Department of Planning and Environment

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Building the river system model for the Namoi regulated river system

Report

November 2022

Acknowledgement of Country

The Department of Planning and Environment acknowledges that it stands on Aboriginal land. We acknowledge the Traditional Custodians of the land and we show our respect for Elders past, present and emerging through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places in which Aboriginal people are included socially, culturally and economically.

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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 Industry, Planning and Environment Water 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 Namoi Valley river system model (referred to as the Namoi Valley 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 14 appendices. Key findings and messages from the model build process are now described in some more detail.

Modelling approach

The Namoi Valley model is designed to support contemporary water management decisions in the Namoi, 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 two overarching objectives, being to: support traditional water policy, planning and compliance uses, such as implementing the Basin Plan and estimating plan limits; and 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 and enable robust estimates of annual water use; and provide a pathway to update and improve accuracy (i.e. be update-able and extensible).

Building the model in the Source modelling platform[1] provides contemporary architecture and functionality for simulation of water availability and management for the coming decades. Undertaking the model build process itself provides an opportunity to use new data and techniques to improve the calibration of model components and to ensure the design criteria have been satisfied. The model was built by connecting Source 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 Namoi, 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).

Closely simulating the water balance at an individual property scale is only possible with fine temporal and spatial data on water movements to and from floodplains and property management practices. 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 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 Namoi has an extensive network of climate and river gauge stations and 26 models (covering every river reach and inflow into 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, gauged flows and advice from river managers. Modelling of the two major **water storages** (Keepit and Split Rock dams) and Mollee Weir 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,

[1] https://ewater.org.au/products/ewater-source/

supplementary access rules, together with the ordering and delivery of water through the system. The water available for **floodplain harvesting** for NSW 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 an important source of water within the regulated Namoi River system, and it has been included in the Namoi Valley model for all scenarios.

Modelling water users

Water users includes 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.

The largest water users are (mainly cotton growing) **irrigation properties** in the floodplain areas between Narrabri and Walgett at the junction with the Barwon River. Those properties assessed as eligible for floodplain harvesting entitlements are represented as individual 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 water user. These included information on-farm infrastructure such as on-farm storages, pumps, areas developed for irrigation, area planning decisions and irrigated crops for the period 2003/04 to 2013/14. These data sets were made available through the Floodplain Harvesting Property farm surveys and from the Natural Resource Access Regulator (NRAR); and ground survey 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 end of the regulated Pian Creek system.

Modelling water management rules

Source's ownership system provides functionality to assign and track the ownership of water throughout the model. The **continuous accounting system** used in the Namoi Valley is modelled to represent operational practice as closely as possible.

While **water trading** is not explicitly 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 harmony operation between Split Rock and Keepit dams, and other regulators (Gunidgera Weir and Mollee Weir) are all 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 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 Namoi 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 the 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 overbank flow events. Simulation of the number of moderate flood events and events above the commence-to-break flows closely match observed.

Farm water balance (i.e. total irrigation water use) was checked at 3 spatial scales. At a 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.

Planted areas did not always agree well with those reported in the farm surveys or via remote sensing, although similar seasonal variability in area planted in response to water availability was observed. Instead, a set of crop areas were calibrated to reproduce the observed metered use in combination with simulated floodplain harvesting access and groundwater use. These calibrated crop areas were used to configure a planting decision in the model. The modelled crop areas matched the calibrated areas well.

Metered diversions from the river agree well with observed data, with small differences (over-estimations) attributable to small 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, management practices, simulated floodplain harvesting or account management transfers, the nuancing of which are not captured in the model.

Summary

This report captures the considerable body of intellectual effort and modelling expertise that sits behind the construction of the Namoi Valley 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 Namoi are general security, followed by supplementary access, then overbank flow harvesting and lastly on-farm rainfall–runoff harvesting.

1. Introduction

The Department of Planning and Environment – Water (the department) has developed a new river system model of the Namoi Valley. The model is a complete rebuild of an earlier departmental model. It has been developed using eWater Source[2] and the redevelopment has enabled improvements due to significant new data sources.

We use river system models for many policy, planning and compliance uses. One key use is that we are using the new model to determine floodplain harvesting entitlements[3] consistent with the *2013 NSW Floodplain Harvesting Policy* (the policy) as revised September 2018.

1.1. Report objectives

Communities in the Namoi 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 sharing plan limits. This report has been written to underpin that confidence.

The Namoi Valley river system model (referred to as the Namoi Valley model) provides support to more than floodplain harvesting. Floodplain harvesting takes place within the context of all other processes operating within the Namoi; 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.

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 Namoi 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).

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.

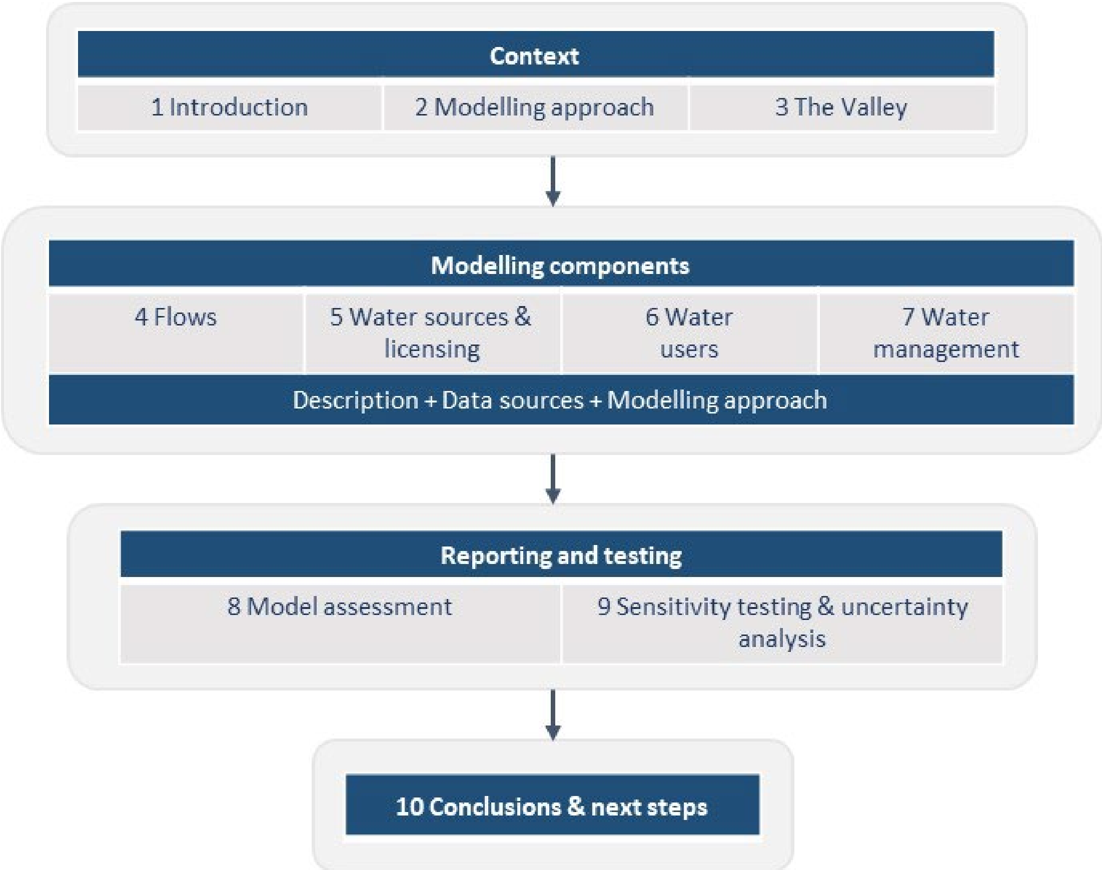
[2] https://ewater.org.au/products/ewater-source/

[3] 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.

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

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

Figure 1. Report structure



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 Plan Limit Scenario results.

Uncertainty analysis and sensitivity testing of key parameters, input data and modelling assumptions is an important step in modelling practice. This is discussed in section 9.

Section 10 concludes the report with an overall assessment of the model suitability, and limitations, 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 river system model for the Namoi Valley regulated river system.

How the model has been used to update the water sharing plan limit and calculate floodplain harvesting entitlements to bring total diversions back within that limit is described in companion report *Floodplain harvesting entitlements for the Namoi Valley river system: model scenarios* (DPE Water 2022a).

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 Namoi Valley* (DPE Water 2022b).

The three reports together serve to describe how the modelling meets the objectives of the policy.

2. Modelling approach

This section describes the modelling approach used to construct a Namoi 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 those to the best of our ability in this report.

The model has been developed using departmental standards and guidelines for good modelling practice. These are constantly refined over time and we also contribute to broader modelling guidelines[4]. 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 Namoi Valley model is designed to support contemporary water management decisions in the Namoi, whether it is a rule change in the Namoi water sharing plan 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 criteria were established for the design of the model to enable it to meet these objectives (Table 1). How well these are met is reported in section 10.1.

In the case of the Namoi Valley model, meeting these objectives and criteria was achieved as part of the development of the new Source model. This will replace the earlier departmental model (DIPNR, 2005) which was built for a different purpose, primarily to model in-channel diversions.

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

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	**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 sustainable diversion limits (SDLs) as set out in the Basin Plan. Modelling using long periods of climate records that captures 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 from 1895 to 2009 for calculating SDLs and Baseline Diversion Limits. (NOTE: The Namoi 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 (river reach up 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

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 department, along with other Australian water agencies, uses or is migrating to use the Source software platform which has been adopted as Australia's National Hydrological Modelling Platform. Source was developed by a consortium of Australian research and industry partners to provide a consistent hydrological and water quality modelling and reporting framework to support integrated planning, operations and governance at urban, catchment to river basin scales. Use of a common platform facilitates collaborative and consistent modelling, analysis and policy development across the Murray Darling Basin, including the accreditation of water resource plans under the Basin Plan.

Source is designed to simulate flows through a system, whether those flows are water, sediment, contaminants, water accounts or water trade. It provides sufficient functionality to simulate the process of water moving out onto floodplains.

Source models are built from components which are linked, through adding nodes and links, to represent the system to be modelled. There are many types of nodes to represent places where water can be added, diverted, stored, and recorded (for reporting) in a model, including:

- water sources (supply), such as inflows, storages
- water users (demand), such as crops, towns, industries, the environment
- reporting points, such as gauges and environmental assets.

Links connect, store and route water passing between nodes.

Source also contains models (hereafter referred to as component models) that can run together to simulate multiple processes within the system. For floodplain harvesting modelling, these include:

- rainfall–runoff models that converts rainfall into runoff across the landscape
- irrigated crop models that simulate the crop growth cycle, and thus water demand
- storage models that simulate the management of storage water.

These models are mentioned here because the choice of model dictates the amount and type of data that must be collected.

Additionally, the Source platform supports the coding of functions to dynamically calculate values based on other values during a model run. An example in the Namoi Valley model is the function that dynamically calculates crop area planted as a function of water availability (described in Section 6.2.2).

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 Source 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.

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
8	Storage operation	subsection in section 7.5

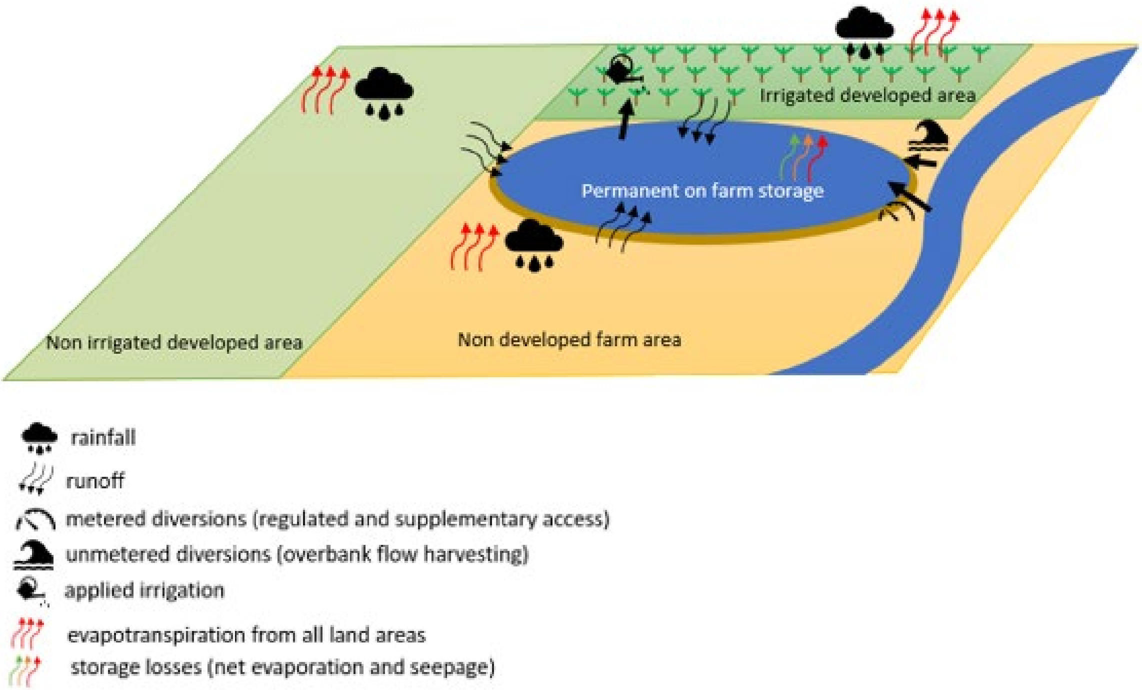
This approach manages uncertainty by firstly setting observed data as a boundary condition for most of these stages, and varying parameter values of the component models to calibrate their response to match observed data, whether this is matching observations, a prior estimate, or system behaviour more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

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 permanent on-farm storage, the irrigated and non-irrigated developed areas, and the non-developed farm area. The focal point for most of these irrigation properties are the on-farm storages 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.

