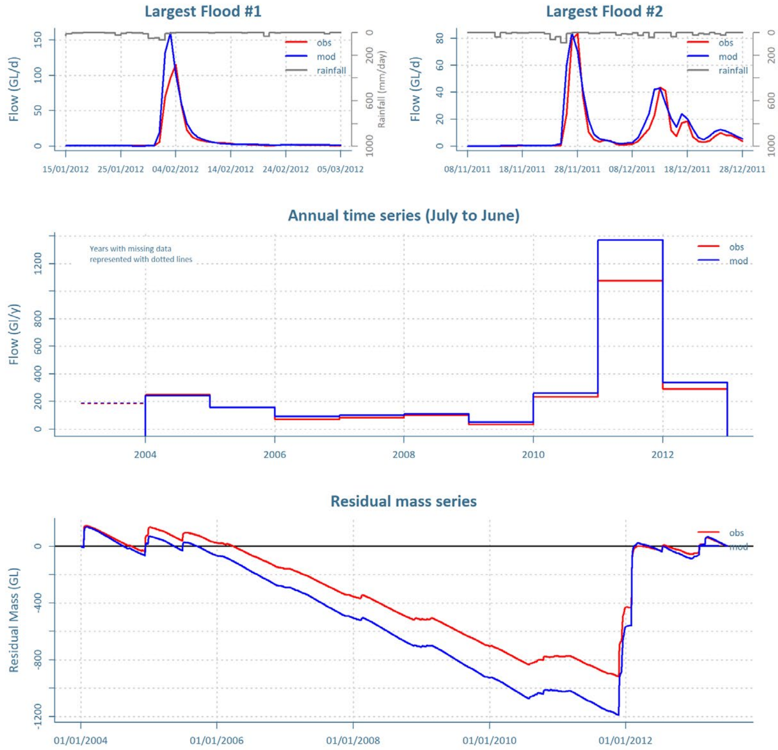
Figure 58 Flow calibration graphs for gauging station 418002

418004 GWYDIR RIVER AT YARRAMAN BRIDGE Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	2,474,126	17.6%	★☆☆☆☆
Total Low Flow Volume (ML)*	2,080	32.1%	★☆☆☆☆
Total Medium Flow Volume (ML)*	594,413	21.6%	★★☆☆☆
Total High Flow Volume (ML)*	1,877,633	16.3%	★★☆☆☆
Mean Flow Volume (ML/d)	713	17.6%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	285	11.5%	★★☆☆☆
Zero Flow Days (%)+	4.0%	1.2%^	★★★☆☆
Standard Deviation (ML/d)	4,494	16.5%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.79	★★★★☆
Non-matching Zero Flow Days	3.2%	★★★★★

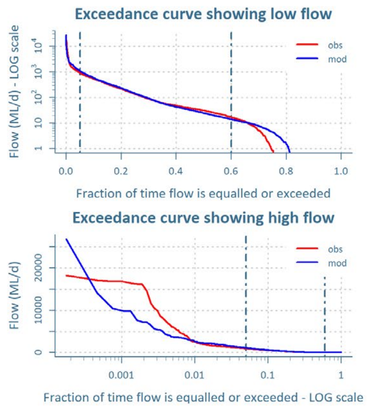
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.9 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.9 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

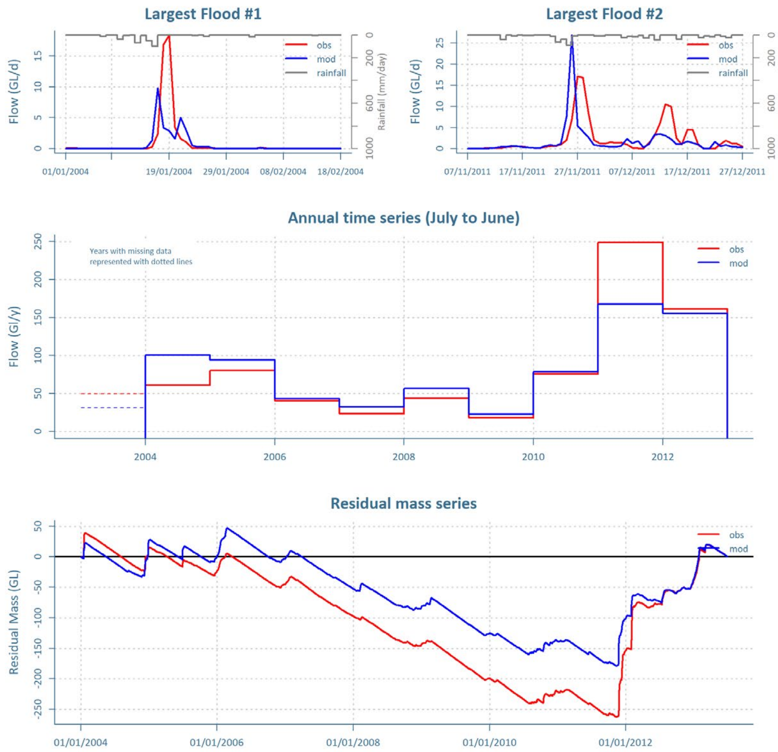
Figure 59 Flow calibration graphs for gauging station 418004

418011 CAROLE CREEK AT DOWNSTREAM REGULATOR(BELLS CROSSING) Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	800,472	-2.4%	★★★☆☆
Total Low Flow Volume (ML)*	4,365	21.6%	★★☆☆☆
Total Medium Flow Volume (ML)*	330,179	7.4%	★★★☆☆
Total High Flow Volume (ML)*	465,928	-9.5%	★★★☆☆
Mean Flow Volume (ML/d)	231	-2.4%	★★★☆☆
Driest 3 Year Mean (ML/d)	130	18.2%	★★☆☆☆
Zero Flow Days (%)+	25.5%	6.3%^	★★☆☆☆
Standard Deviation (ML/d)	992	-20.0%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.17	★☆☆☆☆
Non-matching Zero Flow Days	18.5%	★★★☆☆

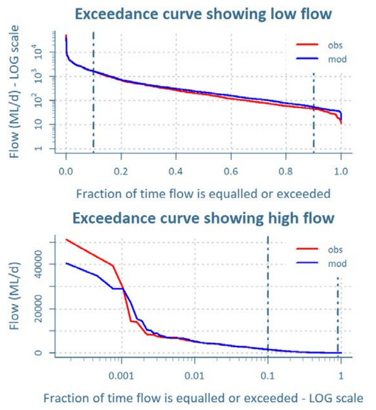
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

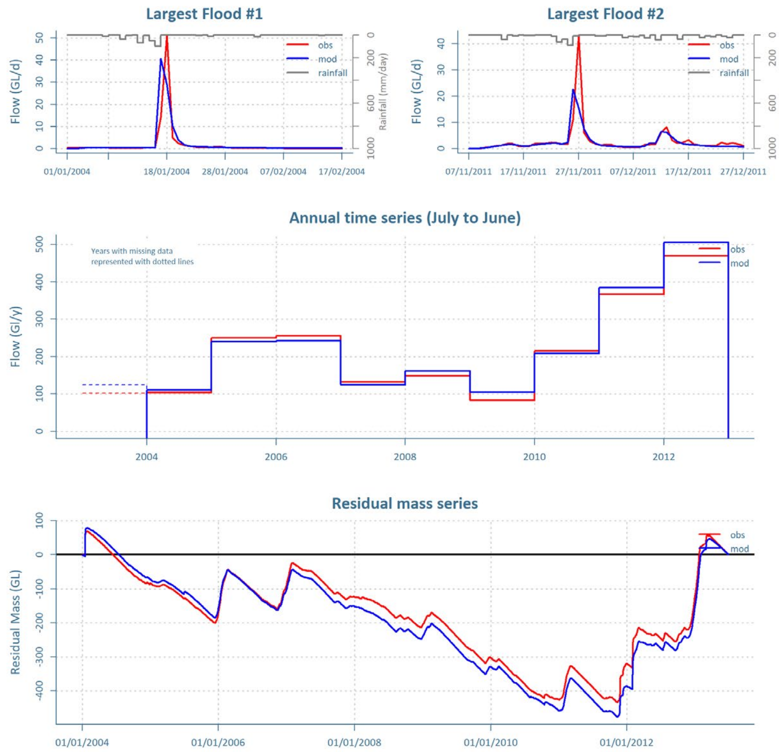
Figure 60 Flow calibration graphs for gauging station 418011

418012 GWYDIR RIVER AT PINEGROVE Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	2,126,032	3.8%	★★★☆☆
Total Low Flow Volume (ML)*	11,323	31.1%	★☆☆☆☆
Total Medium Flow Volume (ML)*	877,972	10.4%	★★☆☆☆
Total High Flow Volume (ML)*	1,236,738	-1.2%	★★★★☆
Mean Flow Volume (ML/d)	613	3.8%	★★★☆☆
Driest 3 Year Mean (ML/d)	581	-4.8%	★★★★☆
Zero Flow Days (%)+	0.0%	0.0%^	★★★★★
Standard Deviation (ML/d)	1,741	-9.1%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.76	★★★★☆
Non-matching Zero Flow Days	0.0%	★★★★★

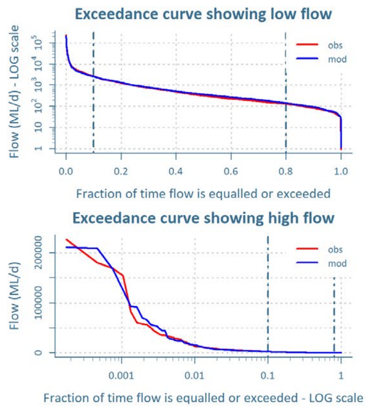
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.9 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.9 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