Figure 2. Schematic of 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.

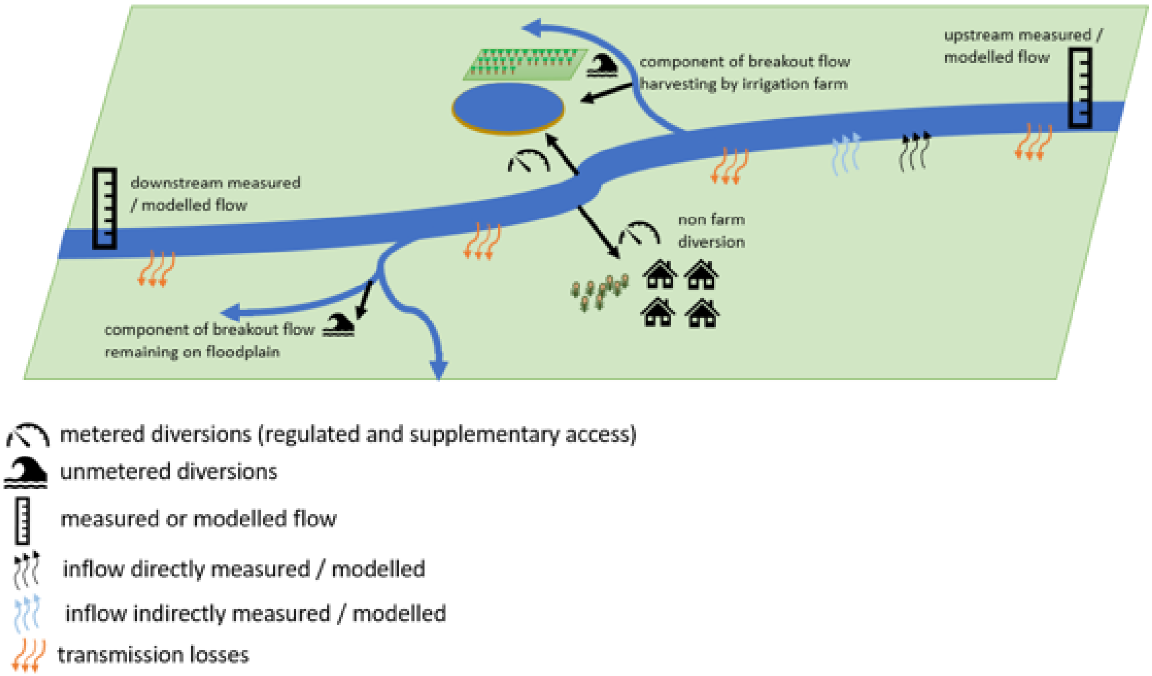
We would not expect a perfect water balance to be achieved at all individual properties due to a number of uncertainties (such as different management practices) at that scale. We place more emphasis on ensuring that the reach and valley scale results make sense in terms of historical production. We 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. Schematic of reach scale water balance components

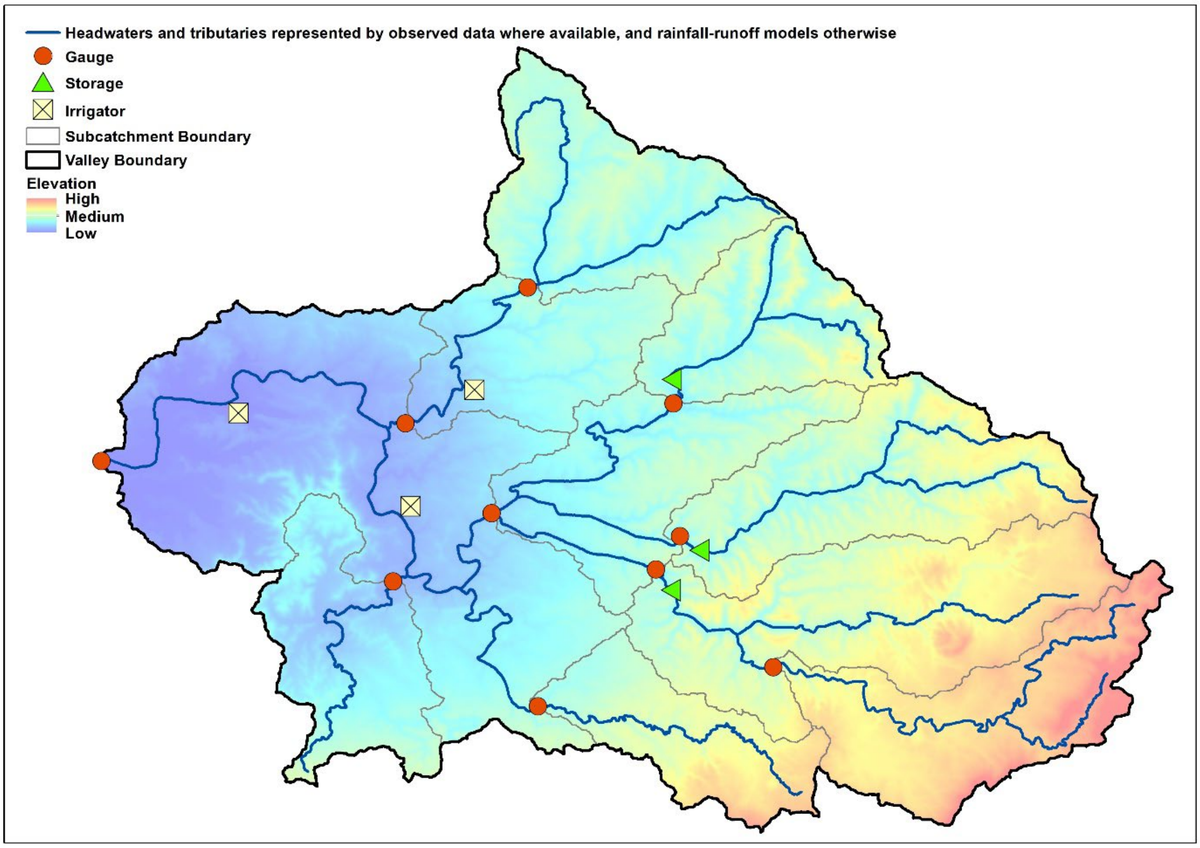


Valley scale

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 (including Source) 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 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 runs the risk of unrealistic parameters that may not result in the model being robust when simulating outside the calibration period.

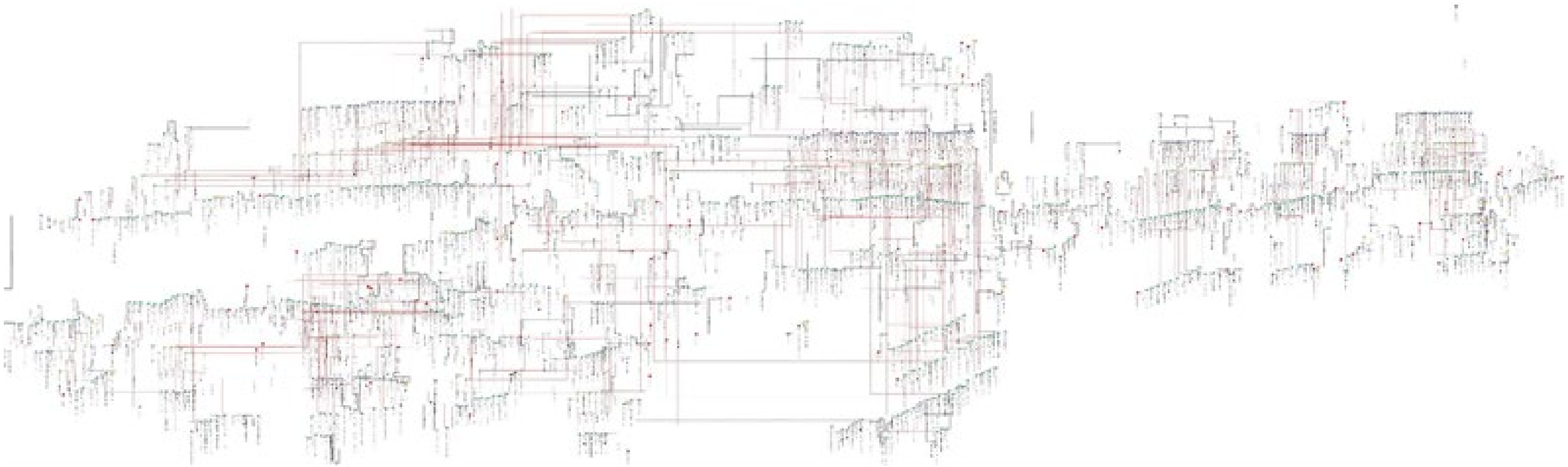
2.3.5. Model assembly and data extension

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.

The assembled Namoi Valley Model does not include the Peel River, which is modelled separately and the output of that model provides input to this model.

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



2.3.6. Data periods

This 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 to 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 Namoi Valley modelling

Period term	Period	Note
Long-term record	2/12/1891–30/6/2020	1891–1895 is model warm-up period[5]; 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 1895/86–2008/09; short form 1895–2009
Available climate data period	2/12/1891–30/6/2020	SDL compliance process required extension to current conditions
Period for calibration and validation of flow modelling	various	Based on data availability
Assessment period for diversions and water management using fully configured model	1/7/2004–30/6/2015	Water years 2004/05 to 2014/2015; short form 2004–2015 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 from 1 July 2008 to 30 June 2009

2.3.7. Validating the model

The assembled model is then tested to evaluate its performance by comparing model results with observed data. We use different tests to validate the model:

- The last step in the flow calibration process was to develop a validation model by amalgamating the individual reach models. The validation model is used to confirm the performance and accuracy of the model run as a complete system and provides a foundation for the development of scenario models.
- The diversions and water management components have been compared over the period 2004-2015, which includes key benchmark years for the policy and the Basin Plan. We also evaluate how well the model performs during two sub-periods.

These tests are further described in section 8.

[5] The initial period of simulation is not used for reporting purposes, as the assumed starting values for parameters in the model can affect results in the first few years.

2.3.8. Scenario development

The fully assembled model with the full period of available climate data are 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 WSP, 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 (DPIE Water 2022a). The scenarios developed for the Namoi are listed in Table 4.

Table 4. Scenarios used in the Namoi Valley model

Scenario name	Description
2008/09 Scenario	Represents the conditions in the valley, licences and diversions, as at 2008/09[6]
Cap Scenario	Generally based on 1993/94 conditions however an allowance was made for enlargement of Pindari Dam which means some development levels are based on November 1999
Plan Limit Scenario	Cap on diversions – uses development levels as at 1999/00 and management arrangements and share components as at 1 July 2004
Baseline Diversion Limit (BDL) Scenario	Equivalent to the Plan Limit Scenario

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 Namoi Valley.

[6] This scenario is configured with all eligible storages, which includes one storage built post 2008.

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[7], 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
Component: crop areas					
Crop type and area planted each year	Farm surveys, remote sensing, survey records (WaterNSW, ABARE, ABS, industry groups)	X	o	o	X
Component: water management					
Water sharing, announcing allocations and supplementary access, planned environmental water requirements	Namoi Water Sharing Plan, Operational procedures	X	o	o	o

[7] Farm surveys refer to the Irrigator Behaviour Questionnaire

3. Overview of the Namoi Valley

3.1 Physical description

The Namoi Valley comprises the catchments of the Namoi, Macdonald, Manilla, and Mooki Rivers. The Peel River is a major tributary with its own storage (Chaffey Dam) and regulated river system that is managed, and modelled, separately. These catchments drain from the Great Dividing Range north of Tamworth in the New England tablelands to the north and the town of Quirindi in the south (Figure 6). It has an area of approximately 43,000 km^2. Grazing (54%) and dryland cropping (17%) are the major agricultural land uses in the valley, with irrigated agriculture, mainly cotton, covering around 4% of the valley by area.

The Namoi catchment has a dry semi-arid climate. Annual average rainfall varies across the Namoi WRPA, from a maximum of 1,300 mm over the ranges in the east to around 400 mm near Walgett. Although rain falls throughout the year, there is a marked wet season in summer through to early autumn. Rainfall in summer months averages twice to four times the rainfall in winter months

Evaporation in the Namoi catchment has a strong east-west gradient. Average Class A pan evaporation varies from around 1,000 mm/year in the south-east, to over 2,200 mm/year in the north-west (Figure 6) and is strongly seasonal throughout the year. At Gunnedah mean monthly evaporation in the summer months is around 250 mm, which is more than three times the average rainfall for those months. In winter evaporation is around 60 mm in June and July.

The river network is made up of the main river and its tributaries, effluents[8] and breakouts[9], with a complex series of branching channels at the lower end of the valley. The main tributaries entering the Namoi River are:

- The Macdonald River, which becomes the Namoi River, and the Manilla River, which enter the Namoi River above Keepit Dam
- The Peel River, which joins the Namoi River just below Keepit Dam, and
- the Mooki River and Cox's Creek which enter the Namoi River further downstream.

The Gunidgera-Pian Creek system is a major effluent, with flows diverted into the system at Gunidgera Weir to support irrigation.

The junction of the Namoi and the Barwon River marks the downstream end of the Namoi Valley.