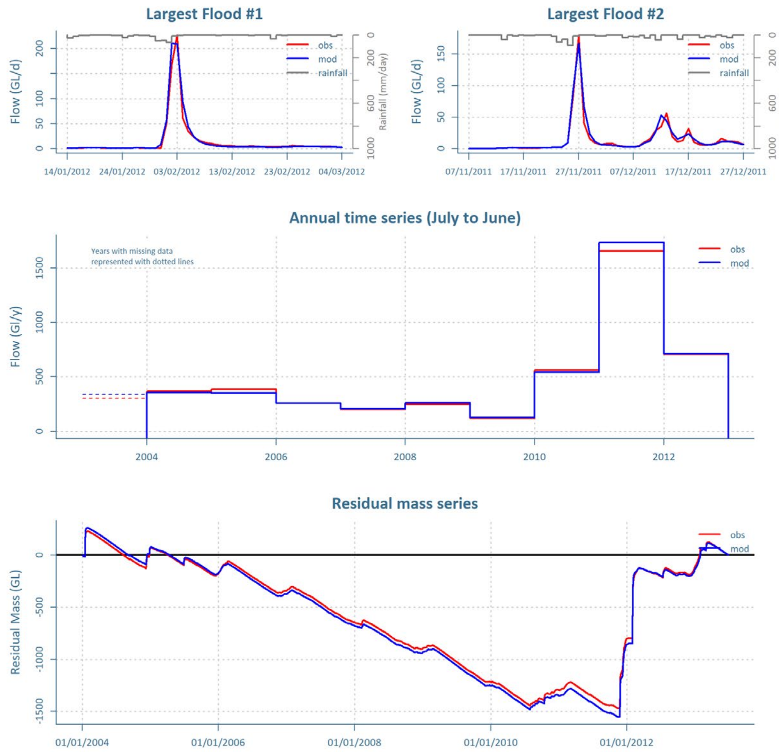
Figure 61 Flow calibration graphs for gauging station 418012

418013 GWYDIR RIVER AT GRAVESEND ROAD BRIDGE Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)



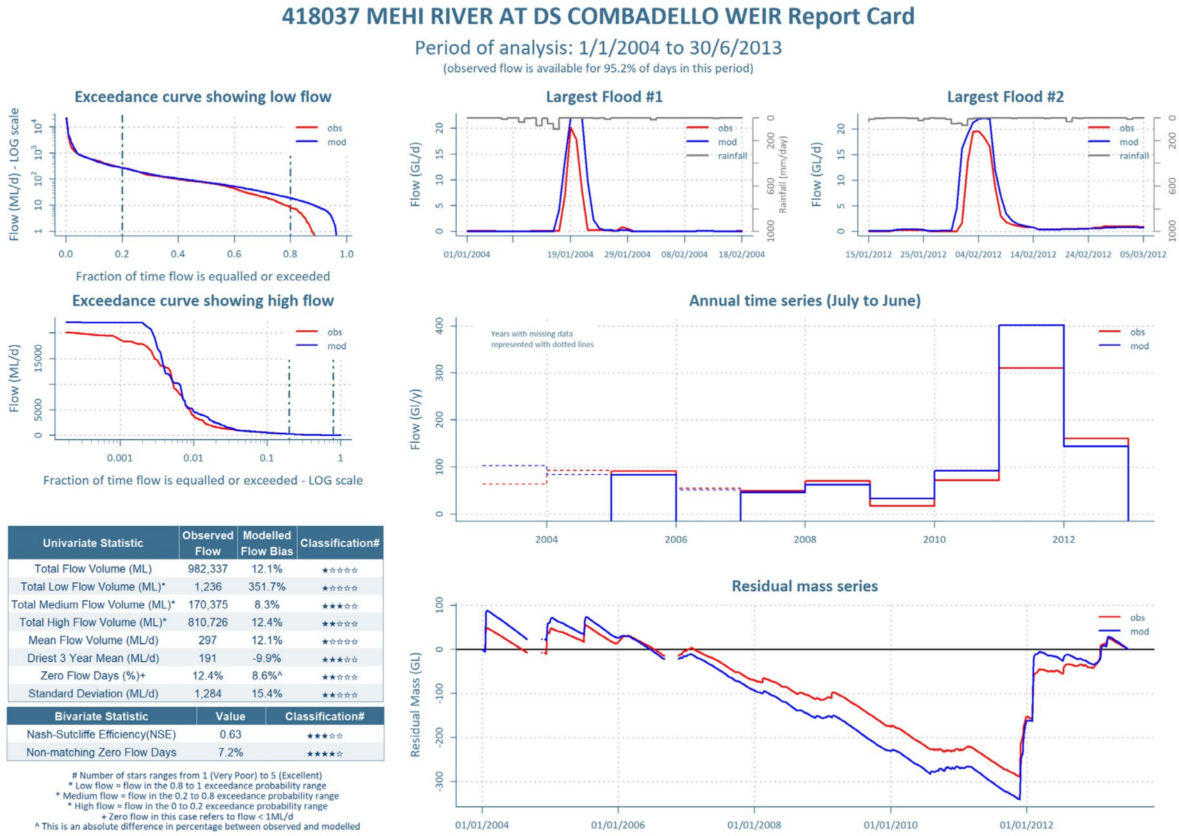


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	4,814,071	1.6%	★★★☆☆
Total Low Flow Volume (ML)*	57,254	9.3%	★★★☆☆
Total Medium Flow Volume (ML)*	1,502,492	6.0%	★★★☆☆
Total High Flow Volume (ML)*	3,254,325	-0.6%	★★★★★
Mean Flow Volume (ML/d)	1,388	1.6%	★★★☆☆
Driest 3 Year Mean (ML/d)	770	-3.1%	★★★★☆
Zero Flow Days (%)+	0.0%	0.1%^	★★★★★
Standard Deviation (ML/d)	7,190	2.2%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.95	★★★★★
Non-matching Zero Flow Days	0.0%	★★★★★

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.8 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.8 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 62 Flow calibration graphs for gauging station 418013

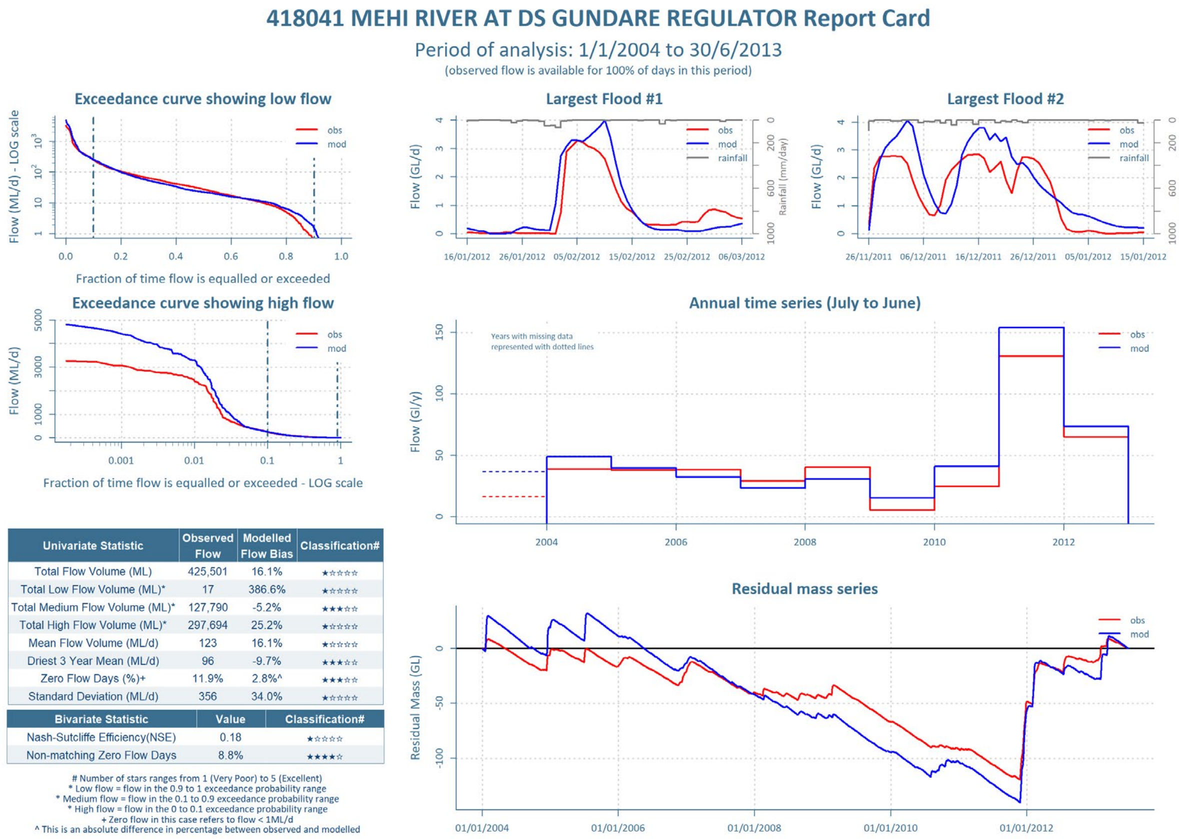


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	982,337	12.1%	★☆☆☆☆
Total Low Flow Volume (ML)*	1,236	351.7%	★☆☆☆☆
Total Medium Flow Volume (ML)*	170,375	8.3%	★★★☆☆
Total High Flow Volume (ML)*	810,726	12.4%	★★☆☆☆
Mean Flow Volume (ML/d)	297	12.1%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	191	-9.9%	★★★☆☆
Zero Flow Days (%)+	12.4%	8.6%^	★★☆☆☆
Standard Deviation (ML/d)	1,284	15.4%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.63	★★★☆☆
Non-matching Zero Flow Days	7.2%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.8 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.8 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 63 Flow calibration graphs for gauging station 418037



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	425,501	16.1%	★☆☆☆☆
Total Low Flow Volume (ML)*	17	386.6%	★☆☆☆☆
Total Medium Flow Volume (ML)*	127,790	-5.2%	★★★☆☆
Total High Flow Volume (ML)*	297,694	25.2%	★☆☆☆☆
Mean Flow Volume (ML/d)	123	16.1%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	96	-9.7%	★★★☆☆
Zero Flow Days (%)+	11.9%	2.8%^	★★★☆☆
Standard Deviation (ML/d)	356	34.0%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.18	★☆☆☆☆
Non-matching Zero Flow Days	8.8%	★★★★☆

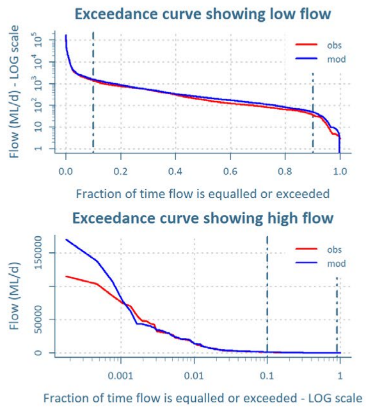
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.9 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.9 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