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

[8] Effluents are rivers/streams that flow out of a river and may have their own local catchment. Some effluent rivers/streams only start flowing when the flows in the main river reach higher levels. They are also called effluent systems, effluent offtakes, effluent rivers, effluent streams

[9] Breakouts are points where the river spills over onto the floodplains.

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 regulated through three major public water storages (Keepit Dam on the Namoi River, Split Rock Dam on the Manilla River, and Chaffey Dam on the separately managed Peel River) and several weirs that regulate the flow pattern and availability of water in the system. The construction of these major dams and the regulation of river flows have enabled the controlled or regulated delivery of water to water users, and the issue of licences for the supply of water.

Access to regulated water is through licences and usage is metered. Unregulated water (e.g. 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.

Flows are diverted from the Namoi River into the Gunidgera-Pian Creek system via the Gunidgera weir across the Namoi River and associated regulator at the offtake to Gunidgera Creek. This creek system has lower channel capacities than the Namoi River, and controlled flows into the creek system are generally limited to 1,230 ML/day.

3.3 Water users

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

The largest water demands are from the irrigation farm properties in the floodplain areas downstream of Boggabri. These areas are principally cotton growing. A map of the primary irrigation areas is provided at Figure 7.

3.4 Legislation, policies and operating procedures

Under the NSW Water Management Act, water sharing plans are made for major water sources such as the Namoi Valley. Water sharing plans set out the rules for sharing water between water users and the environment, and the allocation of water between different categories of water users.

The NSW policies and legislation that are referred to in this report are:

- *Water Management Act 2000*
- *Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources 2020 (draft),* referred to in this report as the *Namoi WSP*
- *Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012*
- *Floodplain Management Plan for the Upper Namoi Valley Floodplain 2019*

- *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2019*
- *NSW Floodplain Harvesting Policy 2013 (revised 2018),* referred to in this report as *the policy.*

The Namoi WSP applies to all regulated river sections in Manilla, Upper Namoi and Lower Namoi Rivers. The management components described in this report closely reference key provisions of the *Namoi 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 Namoi Valley

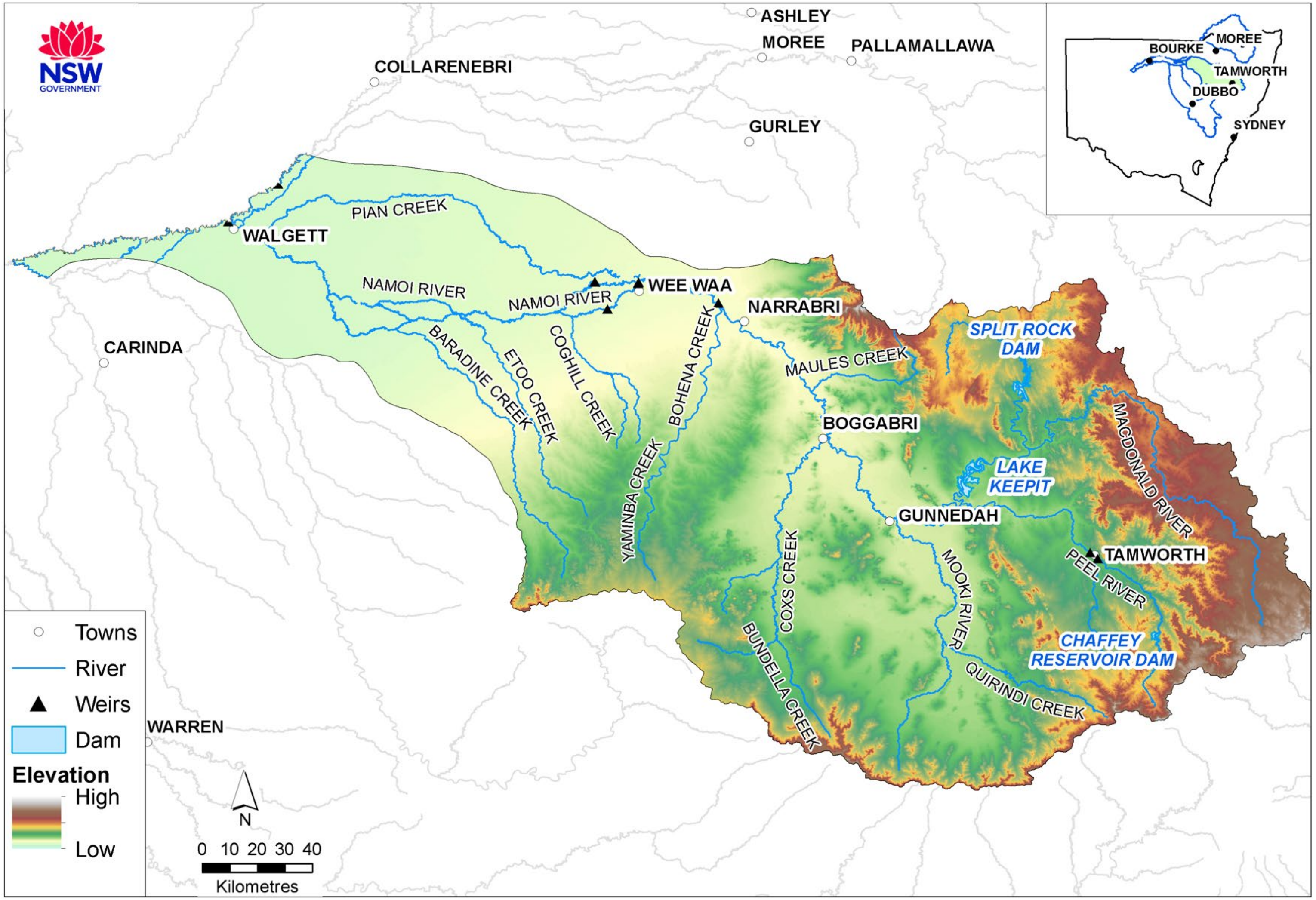
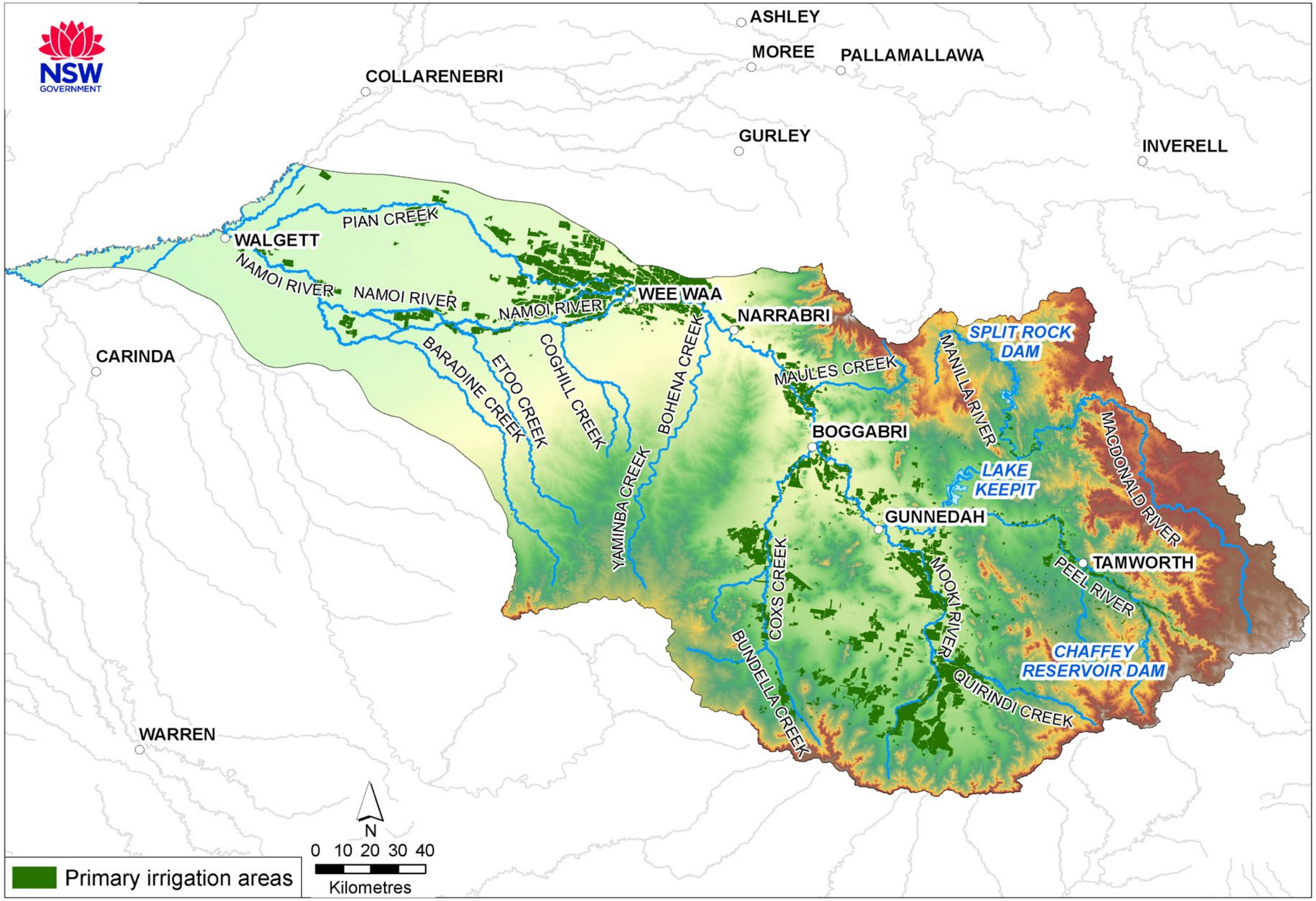


Figure 7. Primary irrigation areas in the Namoi Valley



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 26 modelling units (catchments and sub-catchments (sub-reaches)) (Figure 8). The reaches in the Peel valley are modelled in the separate Peel Valley source model, and are reported separately.

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 Namoi (i.e. the IQQM Namoi model).

4.1.2. Modelling approach

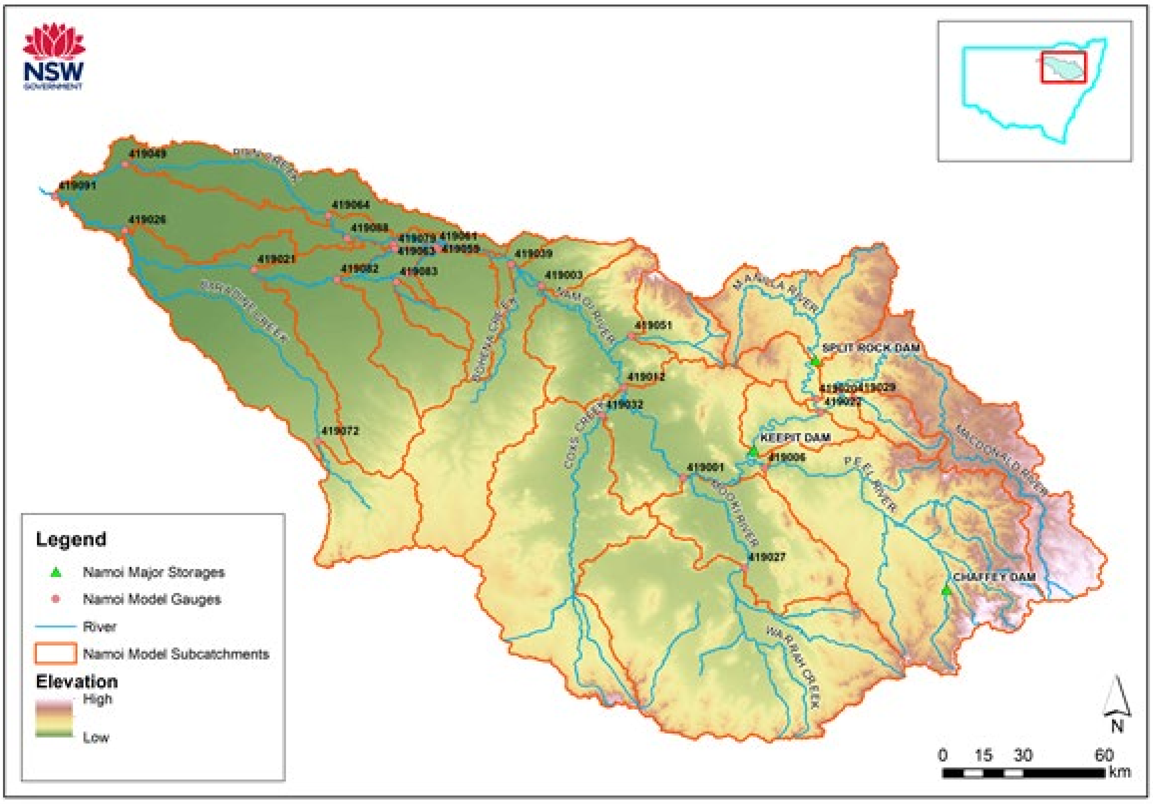
Data availability and design criteria of being able to report at multiple scales (property, reach and whole-of-valley) informed the number of discrete modelling areas needed.

Reaches for the Namoi models are show 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 catchment areas and stream lengths were derived from direct measurement, using standard GIS routines.

Figure 8. Map of modelling units of the Namoi Valley



4.2 Rainfall

Average annual rainfall across the Namoi Valley decreases from east to west, from over 1,300 mm in the eastern ranges around the Great Dividing Range to around 400 mm in the west at Walgett (Figure 9). Although rain falls throughout the year, there is a marked wet season in summer through to early autumn. Rainfall in summer months averages twice to four times the rainfall in winter months.

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 Qld Government's SILO patch point data[10]. 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.

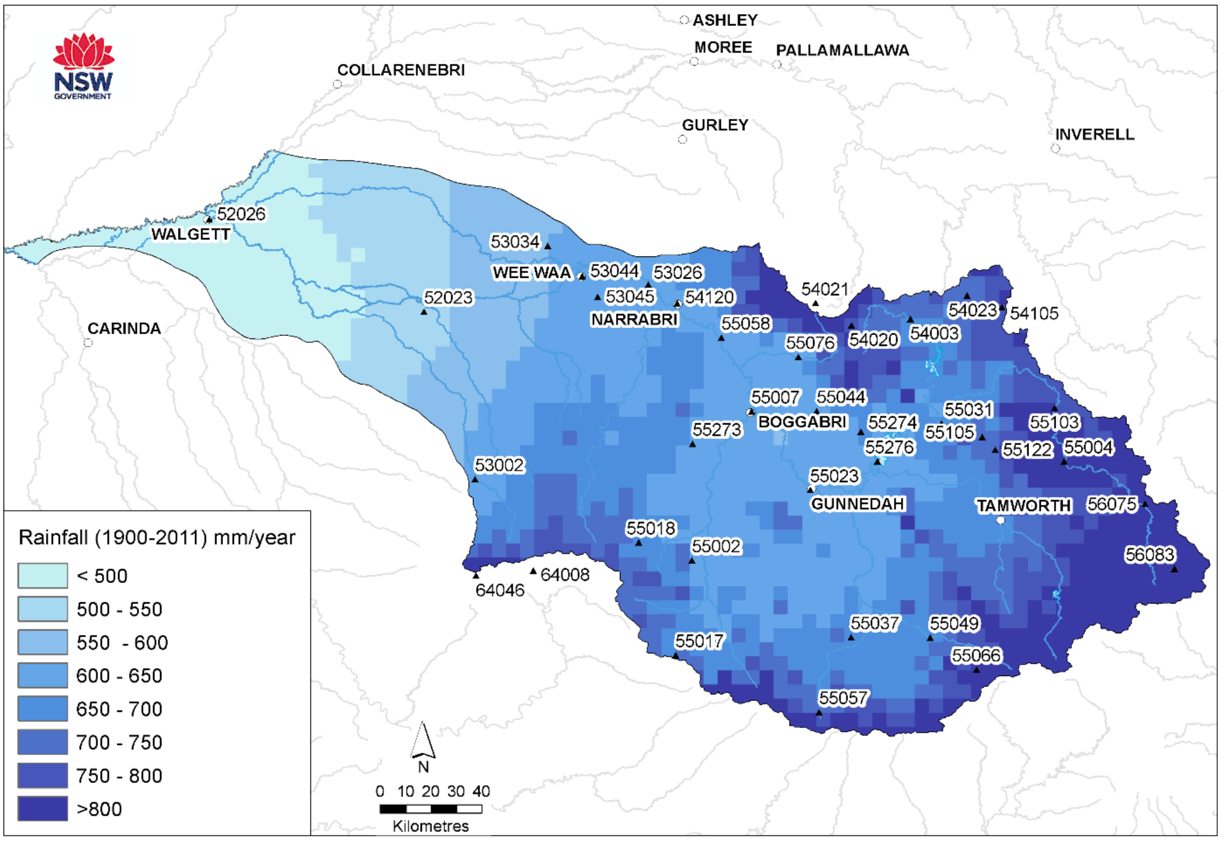
We chose the rainfall stations for each reach based on their location, length and quality of the record. We also used correlation with observed reach inflows during flow calibration. The departmental guideline is to adopt the SILO infilling. Gaps in data were infilled using raw data from

[10] These data are always referred to as SILO, which stands for Scientific Information for Land Owners. Available at https://www.longpaddock.qld.gov.au/silo/

nearby stations as available, and otherwise using SILO Patched Point data, to create records that are complete over the full modelling period. Any significant periods of infilled data were checked for introduction of bias in the data.

The rainfall stations used in the Namoi Valley model are shown at Figure 9. In addition to these stations, a larger number of rainfall stations are used in rainfall–runoff modelling to generate inflow time series data for the Source model (section 4.4.2). This modelling occurs separately to the Source river system model. A full list of rainfall stations including spatial coordinates and long-term annual average is included in Appendix B .

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



4.2.2 Modelling approach

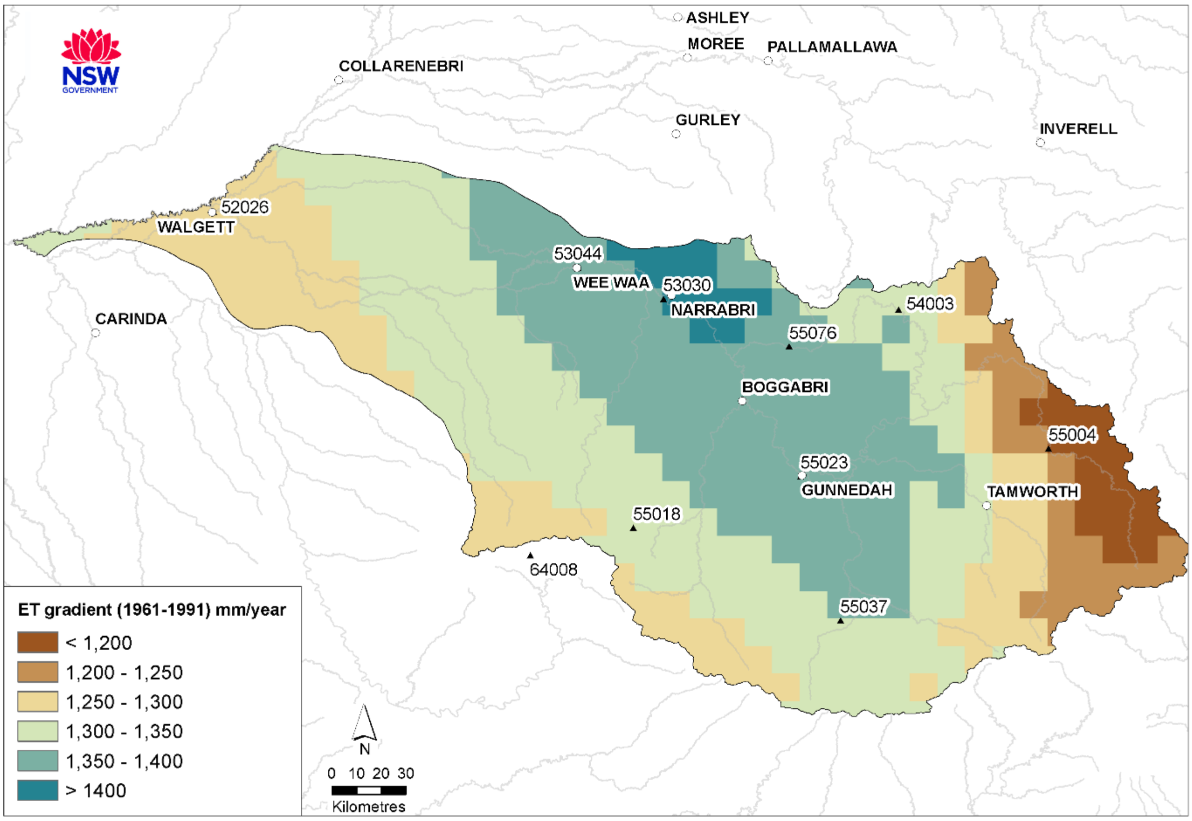
Corresponding to stage 1 of the stages of model assembly (Table 2), rainfall data are used as an input to rainfall–runoff modelling, simulation of rainfall on storages and river surfaces and the modelling of irrigation demands.

We adopt 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 the choice of climate station, with less than 5% change in floodplain harvesting with change between the nearest two climate stations.

4.3 Evaporation

Annual evaporation has a strong east–west gradient across the valley (Figure 10), with average Class A pan evaporation exceeding the average rainfall across the entire valley. Annual evaporation is around 1,000 mm in the southeast and over 2,200 mm in the northwest of the catchment, and is strongly seasonal throughout the year. Mean monthly evaporation at Gunnedah in the summer months is around 250 mm, which is more than three times the average rainfall for those months. In winter evaporation is around 60 mm in June and July.

Figure 10. Map showing the evapotranspiration (ET) gradient (1961 to 1991) across the Namoi 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 Namoi 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 the United Nations Food and Agriculture Organisation FAO56 method. These are the same as the climate stations shown in Figure 9.

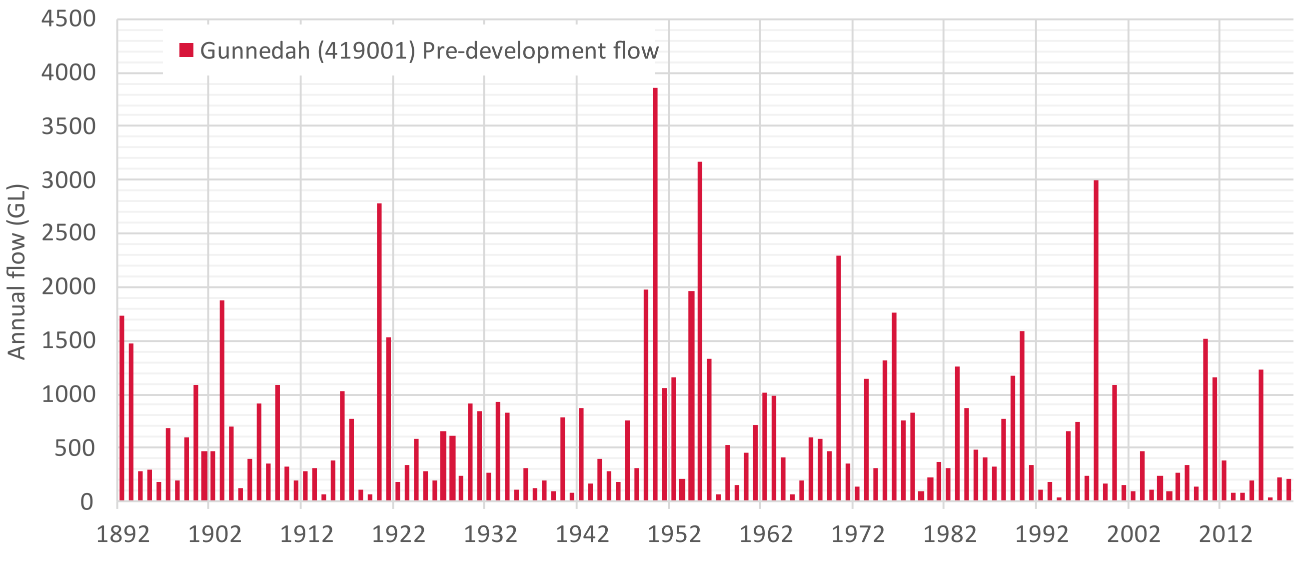
4.3.2 Modelling approach

When choosing evaporation stations for all purposes, the nearest stations were preferred, as local effects may be important.

4.4 Streamflow

As with many northern NSW inland tributaries, the Namoi system experiences high flow variability in response to climate variability. The long-term modelled flow shown in Figure 11 for the Namoi River @ Gunnedah (Station 419001) under pre-development conditions demonstrates this. Pre-development flow conditions are used in preference to observed flow which, due to regulation, does not reflect the natural flow variability. These data show that while the annual average is around 687 GL/year, annual flow is highly variable with extended low flow periods particularly in the period 1921 to 1948, and wet periods particularly in the 1950s.

Figure 11. Modelled historical annual flow (GL) at Namoi River @ Gunnedah (419001) for the period 1892 to 2020



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. The largest flood in terms of peak flow at most stations was recorded in the valley in February 1950. The frequency and occurrence of such daily events plays a big part in floodplain harvesting behaviour.

4.4.1 Data sources

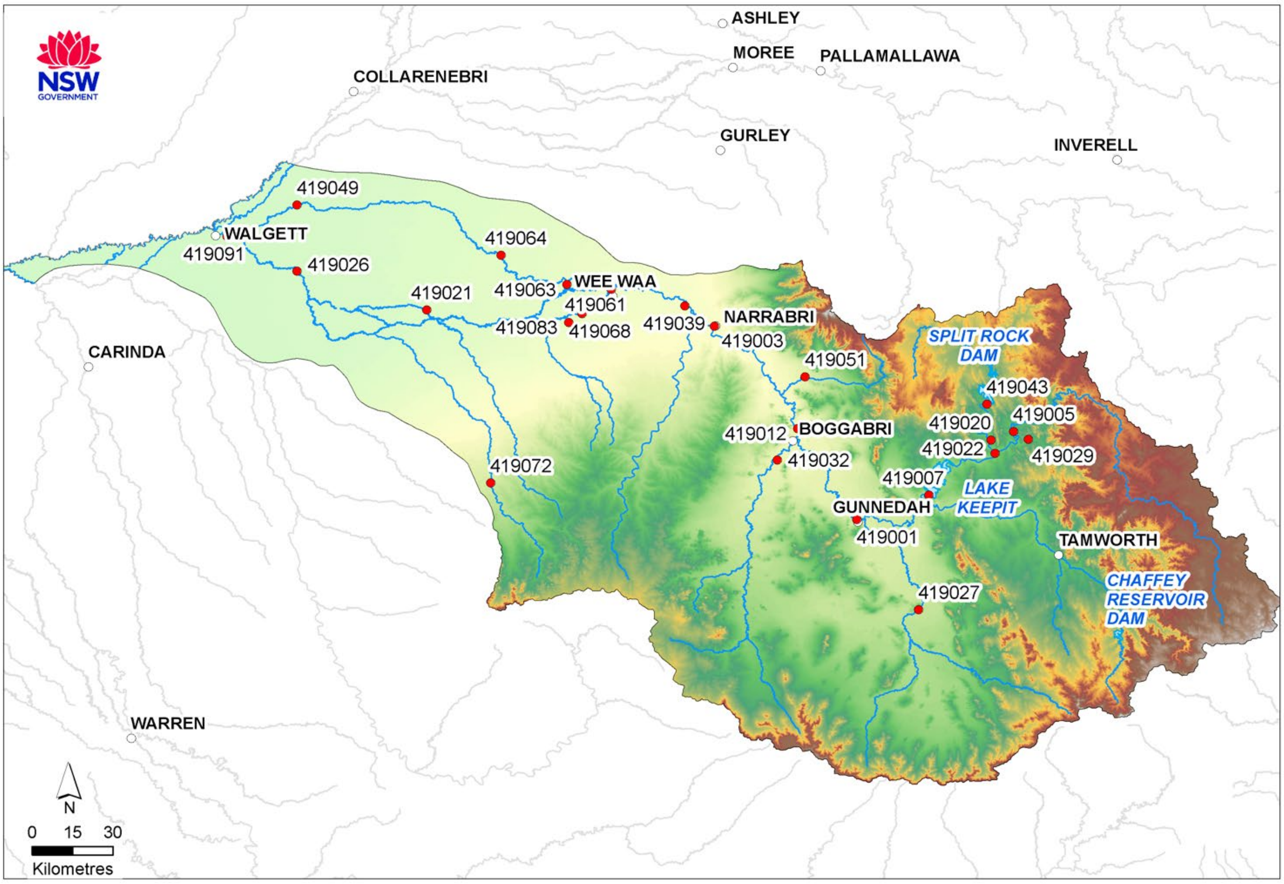
NSW maintains a network of river flow gauging stations across the Namoi Valley to support water management activities. Data for each station are archived in the Department's Hydstra hydrometric database (Kisters Pty Ltd, 2010). These continuous flow records are the foundation of the river system modelling.