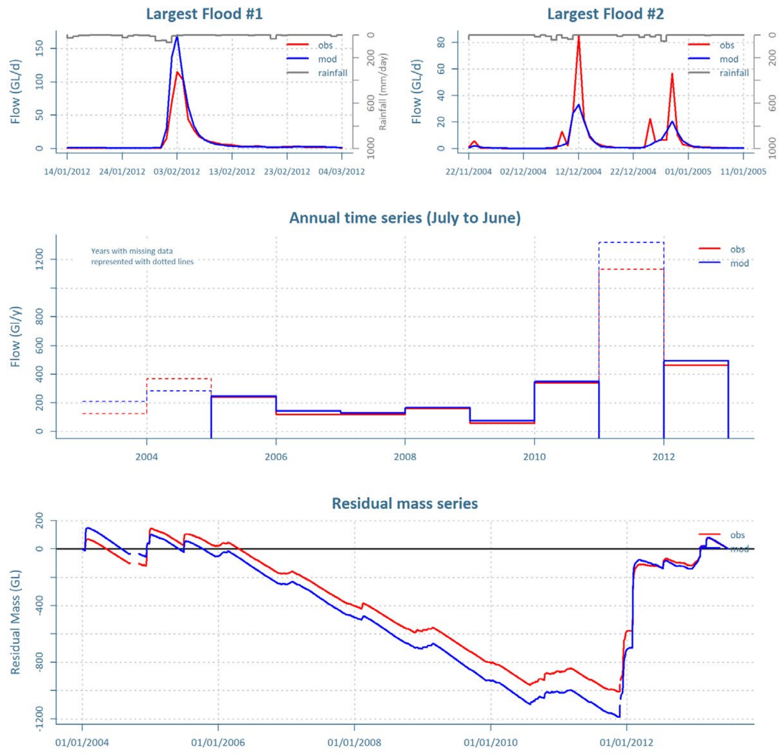
Figure 64 Flow calibration graphs for gauging station 418041

418042 GWYDIR RIVER AT DS TAREELAR0I WEIR Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 98.7% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	3,114,853	9.5%	★★☆☆☆
Total Low Flow Volume (ML)*	5,571	37.8%	★☆☆☆☆
Total Medium Flow Volume (ML)*	900,922	16.0%	★★☆☆☆
Total High Flow Volume (ML)*	2,208,360	6.7%	★★★☆☆
Mean Flow Volume (ML/d)	910	9.5%	★★☆☆☆
Driest 3 Year Mean (ML/d)	434	8.5%	★★★☆☆
Zero Flow Days (%)+	0.0%	0.3%^	★★★★☆
Standard Deviation (ML/d)	4,508	16.8%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.74	★★★☆☆
Non-matching Zero Flow Days	0.0%	★★★★★

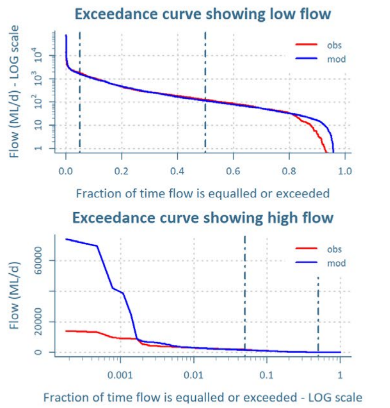
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.9 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.9 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

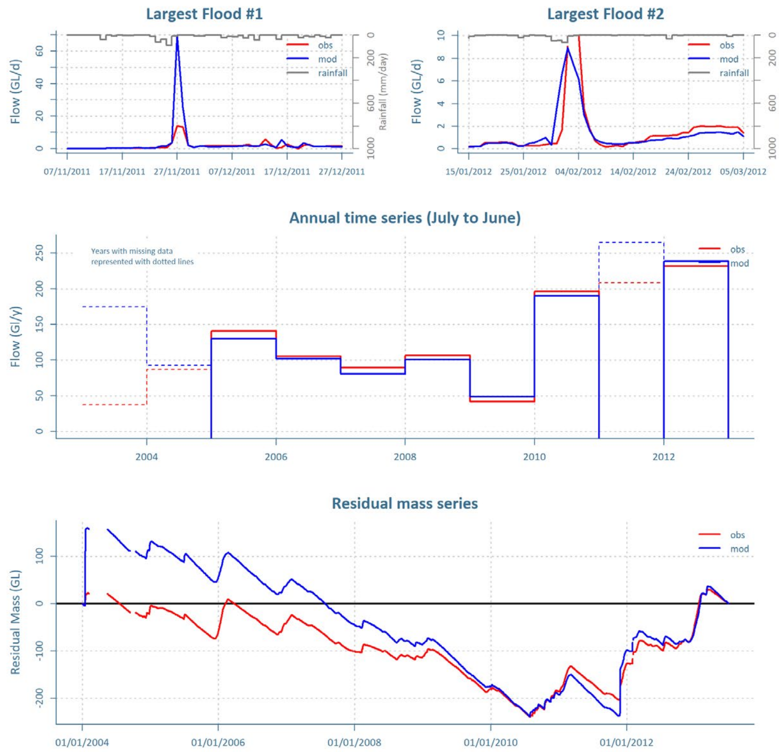
Figure 65 Flow calibration graphs for gauging station 418042

418044 MEHI RIVER DS TAREELAROI REGULATOR Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 96.4% of days in this period)



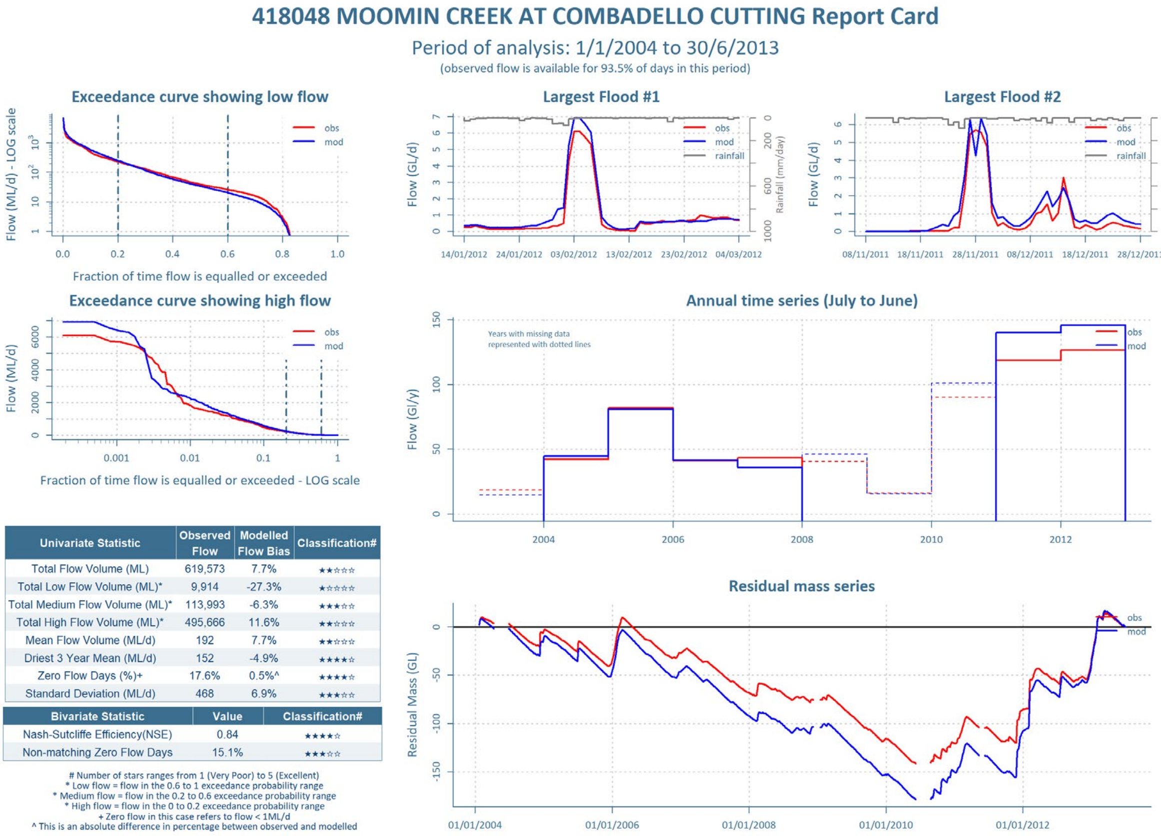


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,243,415	14.4%	★☆☆☆☆
Total Low Flow Volume (ML)*	78,305	-1.6%	★★★★☆
Total Medium Flow Volume (ML)*	702,801	-3.4%	★★★★☆
Total High Flow Volume (ML)*	462,309	44.2%	★☆☆☆☆
Mean Flow Volume (ML/d)	372	14.4%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	306	-6.8%	★★★☆☆
Zero Flow Days (%)+	7.3%	3.0%^	★★★☆☆
Standard Deviation (ML/d)	751	186.8%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	-4.40	★☆☆☆☆
Non-matching Zero Flow Days	0.6%	★★★★★

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.5 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.5 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