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 gaugings over a period of time.

There are 51 flow gauging stations currently operating in the Namoi Valley (including storage level gauges), with a further 34 stations that have operated in the past and have some flow records. 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 7 stations were used to calibrate headwater inflows from about 13,780 km^2 (37%) of the Namoi Valley, excluding the Peel Valley. A further 16 stations were used to calibrate inflows to and flows along each river reach. The locations of these stations are illustrated at Figure 12.

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



4.4.2 Modelling approach

A summary of the parameters used for the tributary inflows and main river reaches flow calibration is provided 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	16 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 it.

A Sacramento rainfall–runoff model was built for every tributary in the model (i.e. 18 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.

Calibration

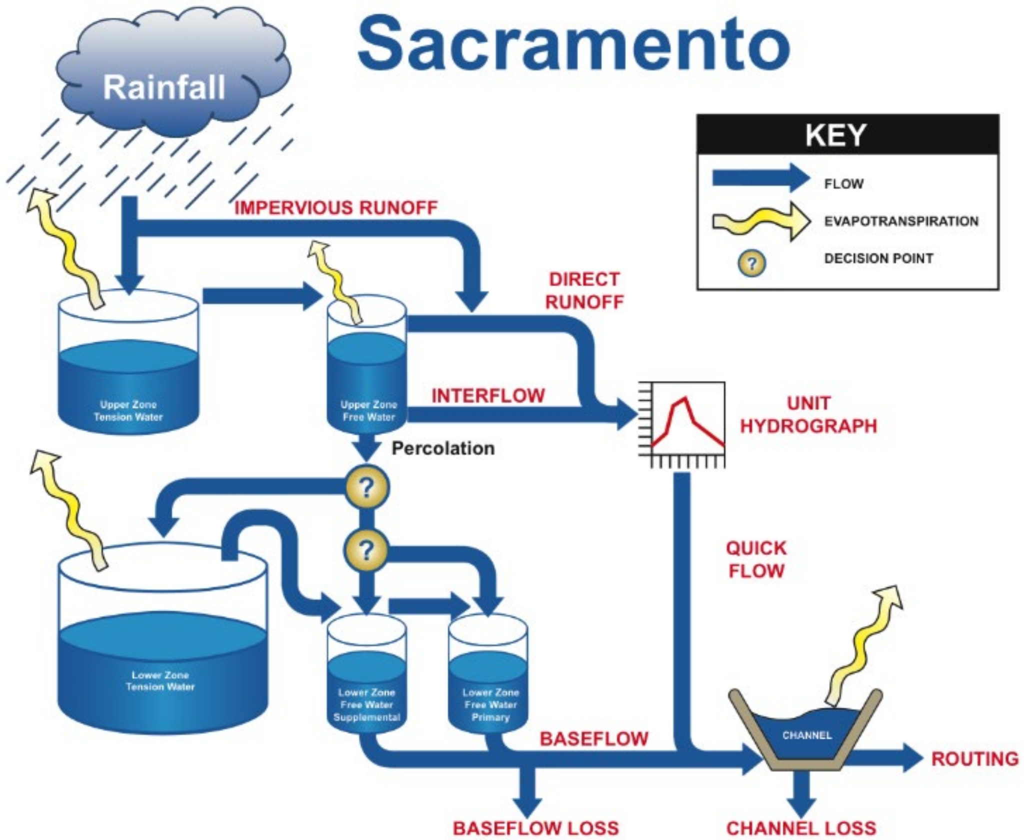
We calibrated the Sacramento model by setting it up with the local climate station data and catchment areas as input, and then applying an automated calibration process using software developed by the Qld Government.

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, based on certain statistical characteristics of the flow record, including 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 .

Figure 13. Conceptual diagram of the Sacramento rainfall-runoff model [Source: eWater, 2016]



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.

A Sacramento rainfall–runoff model was built for every reach in the model (i.e. 17 models). Sacramento rainfall–runoff models were also set up and calibrated to represent the residual inflows for each river reach to infill and extend the observed inflow sequences to cover the full period of model simulation. Flow was calibrated at the downstream gauge in a structured series of actions to estimate routing parameters, ungauged tributary inflows, transmission losses, net evaporative losses, and in some cases breakout relationships:

Use recorded inflows at the upstream gauge and any gauged inflow tributaries as inputs to the model, as well as any known outflows such as metered diversions

Systemically adjust routing parameters to reproduce key characteristic of timing and shape of hydrographs at the downstream gauge

Estimate net evaporation from the river by inputting climate data and defining a flow vs surface area relationship

Estimate transmission and other unaccounted losses based on flow rate with an emphasis on drier periods where residual inflows are not significant

Calculate initial water balance difference between simulated flow and observed flow at downstream gauge as first estimate of indirectly gauged catchment inflows, with an emphasis on wetter periods

Calibrate Sacramento model to a smoothed time series of the water balance difference. An alternative approach was also tested where the Sacramento model was tested as part of a full reach simulation; in this case the calibration target is the downstream flow, rather than the water balance difference. The two methods were compared, and best performing method chosen.

Revise the loss estimate in Step 4.

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

Several effluent rivers/streams leave the main Namoi River, sometimes with other smaller rivers and streams joining them at various points. The main effluent system is the Gunidgera-Pian Creek system that leaves the main river channel downstream of Wee Waa.

Gunidgera-Pian Creek system

The Gunidgera and Pian Creeks are effluent streams from the lower Namoi River that naturally receive flows during high flows in the Namoi River. At other times, flows into the Gunidgera Creek are controlled by a regulator constructed across it adjacent to the Namoi River. The nearby Gunidgera Weir constructed across the main Namoi River creates a deep pool of water that allows a regulated supply of water along much of Gunidgera Creek.

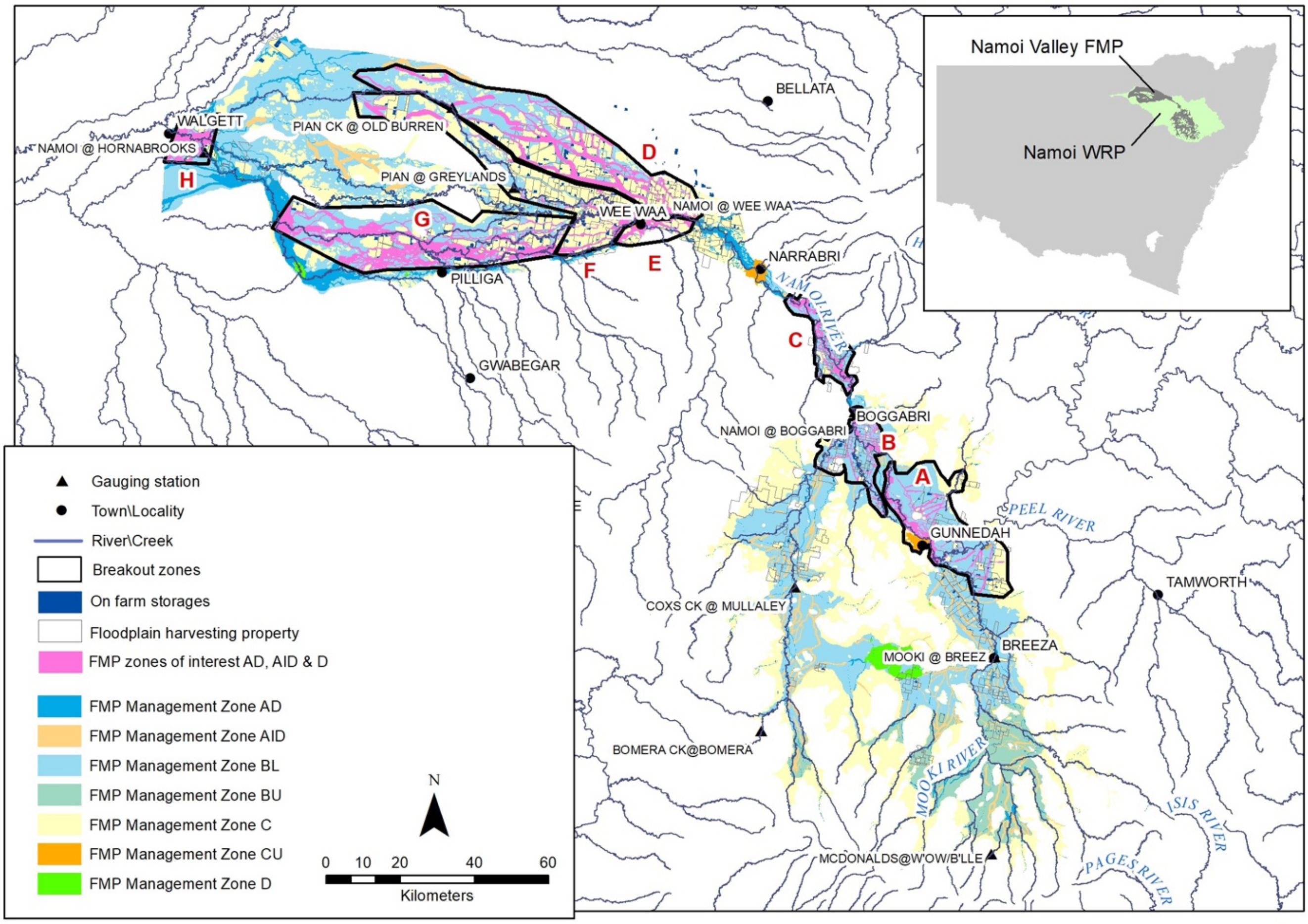
A cutting, and later a separate parallel supply channel, has been constructed from Gunidgera Creek across to Pian Creek to allow the regulated supply of water along much of the Pian Creek down to Dundee Weir. Beyond this point, only periodic flows are provided for stock and domestic purposes. These are known as replenishment flows.

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 become active in very high flows, while others have flow more frequently. Local rainfall–runoff can also contribute to flow in these areas.

There are numerous breakouts into floodway flow paths, and many of the flow paths have inter-connections. A map of key breakout locations and breakout paths is presented in Figure 14. How and when a breakout occurs depends on river levels.

Figure 14. Floodplain Management Plan (FMP) zones and key breakout locations in the Namoi Valley: A Gunnedah, B Boggabri, C Tarriaro, D Glencoe, E Wee Waa, F Merah North, G Bugilbone and H Trilby Park

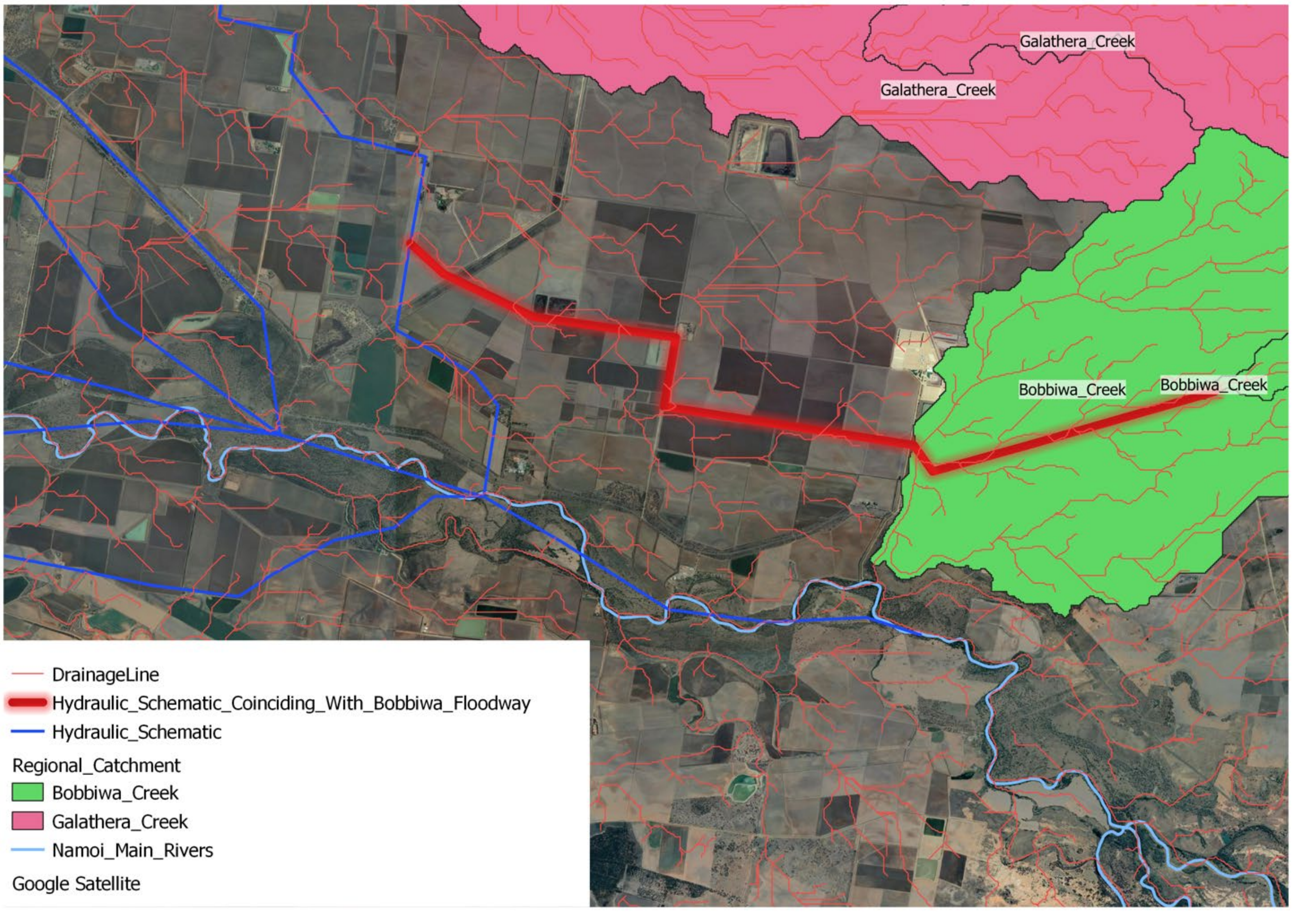


A significant inclusion in the model that affects many properties is the representation of the Bobbiwa Creek system, which becomes an indistinct flow path, known as the Bobbiwa floodway. The creek system originates in the Nandewar range to the northeast of the main irrigation properties and overflows into a floodway that cuts through a number of properties, as shown in Figure 15. In the model, this is represented by a Sacramento rainfall-runoff model using the same rainfall-runoff parameters derived from a nearby gauged catchment (Maules Creek, which also originates in the Nandewar range) and the Bobbiwa catchment area (around 20,600 ha). Further along the floodway, overbank flows from the Namoi River also join the floodway.

Property owners along the Bobbiwa floodway have advised that uncaptured runoff from upstream neighbouring properties is a significant source of water at times. The modelling indicates that some properties produce rainfall-runoff that is not able to be captured, and there is evidence that this enters the floodway. In the model, this uncaptured runoff has been configured to be available for neighbouring downstream properties. However, as with all harvesting access, flow can only be captured in permanent on-farm storages when they have airspace.

The hydraulic model schematic in Figure 15 recognises the flood path coming out of the Bobbiwa floodway. However, previous model iterations focused on representing the high flow breakouts from the main river. In doing so, the previous model set missed the inflow from Bobbiwa floodway as it does not directly enter the river.

Figure 15. Bobbiwa Creek and floodway



4.5.1 Data sources

Major effluent offtakes have flow gauges and follow well-defined channels.

High flow breakouts are well-known locally by river operators, State Emergency Service personnel, and landholders. However, there is no direct measurement 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 21 model which was developed for the (draft) Floodplain Management Plan for the Namoi Valley Floodplain 2018. Further information on these breakouts is given in Appendix D .

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

- cross-section and rating information at flow gauges
- Healthy Floodplain Irrigator Behaviour Questionnaires (farm surveys)
- Bureau of Meteorology flood warning levels
- Landsat data to compare historical flood extent along reaches to recorded flows
- five hydraulic MIKE FLOOD and MIKE 21 models covering the Lower Namoi from Narrabri downstream, developed for the Floodplain Management Plan
- water balance methods by comparing upstream and downstream flow rates (described in section 4.4.2).

The breakout relationships from these information sources were reviewed by comparing the frequency of harvesting with the available survey data. Where there was a consistent bias between simulated and observed reach water balance components, the breakout relationships were reviewed.

The breakout zone, or area of interest, was refined using ArcGIS (10.3.1) to select environmental assets and values for the environmental outcomes analyses. This process is described in the companion Environmental Outcomes report (DPIE Water 2022b).

4.5.2 Modelling approach

We use a relationship between river flow and breakout flow to represent each effluent or floodplain breakout; these are implemented using the Regulated Splitter node in Source. This node type can be used to represent both unregulated flows and channels with regulators. Further information on how we represent regulation is in section 7.5.

The locations and flow conditions for breakouts in the model provide the water for properties to access floodplain harvesting (see Figure 14). The Namoi Valley model includes 3 high flow breakouts that were configured in the previous Namoi IQQM, and 27 additional high flow breakouts. The flow rates at which they breakout from the main channel were determined from a range of sources (section 4.5.1). Further details are provided in Appendix D.

Previous modelling treated flow onto the floodplain as a loss to the system. This Source model represents floodplain breakouts explicitly, i.e. as an effluent. This means the remaining loss, represented as a loss node in the reach models, is reduced. This better reflects within channel losses[11].

When flow breaks out of the river, routing, loss and extraction of flows are simulated. For the main effluents, these are estimated as part of the flow calibration using gauged flow data either on the effluent or on the main river downstream of where the effluent returns. For floodplain breakouts, we use a storage node to represent temporary storage of flows on the floodplain and losses. This is described further in section 6.2.2.

The model includes returns from effluents to the main river. The extent to which water returns from floodplains to the main river is not well understood and is only partially represented in the model. This is further discussed in section 6.2.2 and in the recommendations for future work.

We do not explicitly represent inundation of floodplain assets. The impact of floodplain harvesting on these areas has been estimated using the nearest breakout flow relationship and the simulated floodplain harvesting in that part of the model. This is described further in the companion Environmental Outcomes report (DPIE Water 2022b).

4.6 Regulating infrastructure – dams and re-regulating storages

Flows in the Namoi are regulated by three major public storages – Keepit Dam on the Namoi River, Split Rock Dam on the Manilla River, and Chaffey Dam on the Peel River (see Figure 6 for locations). Basic details of these storages are summarised in Table 7.

[11] The remaining loss relationships can also be compensating for measurement errors so should be interpreted as unaccounted change in flow rather than literally the within channel losses

Table 7. Major headwater storages in the Namoi Valley

Storage	River	Commissioned	Capacity (GL)
Keepit Dam	Namoi River	1960	425
Split Rock Dam	Manilla River	1987	397
Chaffey Dam	Peel River	1979[12]	100.5

These storages were constructed primarily to store and release water to downstream licensed water users (including for environmental flows). Only Keepit Dam has gated spillways that can be used to actively manage spills during major floods. However, the other storages still provide passive flood mitigation as they take time to fill and discharge over spillways.

Chaffey Dam only supplies water to regulated water access licences in the Peel Valley, including Tamworth Regional Council. A separate model has been developed for the Peel system, and the outflows from that model are an input to the Namoi Valley model. Tamworth Regional Council also manage Dungowan Dam, a small storage on Dungowan Creek, with a capacity of 6.3 GL.

There are several smaller weirs within the regulated Namoi river system:

- Mollee Weir is a gated weir commissioned in 1974 on the Lower Namoi River near the town of Narrabri. The weir has a storage capacity of 3,300 ML and re-regulates releases from Keepit Dam and conserves unregulated tributary inflows.
- Gunidgera Weir is a gated weir commissioned in 1976 on the Lower Namoi River near the town of Wee Waa. The weir has a storage capacity of 1,900 ML and is primarily a diversionary weir that provides flows of up to 1,200 ML/day into the Gunidgera-Pian Creek system, but can also re-regulate releases from Keepit Dam and conserve unregulated tributary inflows.
- four small weirs along the Gunidgera-Pian system: Knights Weir on Gunidgera Creek, and Hazeldean Weir, Greylands Weir and Dundee Weir which are all on Pian Creek.

4.6.1 Data sources

Major water management infrastructure such as dams, weirs, and regulators are maintained and operated by WaterNSW, a state owned corporation. WaterNSW operates and maintains the regulating infrastructure and holds records of key parameters such as storage capacity, volume-surface area relationships, and maximum release rates at each structure.

Tamworth Regional Council operate and maintain similar data for Dungowan Dam.

4.6.2 Modelling approach

Major dams

The two major water storages in the Namoi valley were configured based on the relevant engineering parameters provided by Water NSW. Capacities are listed in Table 7 and storage curves are provided in Appendix E.

[12] Chaffey Dam was originally commissioned in 1979 with a capacity of about 62 GL. The work to enlarge it to 100 GL capacity was completed in 2016.

The Source 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

Gunidgera Weir is configured as a diversionary weir that diverts water into Gunidgera Creek to meet demands in the Gunidgera-Pian Creek system (see Table 29 in section 7.5 Storage and weir operation for more details). In the model, it is configured as a Source regulated splitter. The model simulates diversion of regulated water from upstream into the Gunidgera-Pian Creek system. The Knights Weir node on Gunidgera Creek then forces most of the regulated flows into a cutting and channel across to Pian Creek.

The re-regulatory capacity of Mollee Weir has been included in the model, with a storage capacity of 3,300 ML. The Gunidgera Weir re-regulatory capacity has not been represented in the model, as it is considered too small to be significant. The smaller fixed crest weirs along the Gunidgera-Pian Creek system do not have significant volumes of water in storage and are not configured in the model. To the extent that these weirs affect flow travel times and river transmission losses is captured implicitly in the calibration of river flows for the reach.

5. Modelling water sources and licensing

Water can only be taken from rivers and streams in NSW under a licence or a right. Water sources as listed in the Namoi WSP are:

- regulated water source
- supplementary water source
- floodplain harvesting water source
- unregulated water source
- groundwater source.

5.1 Water licences

The main licence types to 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 Namoi WSP.

Table 8. Surface water access licence types in the Namoi

Licence type (NSW)	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
Unregulated river	Not included in the regulated system, but some properties with licences in the regulated river system may also have separate access to unregulated rivers or streams.

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 large entitlements 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.

NSW issues water access licences with volumetric share components and an associated water account. When water is assessed as becoming available in the regulated river system, typically following inflows, the department makes an allocation announcement (as a percentage of each share component) for each licence category that indicates how much individual water licences receive. This water is credited to each licence's water account for subsequent ordering and extraction from the river. Water access licences must be linked to a works approval to take water from a river. The works approval describes the type of authorised works at a particular location (e.g. pumps or a gated regulator and associated channel) and any conditions on the use of those works.

Under the *NSW Water Management Act 2000*, extraction of water for basic stock and domestic rights from a property with river frontage (basic landholder rights), 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 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.

No information is available on water use under basic landholder rights, other than the estimate in Part 4 in the Namoi WSP.

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

Category	Consumptive	Environmental water	Total
Domestic and stock	2,097	0	2,097
Local water utility	2,786	0	2,786
Regulated river (high security)	3,984	0	3,984
Regulated river (general security)	242,978	13,653	256,631
Supplementary water access	115,479	0	115,479
Total	**367,324**	**13,653**	**380,977**

5.1.2 Modelling approach

Licences are configured for all individual water user nodes in the model representing each irrigation property, and all groups of properties. Small amounts of stock, or domestic entitlements have been modelled as a single stock and domestic use node for river reaches where that category of licence exists. 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 is implicitly accounted for in the calibration of flow loss relationships.

5.2 Regulated water

Regulated water is water made available through the resource assessment process (section 7.1) to supply the various access categories. Water can be ordered from the river operator (WaterNSW), 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 these 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 take of water by the majority of regulated water users.

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, with the exception of 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. Pre-2004 water use records are maintained in a predecessor database. Larger water users may have meter readings taken monthly or quarterly, whereas smaller water users have less frequent readings.

Water use records are available for the reaches below Split Rock Dam and Keepit 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 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 the WAS.