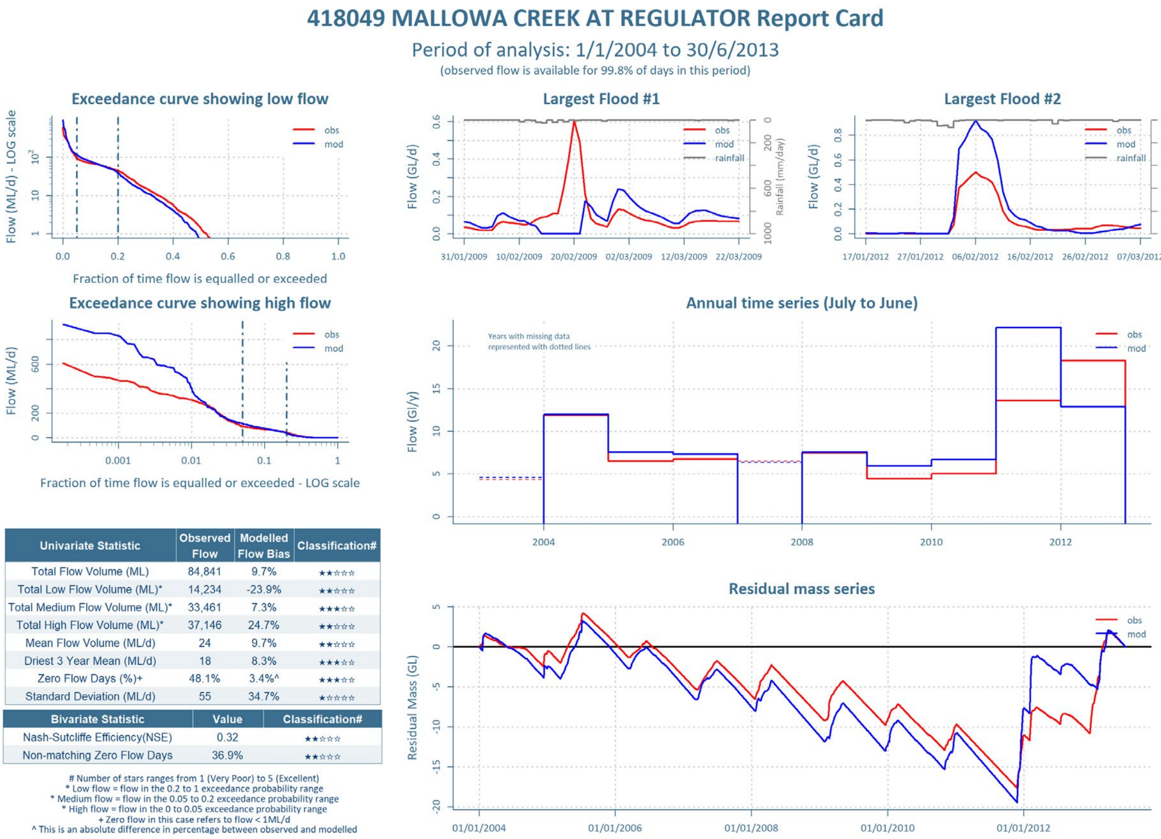
Figure 66 Flow calibration graphs for gauging station 418044



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	619,573	7.7%	★★☆☆☆
Total Low Flow Volume (ML)*	9,914	-27.3%	★☆☆☆☆
Total Medium Flow Volume (ML)*	113,993	-6.3%	★★★☆☆
Total High Flow Volume (ML)*	495,666	11.6%	★★☆☆☆
Mean Flow Volume (ML/d)	192	7.7%	★★☆☆☆
Driest 3 Year Mean (ML/d)	152	-4.9%	★★★★☆
Zero Flow Days (%)+	17.6%	0.5%^	★★★★★
Standard Deviation (ML/d)	468	6.9%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.84	★★★★☆
Non-matching Zero Flow Days	15.1%	★★★☆☆

Figure 67 Flow calibration graphs for gauging station 418048



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	84,841	9.7%	★★☆☆☆
Total Low Flow Volume (ML)*	14,234	-23.9%	★★☆☆☆
Total Medium Flow Volume (ML)*	33,461	7.3%	★★★☆☆
Total High Flow Volume (ML)*	37,146	24.7%	★★☆☆☆
Mean Flow Volume (ML/d)	24	9.7%	★★☆☆☆
Driest 3 Year Mean (ML/d)	18	8.3%	★★★☆☆
Zero Flow Days (%)+	48.1%	3.4%^	★★★☆☆
Standard Deviation (ML/d)	55	34.7%	★☆☆☆☆

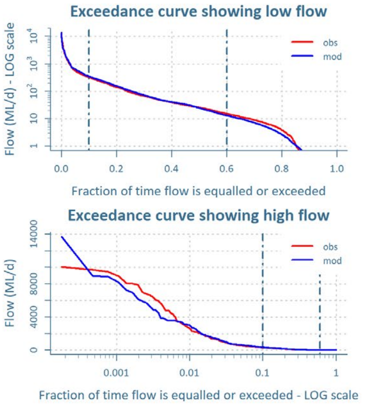
Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.32	★★☆☆☆
Non-matching Zero Flow Days	36.9%	★★☆☆☆

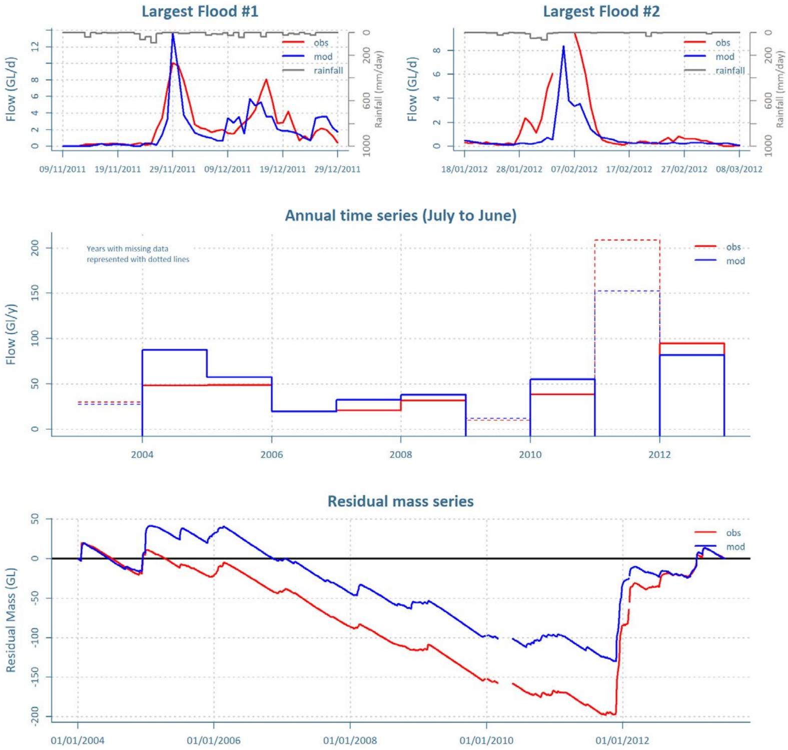
Figure 68 Flow calibration graphs for gauging station 418049

418052 CAROLE CREEK AT NEAR GARAH Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 97.4% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	550,634	2.2%	★★★☆☆
Total Low Flow Volume (ML)*	6,658	-19.0%	★★☆☆☆
Total Medium Flow Volume (ML)*	141,388	7.2%	★★★☆☆
Total High Flow Volume (ML)*	402,588	0.8%	★★★★★
Mean Flow Volume (ML/d)	163	2.2%	★★★☆☆
Driest 3 Year Mean (ML/d)	81	22.0%	★★☆☆☆
Zero Flow Days (%)+	14.6%	0.1%^	★★★★☆
Standard Deviation (ML/d)	620	-4.8%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.53	★★★☆☆
Non-matching Zero Flow Days	12.2%	★★★☆☆

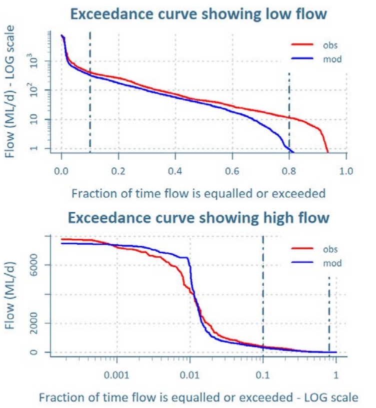
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

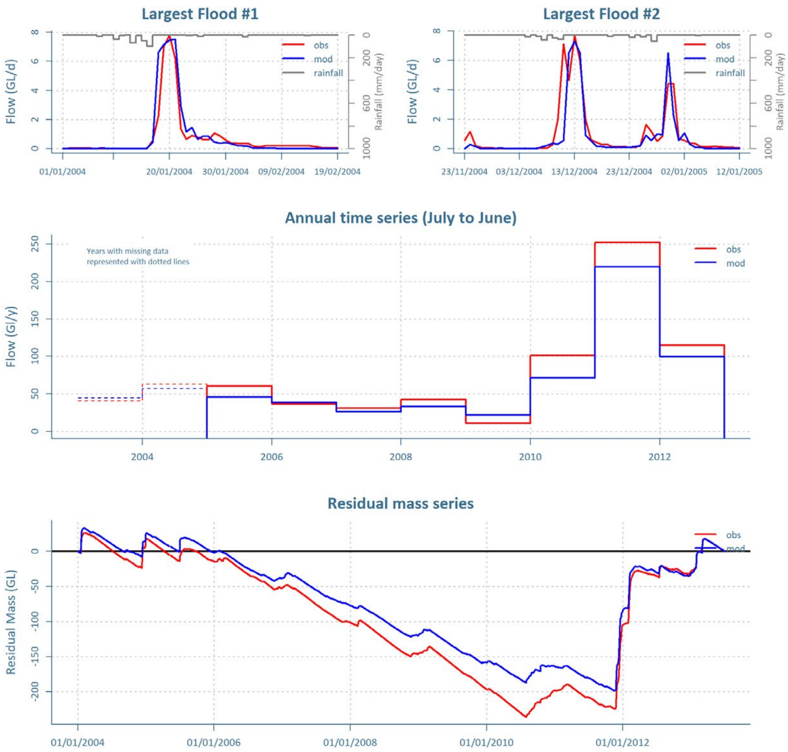
Figure 69 Flow calibration graphs for gauging station 418052

418053 GWYDIR RIVER AT BRAGEEN CROSSING Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 99.8% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	753,288	-12.7%	★☆☆☆☆
Total Low Flow Volume (ML)*	3,248	-96.7%	★☆☆☆☆
Total Medium Flow Volume (ML)*	256,075	-26.8%	★☆☆☆☆
Total High Flow Volume (ML)*	493,964	-4.9%	★★★★☆
Mean Flow Volume (ML/d)	218	-12.7%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	117	-13.7%	★★☆☆☆
Zero Flow Days (%)+	6.8%	13.5%^	★☆☆☆☆
Standard Deviation (ML/d)	684	7.5%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.79	★★★★☆
Non-matching Zero Flow Days	13.1%	★★★☆☆