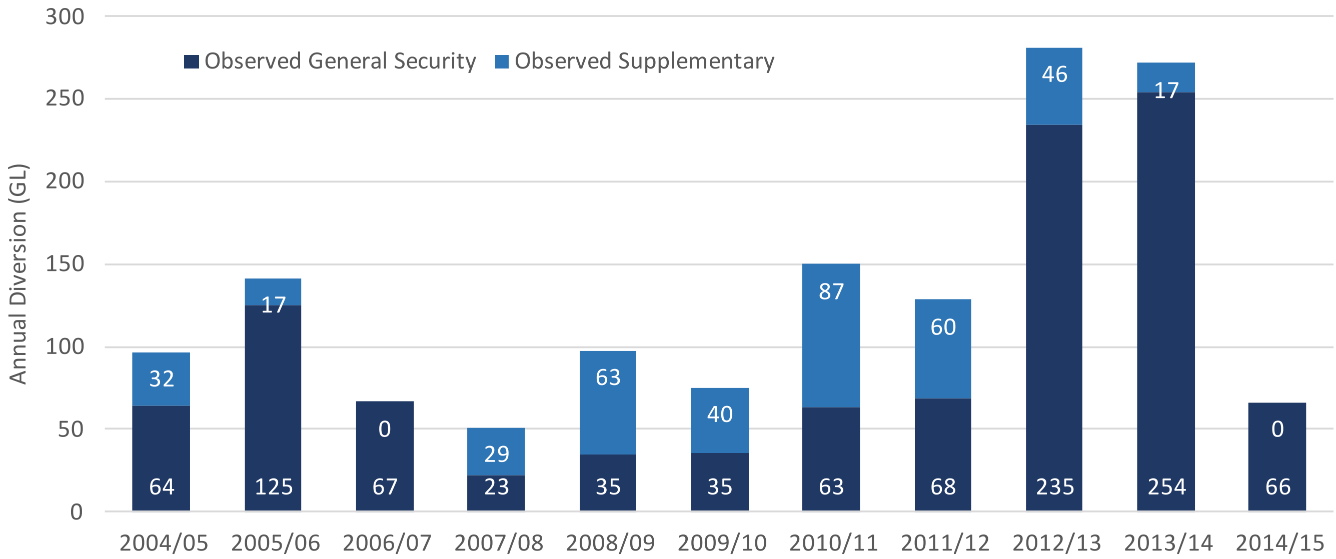
Accuracy of meter readings varies depending on the type of meter, and the nature of the installation. Meter manufacturers have layout requirements (usually the length of straight pipe either side of the meter) for meters to operate accurately. Over time, propeller type meters have been progressively 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 estimate water losses.

Records for the period prior to 2004 that were disaggregated from monthly or longer periods for previous Namoi Valley model builds have been re-used for the current work. Post-2004 metered data has been 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 16.

Figure 16. Total metered diversions in the Namoi Valley



5.2.2 Modelling approach

The supply of regulated water involves the sharing of water between consumptive water use and environmental requirements under the *Namoi WSP*, 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.

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 Namoi 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 the majority of supplementary water access licences.

The river operator usually manages access unless the event is sufficiently large that there is more than enough flow for all supplementary access licence holders. Within the Namoi regulated river system, 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 user configurable thresholds that 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. Licence flow thresholds are listed in Table 11, as set out in cl.48 of the Namoi WSP.

Table 10. Simulation of the components of supplementary water access

Component	Modelling method
Supplementary access reach definition	5 reaches are modelled: • Upstream of Narrabri Creek at Narrabri plus Namoi River at Narrabri • Narrabri Creek at Narrabri plus Namoi River at Narrabri to Mollee. • Namoi River at Mollee to Gunidgera Weir. • Namoi River at Gunidgera Weir to Weeta Weir (including the Gunidgera-Pian Creek system). • Namoi River at Weeta Weir to Walgett
Reserves for downstream	Available surplus is shared to downstream water users based on supplementary access licence shares. A threshold on the volume of supplementary access is also used to reflect operational limitations on sharing of small volumes, and the use of small flow events to meet replenishment flow requirements (see Section 7.6).

Component	Modelling method
Thresholds	Event starts if: Flow > ‘threshold volume’ Event ends if: Flow < ‘threshold volume’ Threshold volumes are based on Namoi WSP rules as summarised in Table 11. For the lower reaches, the threshold volume and orders are assessed as two separate steps rather than jointly: this achieved an acceptable frequency / calibration result so was not adjusted It is assumed that during large flood events most irrigators would plan to fill storages with floodplain harvesting instead. When there is Supplementary announcement in the model and there is floodplain harvesting opportunity, we have used Execution Order Rules in Source so that the model takes floodplain harvesting prior to other forms of available water.

Event usage limits	• The water made available in each supplementary event shall not exceed:
	• prior to 1 July 2019, 50% of the supplementary event volume, and
	• after 30 June 2019:
	  ○ 10% of the supplementary event volume between 1 July and 31 October, and
	  ○ 50% of the supplementary event volume between 1 November and 30 June.

Table 11. Supplementary water access licence flow thresholds

Date	Supplementary water event start flow (ML/day)	Supplementar y water event finish flow (ML/day)	Flow measurement location
When the volume of water in general security accounts is below 90,000 ML	500	500	All reaches downstream of Narrabri
1 August–31 December	5,000	3,000	Narrabri Creek at Narrabri plus Namoi River at Narrabri
1 January–31 January	4,000	2,000	
1 February–31 July	2,000	1,000	
1 August–31 December	5,000	3,000	Namoi River at Mollee
	4,000	2,500	Namoi River at Gunidgera Weir
	3,000	2,000	Namoi River at Weeta Weir
1 January–31 January	4,000	2,000	Namoi River at Mollee
	3,000	2,000	Namoi River at Gunidgera Weir
	2,000	1,500	Namoi at River Weeta Weir
1 February–31 July	2,000	1,000	Namoi River at Mollee
	2,000	1,000	Namoi River at Gunidgera Weir
	1,500	1,000	Namoi River at Weeta Weir

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 regulation of harvesting of overland flows is being implemented through the issuing of Floodplain Harvesting Licences. 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 areas are shown in Figure 7.

5.4.1 Data sources

Overbank flow

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

Due to the absence of recorded data, we undertook a multiple lines of evidence approach to estimate floodplain harvesting volumes. We used a capability assessment to consider the physical infrastructure used for floodplain harvesting and the opportunity irrigators have to access floodplain flows based on their location and climatic variability. We also used a water balance assessment based on historical crops and their estimated water requirements. This assessment focuses on the reach and valley scale to ensure that the total volume of metered use and estimated floodplain harvesting is representative of the estimated crop water use.

Rainfall runoff harvesting

The farm survey requested information on rainfall–runoff harvested on property. Harvesting occurs from areas developed for irrigation as well as other non-developed areas within the property. The non-developed areas that were reported as contributing to rainfall–runoff harvesting represented about 43% of the developed area. In some instances, runoff can be intercepted from local areas outside the farm.

To improve our confidence in runoff rates, alternate lines of evidence were considered as detailed in Appendix F. 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 for water users is simulated through the breakouts (as described in section 4.5). The extraction of this water is simulated through supply point nodes, which 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. This data was obtained from the NSW Natural Resources Access Regulator (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.

Rainfall-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 rainfall–runoff model tracks the soil moisture of undeveloped, developed and irrigated areas in the crop water model for each property. 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 (section 6.2.2). While rainfall–runoff harvesting generally refers to harvesting within the property, in a few instances eligible access to localised runoff outside the property has been incorporated into the property area model and reported as part of the rainfall–runoff harvesting result.

5.5 Unregulated water

NSW has issued licences on rivers and streams 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.

As part of the Healthy Floodplains project, 17 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 upstream of the regulated river reaches.

5.5.1 Data sources

Most diversions of water under unregulated water access licences are not measured. However, larger water users will soon be required to install meters under the NSW metering policy.

5.5.1 Modelling approach

The Namoi Valley model is largely configured to represent the regulated Namoi system. While water use in unregulated streams can be accessed by some regulated water users, this take is not explicitly represented in the model[13].

Other unregulated use

Unregulated flow access in the upper parts of catchments is not explicitly represented. The effect of unregulated diversions on tributary inflows is reflected in the gauged inflow data – i.e. the inflows (observed and modelled) are the net result of any unregulated take.

5.6 Groundwater

NSW has issued licences that allow taking of water from the alluvial aquifers that underlie the Namoi River and other streams for irrigation and town water supply. NSW has issued approximately 110,000 ML/year of aquifer access licences in the Upper Namoi alluvium, and 81,500 ML/year of aquifer access licences in the Lower Namoi alluvium under the *Water Sharing Plan for the Namoi Alluvial Groundwater Sources 2020* (the Namoi Groundwater Plan). The initial Namoi Groundwater Plan that commenced in 2003 introduced significant reductions to groundwater licences. Conjunctive surface water and groundwater access conditions, where additional access to groundwater was permitted when surface water allocations were low, were also discontinued. These significant changes affect modelling of scenarios based on the earlier groundwater licences, as described in the companion report *Floodplain Harvesting entitlements for NSW Namoi Valley regulated river system: model scenarios* (DPIE Water 2022a).

Table 12. Groundwater bores and average annual use

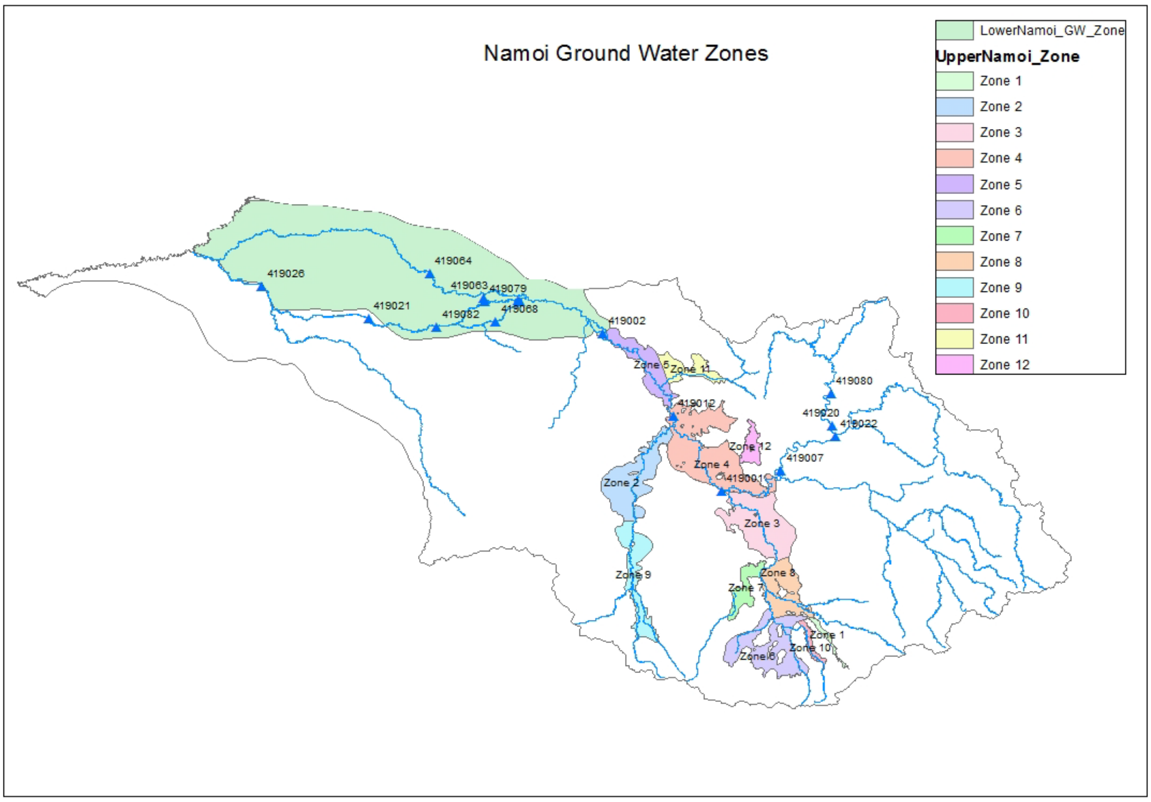
SDL Resource Unit	Registered stock and domestic bores	Registered production bores	Average Annual Use (ML/year)
Upper Namoi Alluvium	2,789	973	83,121
Lower Namoi Alluvium	1,724	553	79,535

Source: Namoi Alluvium Water Resource Plan, Status and Issues paper (DPIE Water, 2017)

The Namoi alluvium is divided into management areas and sub-zones zones, which overlap the main areas of the regulated river system where floodplain harvesting occurs (Figure 17).

13 The determination of FPH licence shares in regulated river systems has taken any unregulated access into account.

Figure 17. Namoi Valley groundwater management zones

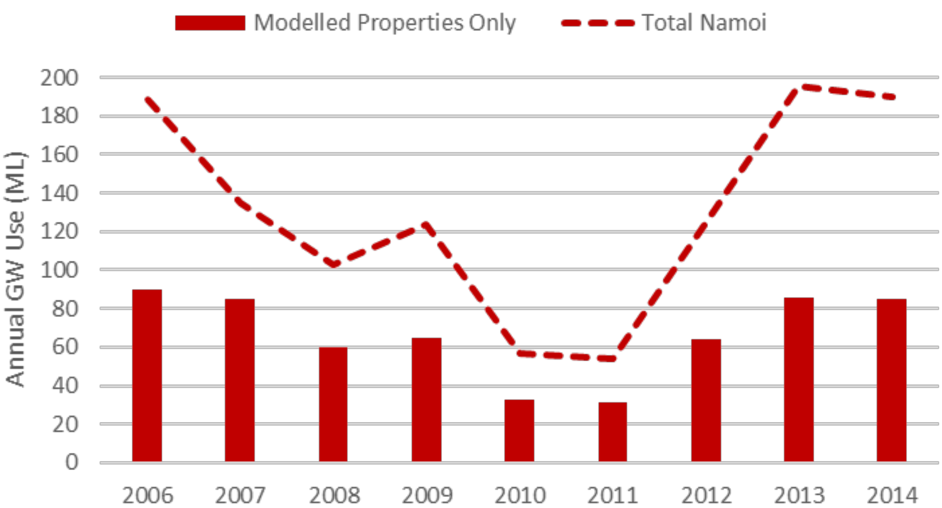


5.6.1 Data sources

The department maintains a database of metered water use for production bores in the Namoi Valley. A significant number of regulated river water users also have groundwater water licences, but no groundwater usage information was reported in the farm surveys, and limited usage data for these properties has been recorded.