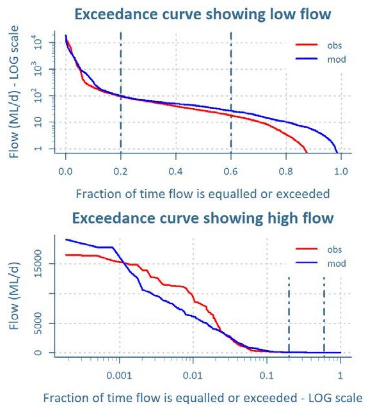
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.8 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.8 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

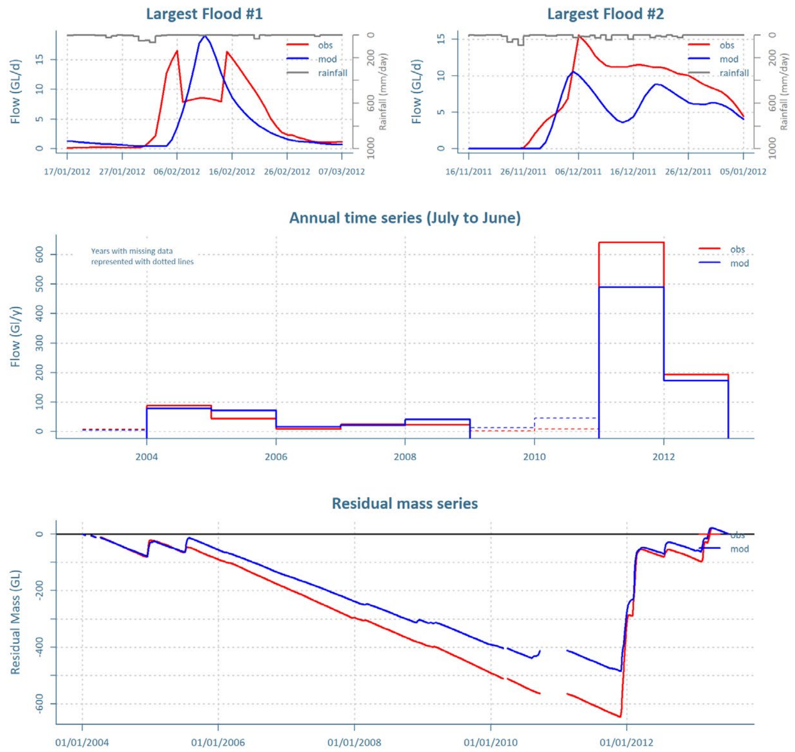
Figure 70 Flow calibration graphs for gauging station 418053

418055 MEHI RIVER AT NEAR COLLARENEBRI Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 93.8% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,035,859	-8.7%	★★☆☆☆
Total Low Flow Volume (ML)*	7,342	103.4%	★☆☆☆☆
Total Medium Flow Volume (ML)*	59,126	17.1%	★★☆☆☆
Total High Flow Volume (ML)*	969,392	-11.1%	★★☆☆☆
Mean Flow Volume (ML/d)	318	-8.7%	★★☆☆☆
Driest 3 Year Mean (ML/d)	68	43.2%	★☆☆☆☆
Zero Flow Days (%)+	13.4%	11.3%^	★☆☆☆☆
Standard Deviation (ML/d)	1,476	-19.9%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.66	★★★☆☆
Non-matching Zero Flow Days	10.1%	★★★☆☆

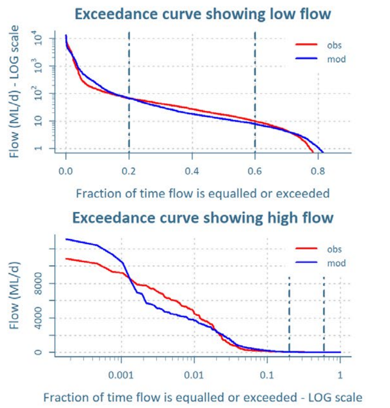
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

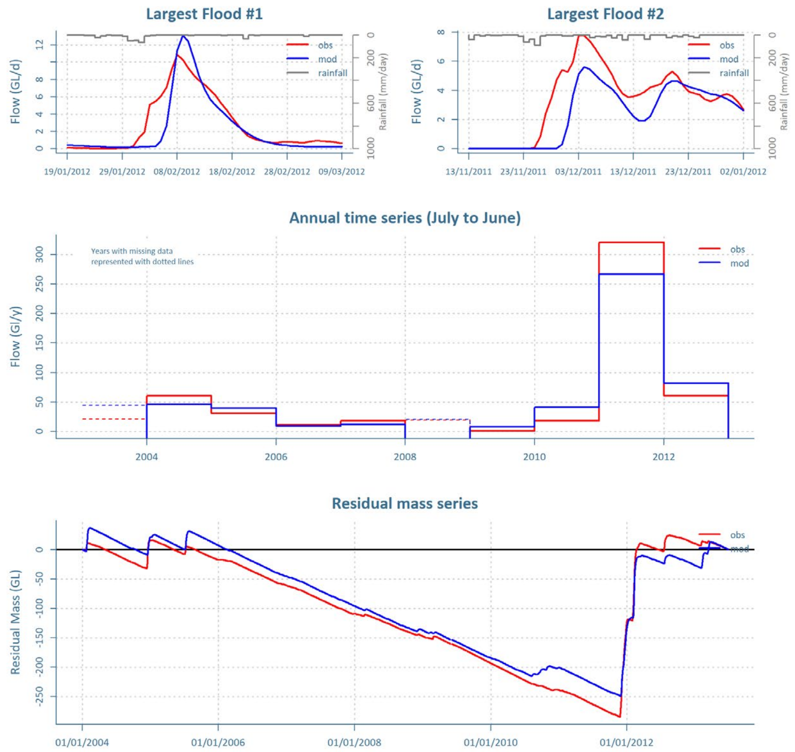
Figure 71 Flow calibration graphs for gauging station 418055

418058 MEHI RIVER AT BRONTE Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 99.8% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	559,633	1.3%	★★★☆☆
Total Low Flow Volume (ML)*	3,186	-3.9%	★★★★☆
Total Medium Flow Volume (ML)*	42,805	-22.7%	★★☆☆☆
Total High Flow Volume (ML)*	513,642	3.3%	★★★★☆
Mean Flow Volume (ML/d)	162	1.3%	★★★☆☆
Driest 3 Year Mean (ML/d)	54	1.9%	★★★★☆
Zero Flow Days (%)+	22.6%	2.8%^	★★★☆☆
Standard Deviation (ML/d)	771	-8.0%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.66	★★★☆☆
Non-matching Zero Flow Days	25.5%	★★☆☆☆

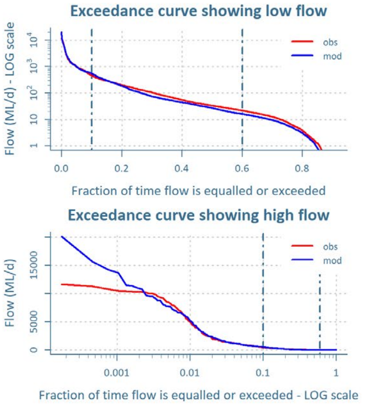
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

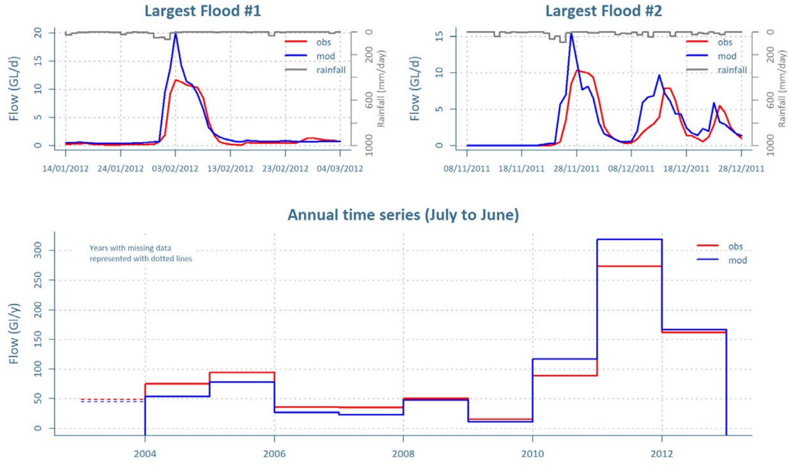
Figure 72 Flow calibration graphs for gauging station 418058

418060 MOOMIN CREEK AT GLENDELLO Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	878,130	1.0%	★★★☆☆
Total Low Flow Volume (ML)*	9,037	-24.5%	★★☆☆☆
Total Medium Flow Volume (ML)*	203,959	-6.9%	★★★☆☆
Total High Flow Volume (ML)*	665,135	3.8%	★★★★☆
Mean Flow Volume (ML/d)	253	1.0%	★★★☆☆
Driest 3 Year Mean (ML/d)	150	-22.9%	★★☆☆☆
Zero Flow Days (%)+	14.4%	1.2%^	★★★☆☆
Standard Deviation (ML/d)	936	8.0%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.62	★★★☆☆
Non-matching Zero Flow Days	11.7%	★★★☆☆

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

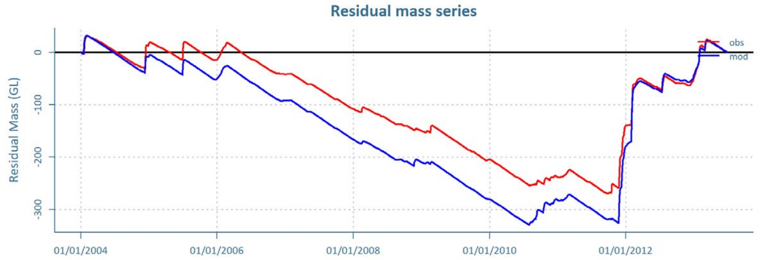
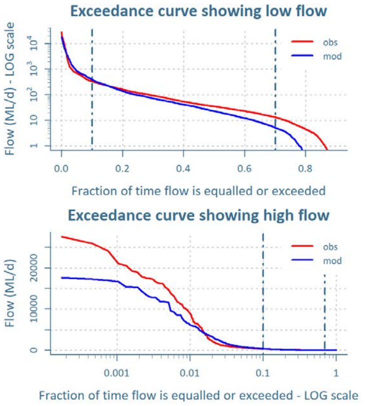


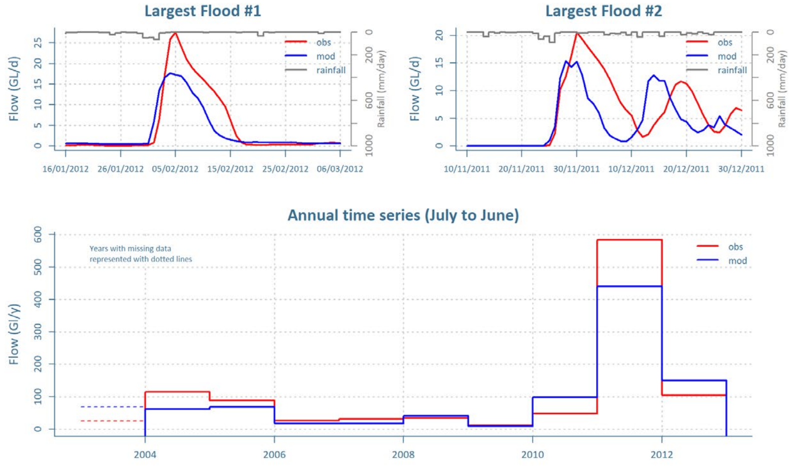
Figure 73 Flow calibration graphs for gauging station 418060

418061 MOOMIN CREEK AT ALMA BRIDGE (DERRA ROAD) Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,067,097	-9.3%	★★☆☆☆
Total Low Flow Volume (ML)*	3,585	-74.3%	★☆☆☆☆
Total Medium Flow Volume (ML)*	177,743	-13.2%	★★☆☆☆
Total High Flow Volume (ML)*	885,769	-8.3%	★★★☆☆
Mean Flow Volume (ML/d)	308	-9.3%	★★☆☆☆
Driest 3 Year Mean (ML/d)	133	-29.7%	★☆☆☆☆
Zero Flow Days (%)+	13.7%	8.3%^	★★☆☆☆
Standard Deviation (ML/d)	1,656	-23.5%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.59	★★★☆☆
Non-matching Zero Flow Days	14.3%	★★★☆☆

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.7 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.7 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

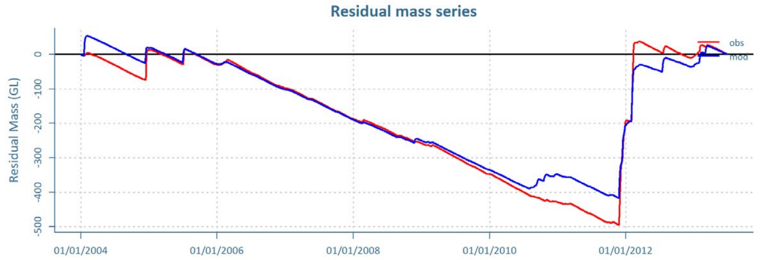
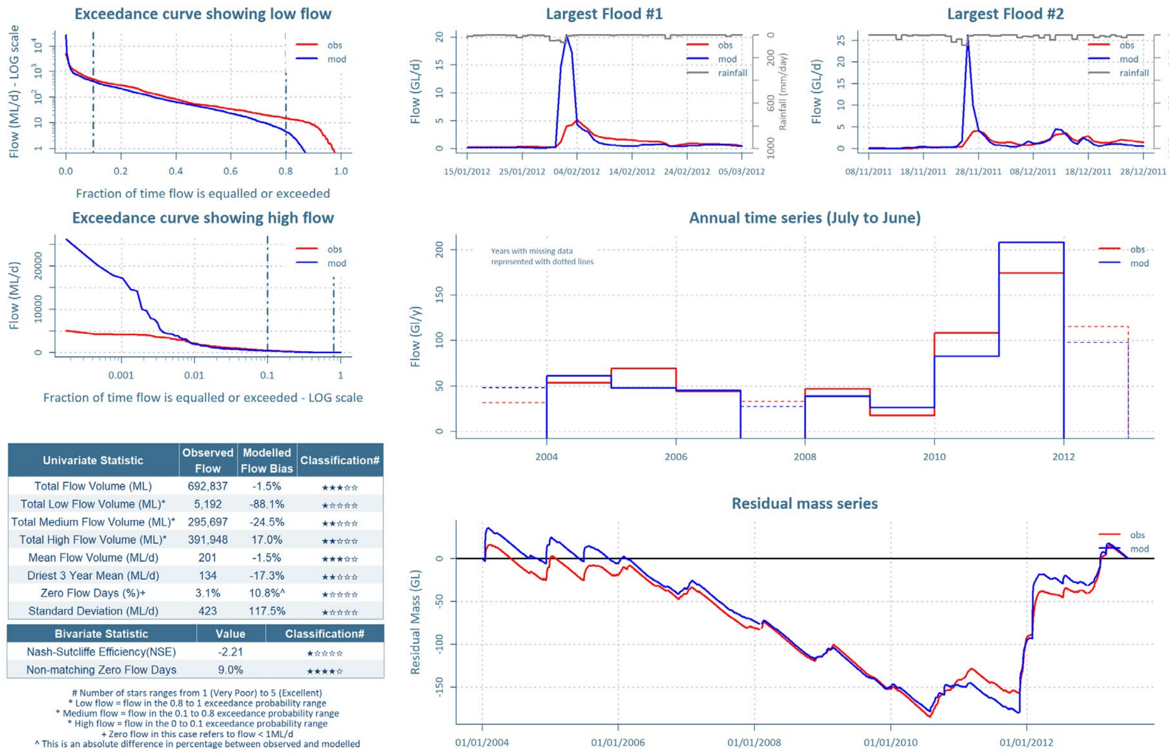


Figure 74 Flow calibration graphs for gauging station 418061

418063 GWYDIR RIVER (SOUTH ARM) AT DS TYREEL OFFTAKE REGULATO Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 99.4% of days in this period)



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	692,837	-1.5%	★★★☆☆
Total Low Flow Volume (ML)*	5,192	-88.1%	★☆☆☆☆
Total Medium Flow Volume (ML)*	295,697	-24.5%	★★☆☆☆
Total High Flow Volume (ML)*	391,948	17.0%	★★☆☆☆
Mean Flow Volume (ML/d)	201	-1.5%	★★★☆☆
Driest 3 Year Mean (ML/d)	134	-17.3%	★★☆☆☆
Zero Flow Days (%)+	3.1%	10.8%^	★☆☆☆☆
Standard Deviation (ML/d)	423	117.5%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	-2.21	★☆☆☆☆
Non-matching Zero Flow Days	9.0%	★★★★☆

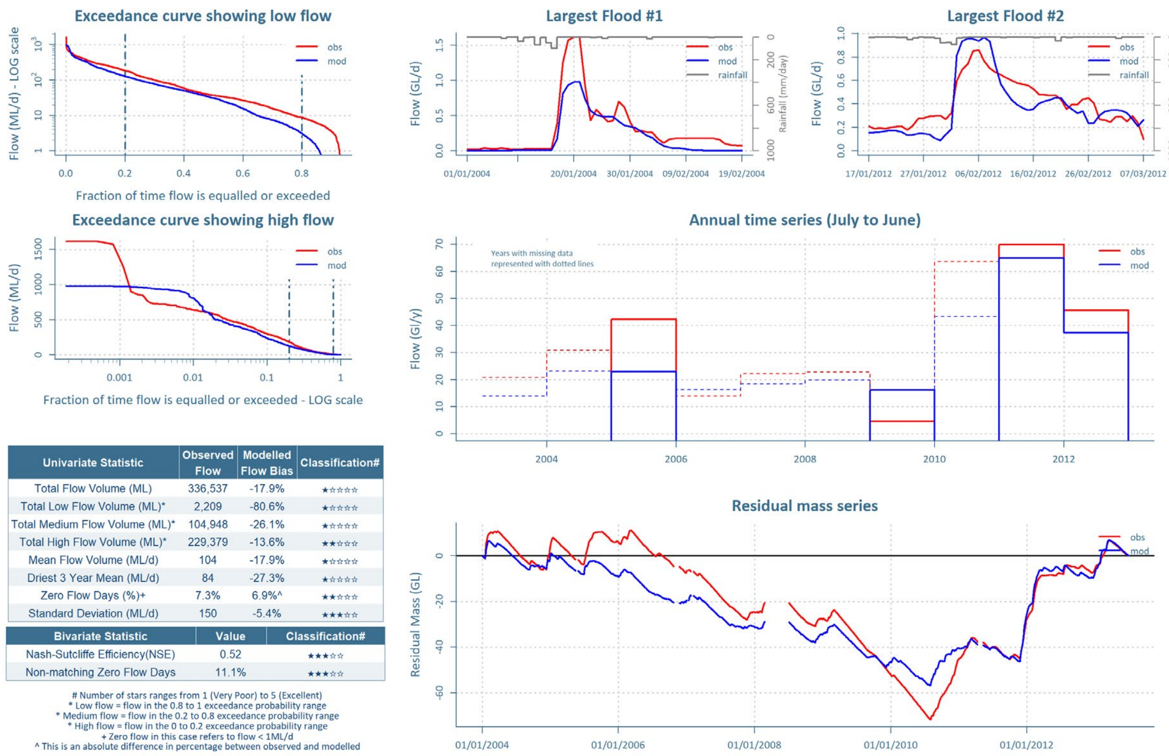
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.8 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.8 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 75 Flow calibration graphs for gauging station 418063

418066 GWYDIR RIVER AT MILLEWA Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 93.7% of days in this period)



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	336,537	-17.9%	★☆☆☆☆
Total Low Flow Volume (ML)*	2,209	-80.6%	★☆☆☆☆
Total Medium Flow Volume (ML)*	104,948	-26.1%	★☆☆☆☆
Total High Flow Volume (ML)*	229,379	-13.6%	★★☆☆☆
Mean Flow Volume (ML/d)	104	-17.9%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	84	-27.3%	★☆☆☆☆
Zero Flow Days (%)+	7.3%	6.9%^	★★☆☆☆
Standard Deviation (ML/d)	150	-5.4%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.52	★★★☆☆
Non-matching Zero Flow Days	11.1%	★★★☆☆

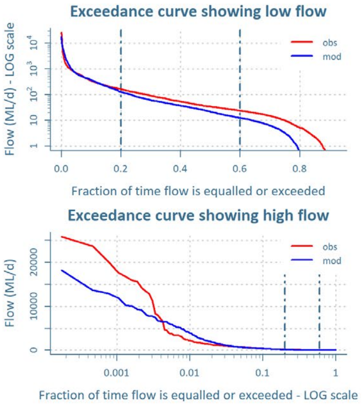
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.8 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.8 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

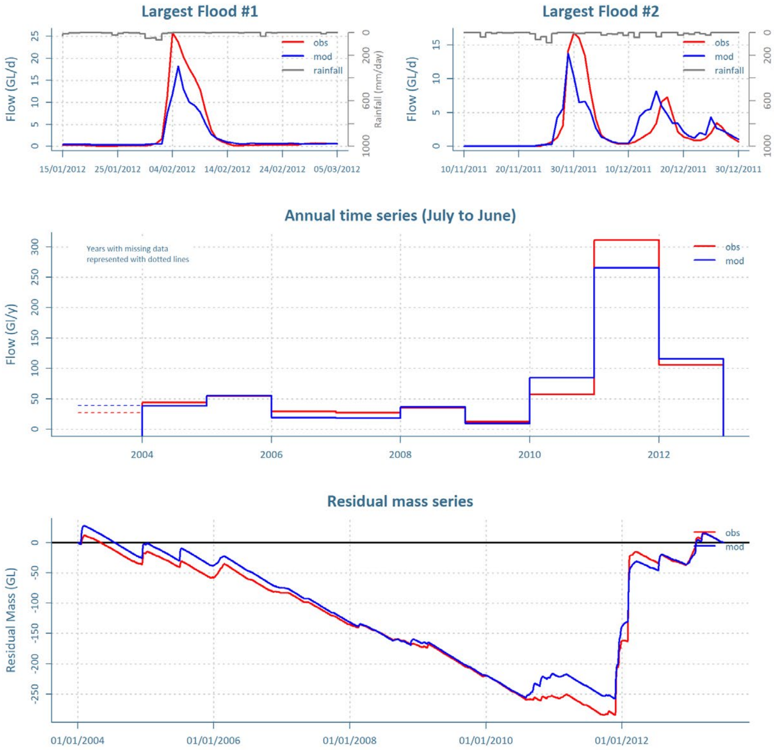
Figure 76 Flow calibration graphs for gauging station 418066

418067 MOOMIN CREEK AT CLARENDON BRIDGE (HEATHFIELD) Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	701,567	-3.0%	★★★☆☆
Total Low Flow Volume (ML)*	11,053	-59.9%	★☆☆☆☆
Total Medium Flow Volume (ML)*	91,704	-30.9%	★☆☆☆☆
Total High Flow Volume (ML)*	598,809	2.3%	★★★★☆
Mean Flow Volume (ML/d)	202	-3.0%	★★★☆☆
Driest 3 Year Mean (ML/d)	101	-16.4%	★★☆☆☆
Zero Flow Days (%)+	12.3%	8.5%^	★★☆☆☆
Standard Deviation (ML/d)	1,069	-21.7%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.73	★★★☆☆
Non-matching Zero Flow Days	15.6%	★★★☆☆

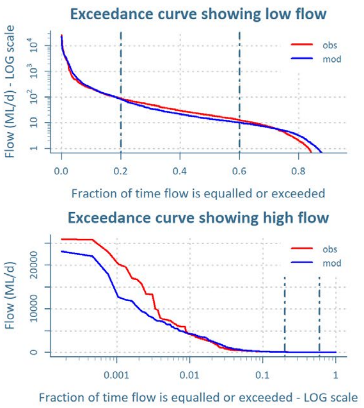
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

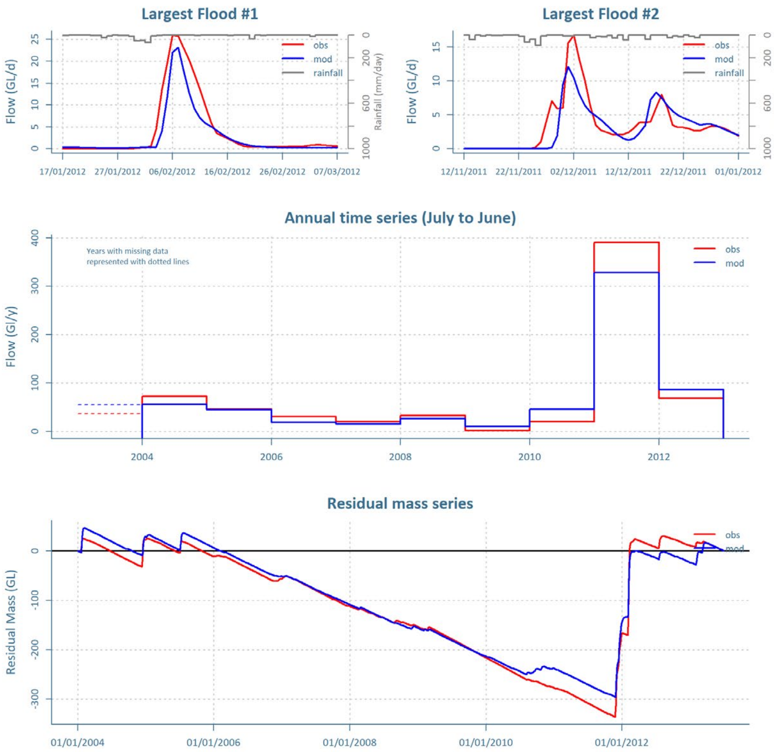
Figure 77 Flow calibration graphs for gauging station 418067

418068 MEHI RIVER AT US BALLIN BOORA CREEK Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	718,151	-4.7%	★★★☆☆
Total Low Flow Volume (ML)*	5,204	-0.2%	★★★★★
Total Medium Flow Volume (ML)*	50,867	-23.0%	★★☆☆☆
Total High Flow Volume (ML)*	662,080	-3.3%	★★★★☆
Mean Flow Volume (ML/d)	207	-4.7%	★★★☆☆
Driest 3 Year Mean (ML/d)	88	-18.4%	★★☆☆☆
Zero Flow Days (%)+	16.6%	3.1%^	★★★☆☆
Standard Deviation (ML/d)	1,251	-19.6%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.79	★★★★☆
Non-matching Zero Flow Days	17.4%	★★★☆☆

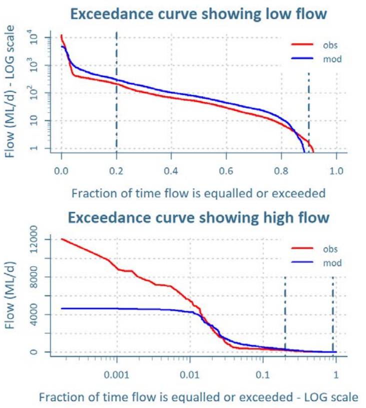
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

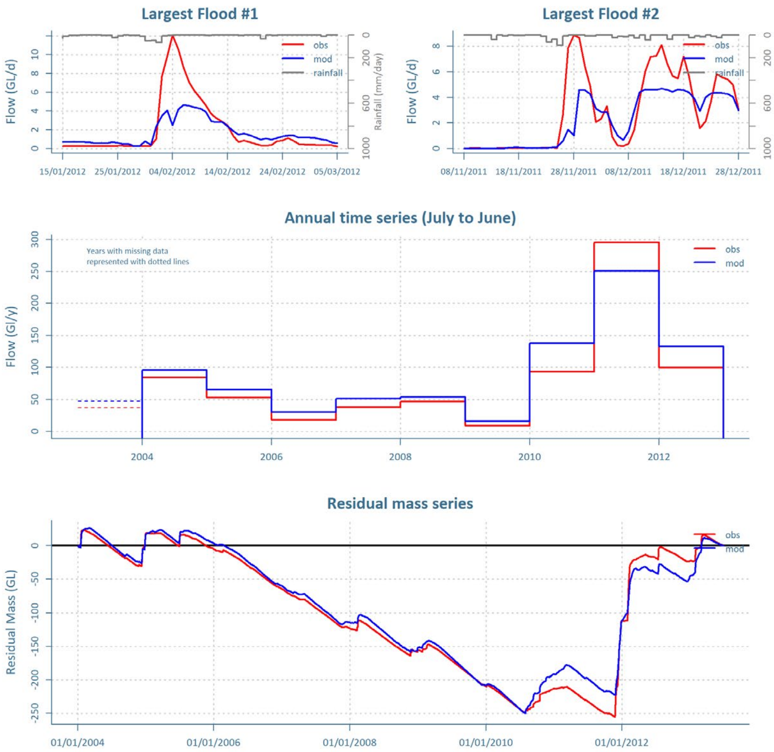
Figure 78 Flow calibration graphs for gauging station 418068

418074 GINGHAM CHANNEL AT TERALBA Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 100% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	772,581	13.8%	★☆☆☆☆
Total Low Flow Volume (ML)*	78	-100.0%	★☆☆☆☆
Total Medium Flow Volume (ML)*	125,907	54.6%	★☆☆☆☆
Total High Flow Volume (ML)*	646,596	5.9%	★★★☆☆
Mean Flow Volume (ML/d)	223	13.8%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	99	34.6%	★☆☆☆☆
Zero Flow Days (%)+	8.8%	3.2%^	★★★☆☆
Standard Deviation (ML/d)	845	-26.7%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.74	★★★☆☆
Non-matching Zero Flow Days	6.7%	★★★★☆

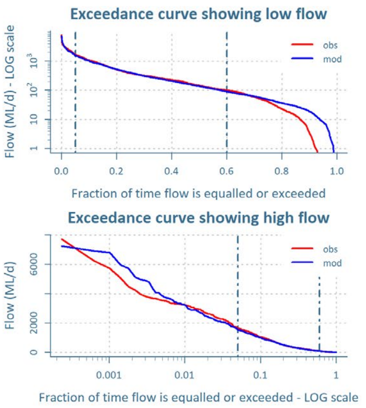
\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.9 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.9 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

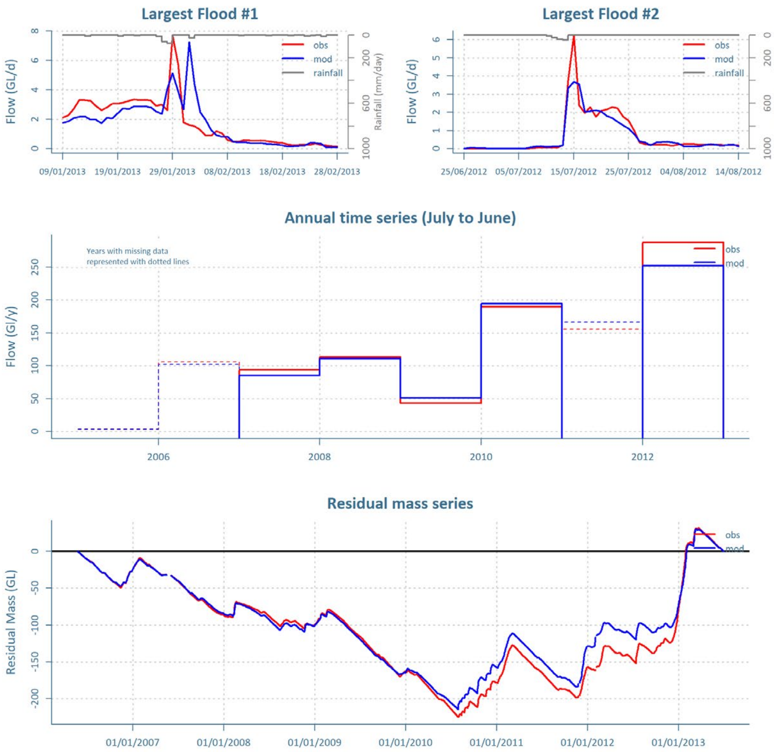
Figure 79 Flow calibration graphs for gauging station 418074

418087 MEHI RIVER AT CHINOOK Report Card

Period of analysis: 25/5/2006 to 30/6/2013

(observed flow is available for 99.1% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	992,014	-2.7%	★★★☆☆
Total Low Flow Volume (ML)*	34,169	18.5%	★★☆☆☆
Total Medium Flow Volume (ML)*	616,685	-4.5%	★★★★☆
Total High Flow Volume (ML)*	341,159	-1.7%	★★★★☆
Mean Flow Volume (ML/d)	386	-2.7%	★★★☆☆
Driest 3 Year Mean (ML/d)	228	-1.4%	★★★★☆
Zero Flow Days (%)+	7.7%	6.4%^	★★☆☆☆
Standard Deviation (ML/d)	653	-0.3%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.69	★★★☆☆
Non-matching Zero Flow Days	4.4%	★★★★★

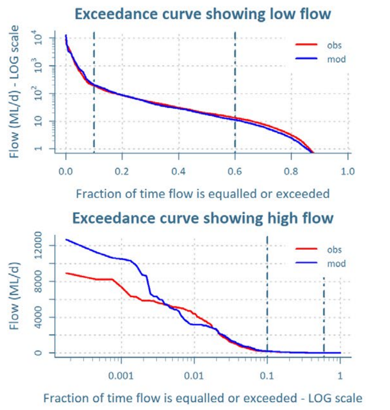
\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

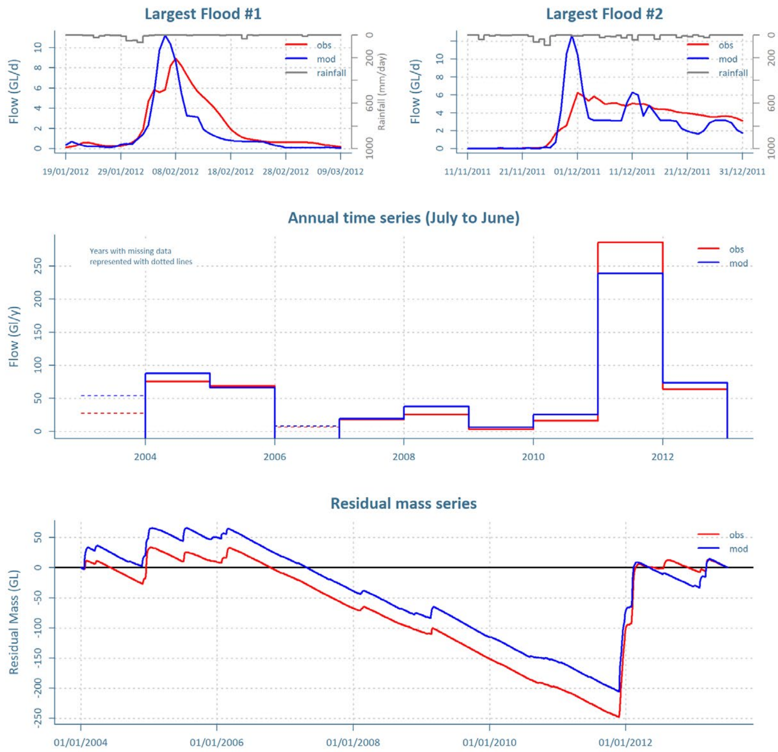
Figure 80 Flow calibration graphs for gauging station 418087

416052 GIL GIL CREEK AT GALLOWAY Report Card

Period of analysis: 1/1/2004 to 30/6/2013

(observed flow is available for 99.9% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	589,404	4.4%	★★★☆☆
Total Low Flow Volume (ML)*	5,994	-19.8%	★★☆☆☆
Total Medium Flow Volume (ML)*	93,065	0.7%	★★★★★
Total High Flow Volume (ML)*	490,346	5.4%	★★★☆☆
Mean Flow Volume (ML/d)	170	4.4%	★★★☆☆
Driest 3 Year Mean (ML/d)	85	0.3%	★★★★★
Zero Flow Days (%)+	13.5%	1.0%^	★★★★☆
Standard Deviation (ML/d)	685	8.2%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.47	★★☆☆☆
Non-matching Zero Flow Days	8.8%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 81 Flow calibration graphs for gauging station 416052

Appendix K Glossary

In addition to the information provided in this appendix, the reader is directed to online resources, such as that provided by Water NSW[31].

Table 46 Abbreviations/acronyms

Abbreviation	Description
3T	3 tributaries (rule)
ABARE	Australian Bureau of Agricultural Research
ABS	Australian Bureau of Statistics
ACF	Australian Cotton Foundation
AWD	Available Water Determination
BDL	Baseline Diversion Limit
CAiRO	Computer-Aided River Operations
CEWH	Commonwealth Environmental Water Holder
d/s	downstream
ECA	Environmental Contingency Allowance
ESID	Extraction Site Identification number
ET	Evapotranspiration
FAO	Food and Agriculture Organization (of the United Nations)
FMP	Floodplain Management Plan (and FMP zones)
FPH	Floodplain harvesting
GL	Gigalitre (1,000 megalitres; 1,000,000,000 litres)
HEW	Held Environmental Water
Hydstra	Product brand name
IBQ	Irrigator Behaviour Questionnaire (used interchangeably with 'farm survey')
IGA	Inter-Governmental Agreement
IQQM	Integrated Quantity-Quality Model (the department's in-house river system model)
LANDSAT	A series of Satellites that monitor the Earth's surface
LIDAR	Light Detecting And Ranging (a remote sensing method)
m	metre
ML	Megalitre (one million litres)
MODIS	Moderate Resolution Imaging Spectroradiometer (a remote sensing instrument)

[31] https://www.waternsw.com.au/customer-service/service-and-help/tips/glossary#:~:text=Glossary%20of%20water%20terms%201%20Basic%20landholder%20rights.,7%20Carryover%20Spill%20Reduction.%20...%20More%20items...%20

Abbreviation	Description
NDVI	Normalised Difference Vegetation Index
NRAR	Natural Resources Access Regulator
NSE	Nash-Sutcliffe Efficiency (a goodness-of-fit calibration measure)
OFS	Off-farm storage
PET	Potential evapotranspiration
SBM	Storage bathymetry model
SDL	Sustainable Diversion Limit
SILO	Scientific Information for Land Owners (always called SILO)
TOL	Transmission and Operational Loss
u/s	upstream
WAS	Water Accounting System (database)
WLS	Water Licensing System
WSP	Water Sharing Plan

Table 47 Terms

Term	Description
2008/2009 Scenario	Uses the levels of irrigation infrastructure, water licences, and management rules in the Gwydir regulated river system in place at the start of 2008/09
2020/21 water year	A water year runs from 1 July to 30 June, in this example from 1 July 2020 to 30 June 2021. A slash is used to identify this and to be consistent with Basin legislation. (2020–2021 would refer to the range of years, 2020 and 2021)
Baseline Diversion Limit (BDL) Scenario	Equivalent to the lesser of the Cap and WSP scenarios, also referred to as the Plan Limit Scenario
Cap Scenario	Uses the irrigation infrastructure, water licences, and management rules in place at 30 June 1994, to assess the diversions permissible under the Murray-Darling Basin Ministerial Council's Cap on diversions
Current Conditions Scenario	Uses the best available (more contemporary than 2008) information on current levels of irrigation infrastructure, water licences, and current water management arrangements, in the Gwydir regulated river system
Eligible Development Scenario	Uses the levels of irrigation infrastructure determined to be eligible for floodplain harvesting entitlement, water licences, and management rules in the Gwydir regulated river system as at the start of 2008/09
Gwydir Valley model	Shortened term for the Gwydir Valley regulated river system model
Gwydir WSP	Shortened term for the Water Sharing Plan for the Gwydir Regulated River Water Sources 2020
Plan limit	The authorised long-term average annual extraction limit as defined in the Water Sharing Plan
Plan limit compliance	Compliance with the Plan limit, which is assessed using long-term modelling.
Plan Limit Scenario	See BDL Scenario

Term	Description
Scenario Input Set	Each scenario has its unique set of input parameters. The model provides functionality to store these as a set of parameters. The model can then be run with a unique input set that represents that scenario. Within the modelling platform, sets can be named. These are listed in the companion Scenarios report (DPEDPE Water 2021a)
WSP Scenario	Uses the irrigation infrastructure in place in the 1999/00 water year, and the management arrangements and water licences set out in the water sharing plan
Source	Australian National Hydrological Modelling platform, managed by eWater and adopted by the department as its default modelling platform (to replace IQQM)
the policy	Shortened term for the NSW Floodplain Harvesting Policy

Scenario definitions are taken from Table 4.