Figure 18 shows annual groundwater use between 2006 and 2014 for properties represented in the Namoi Valley model and for the whole Namoi Valley based on the database record.

Figure 18. Metered groundwater use by individually modelled properties for water years 2006/07 to 2014/15

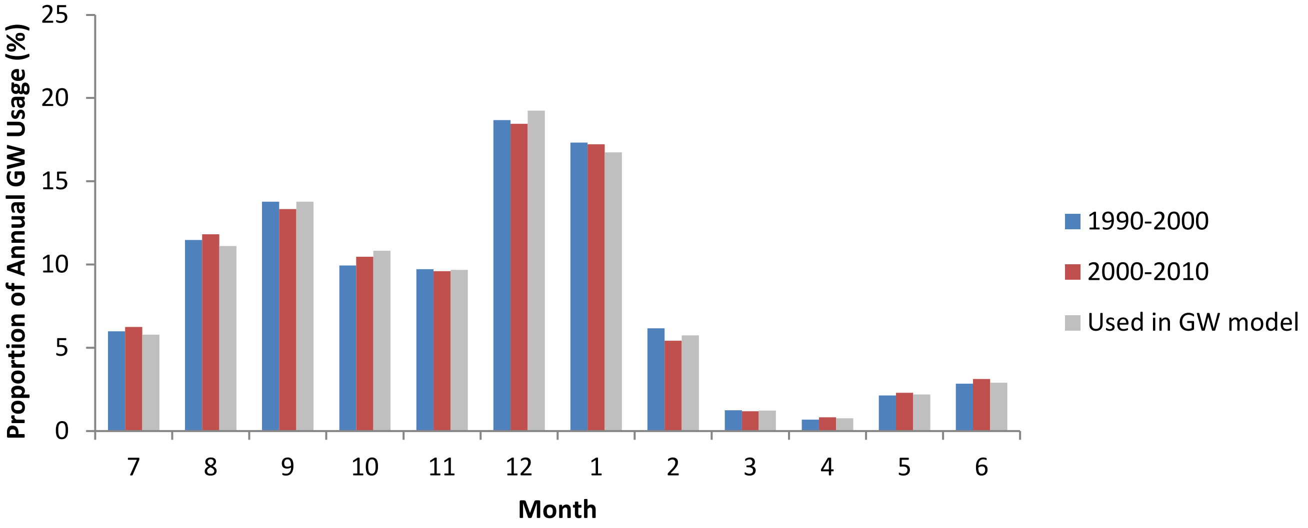


5.6.2 Modelling approach

Where the individually modelled floodplain harvesting properties on the regulated river system also have groundwater access licences, their bores have been configured as a source of water. Groundwater volumetric entitlements and historical usage were sourced from the departmental database.

Groundwater use in the model is linked to rainfall over the three months prior to summer crop planting, with lower rainfall totals increasing the modelled groundwater use. Usage records indicate that there is a consistent seasonal pattern, as shown in Figure 19, which is applied dynamically each year.

Figure 19. Monthly patterns of groundwater use over time



6. Modelling water users

6.1 Urban water supply

The towns of Manilla (Upper Namoi) and Walgett (Lower Namoi) are the only towns that have a local water utility licence in the regulated Namoi River system. These two licences only represent a small proportion of the total entitlement, but have the highest priority of supply.

6.1.1 Data sources

The two urban water utilities take water from the Namoi regulated river system to supply domestic, commercial, and industrial users in the town, and water use records are available for each town.

6.1.2 Modelling approach

The representation of diversions used for Manilla in the Namoi IQQM was adopted in the new Source model. Walgett is modelled using a monthly step seasonal pattern that is scaled by climate and population, based on observed diversions. Walgett takes its water from a weir pool on the Barwon River that receives water from both the Barwon and Namoi Rivers, and water is ordered from the Namoi River only when the weir pool becomes depleted.

6.2 Irrigators

Diversions in the regulated part of the Namoi 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, although they number relatively in the Namoi. Some irrigators also have licences for stock and domestic use.

Most irrigated agriculture is cotton, with varying amounts of winter cereal grown depending on seasonal conditions, and only a very few permanent plantings in the Namoi.

Numbers and distribution

There were 433 individual licences as at July 2019, with most being in general security (232 licences) and supplementary (129 licences) categories. Smaller entitlement holders, who generally do not have on-farm storages, are typically located in the upper parts of the regulated system and take relatively small volumes of water for irrigation. Most of the larger water users are located on the floodplains below Narrabri. The locations and areas covered by these larger water users are shown in 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 Namoi each year are essential for configuring our model and for calibrating the modelled demand and water use patterns by irrigators. A summary of data sources is presented in Table 13.

Table 13. 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 corrected for permanent and temporary trades. 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 survey data. For smaller modelled as a single irrigator node in each river reach based on largest year of supplementary access water use during the calibration period. On-farm storage losses modelled through Morton's Lake evaporation data and seepage based on 2mm/day based on data from Wigginton (2012a)	Configuring permanent on-farm storage geometry for relevant Water User nodes
Area on farms developed for cropping, and undeveloped area contributing to rainfall–runoff	Farm survey for individually modelled water users. Smaller water users modelled as a single irrigator node in each river reach are based on earlier survey data as per the Namoi IQQM For other relatively small water users estimated based on year of maximum diversions and an assumed rate of 8 ML 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 for individually modelled irrigation enterprises Smaller water users modelled as a single irrigator node in each river reach are based on the WLS.	Configuring rate of water diversions from the river for regulated and supplementary access for all Water User nodes
Floodplain harvesting (FPH) 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 data. In a couple of instances, 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 pipe capacities	Configuring rate of water harvesting from floodplains and rainfall–runoff for relevant Water User nodes

Data type	Data source	Model use
	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 G). They also supplied estimated rates for pipes; in general, these rates were not important to the model as the pump rates were lower, hence the pipe rates were not used	
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 variation was permitted in this parameter down to 15%.
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 20 Total available water is defined based on root depth for each crop type (DLWC, 2000) and 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) and NSW Dept Agriculture advice (DLWC 2000) otherwise	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 WaterNSW Water Licensing System (WLS). Information on some on farm infrastructure has been collected in the past by WaterNSW.

The Irrigator Behaviour Questionnaire (IBQ) farm survey 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 2003/04 to 2013/14 (NOW, 2016). The participants in the farm survey represented approximately 90% of the licensed entitlement to water and over 90% of annual water use in the regulated Namoi River system.

NRAR conducted field inspections for all floodplain harvesting properties as part of the licensing of relevant infrastructure for floodplain harvesting. Infrastructure information in the farm surveys was verified as far as possible 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. Other alternate lines of evidence considered were 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 LIDAR data. Where good quality survey data were provided by irrigators this was used instead. In both instances a 1 m freeboard was assumed for permanent storages. Both methods provide an objective basis to determine capacity. Remote sensing methods were used to validate the history of development of storages. This is explained further in Appendix G .

River pump capacities were based on information from farm surveys. On-farm storage pumps were initially based on 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 the rate at which overland flow can be brought into the property (Appendix G).

Historical on-farm storage pump capacity was determined at key dates based on which storages were constructed at that date. If a 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.

Areas developed for irrigation were primarily based on information from the farm survey and verified by NRAR staff. We 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 Namoi regulated river system are set out in Table 14. The developed area and river pump capacities are from IBQ farm survey so represent 2014 levels of development. The permanent on-farm storage capacity and pumps provide a more recent estimate of capacity. LIDAR data were obtained in 2013, which were supplemented by photogrammetry in 2019 and by many professional surveys undertaken 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 15.

Table 14. Latest estimates for on-farm irrigation infrastructure

Reaches	Developed area (ha)	Permanent on-farm storage capacity (ML)	River pump capacity (ML/day)	On-farm storage pump capacity (ML/day))
Keepit Dam to Narrabri	13,148	12,872	1,463	2,716
Narrabri to Walgett	49,777	113,562	6,754	17,153
Gunidgera – Pian Creek system	34,333	91,810	4,474	10,840
Total	**97,258**	**218,245**	**12,691**	**30,709**

Table 15. On-farm irrigation infrastructure estimates at prior dates

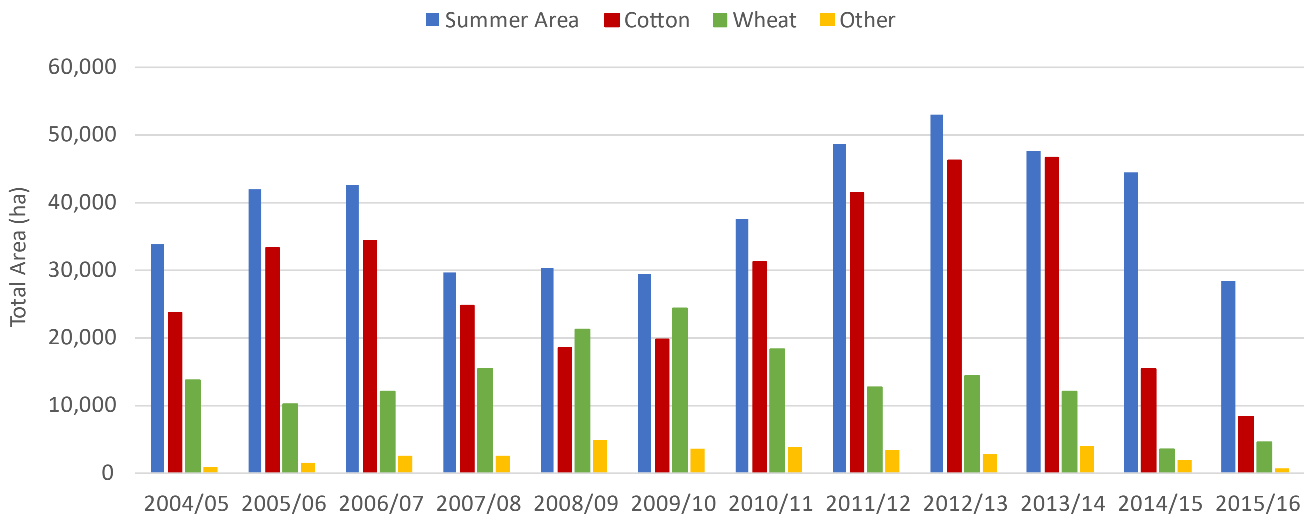
Infrastructure	1994	2000	2008	Latest estimate
On-farm storage capacity (GL)	139,579	173,178	208,824	218,245
On-farm storage pump capacity (ML/d)	21,692	25,333	31,980	30,709
Installed river pump capacity (ML/d)	9,932	11,155	12,271	12,691
Maximum irrigable area (ha)	68,174	69,477	93,449	97,258

Irrigated crops and crop water use

Having access to historical crop area and crop mix data improves the ability of the model to simulate the planting of crops under a range of climate and water availability situations, which enables a more robust estimate of water requirements and diversions from rivers and floodplains over the longer term.

About 80% of the surveyed irrigators provided irrigated cropping records for 3-4 years of the 11-year period covered in the farm surveys. Only 20% of surveyed irrigators provided crop area information for longer periods (6-8 years).

Figure 20. Reported summer and winter planted crop areas from 2004/05 to 2015/16



Source: IBQ farm surveys. Summer Area has been infilled with remote sensed data

Between 2004/05 and 2015/16, the crop mix was dominated by cotton in summer, with wheat regularly grown in the winter growing season (Figure 20). Small areas of a few other crop types were also grown.

The farm surveys indicate that the area planted in summer is strongly related to water availability, whereas this was not as significant a factor for winter crops. The decision on how much crop to plant based on water availability varied widely between individual properties. 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. A large range of water use rates were reported. The reasons for this were difficult to resolve, as there is no geographic basis for the variability. Potential reasons include different periods over which water use rates have been calculated, whether the rates factored in pre-watering and irrigation efficiency, possibly different approaches to recordkeeping and different practices.

Remote sensing of crop areas was undertaken to validate the farm survey information and to fill gaps in the survey data, and is used for comparison against model results (section 8.3.2). Initially, auto-classification remote sensing was used at a regional scale to estimate irrigated crop areas across years using MODIS and Landsat imagery. However, these datasets were found to vary significantly from each other and the farm survey data. Additional remote sensing was visually inspected for 30 properties (out of a total of 150 properties), covering larger water users and properties where further information was required. The 30 properties investigated in more detail represent approximately 70% of the general security entitlement in the valley. Additional manual checks were undertaken using the online IrriSat[14] service for a wider range of properties.

The manually supervised remote sensing tended to result in smaller estimates of crop area than the remote sensing conducted at a regional scale. As found in other valleys, the remote sensing data provides evidence of under-irrigation and shortened cropping seasons. This work is described in Appendix H .

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 Source for this purpose. We refer to this as the irrigator node.

[14] 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

Overview

Each irrigator node is represented using the best available data and methods for long-term simulation modelling as outlined in Table 16. In the model, all processes operate on a daily time step.

Table 16. 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. 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	Source provides crop models that simulate total irrigation demand for a given area and types of crops. This is done by simulating the soil moisture balance, using 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 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 can include localised rainfall–runoff

The parameter summary for the simulation of water demands is given in Table 17.

Table 17. 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 a 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 remote sensed data	Planting decision function

The Source model includes a number of scenarios representing development at different points in time. The default model (default Scenario Input Set) 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 is undertaken in subsequent stages of the model building process, when system operation and management rules are introduced. Adjustments made during these later stages are noted in relevant sections.

While the period 2004/05 to 2014/15 was used as a calibration period for some components of the model, many components were configured or calibrated using other periods of time, as noted throughout this report. For example, rainfall–runoff rates were calibrated using a longer period to match published data. We refer to the 2004/05 to 2014/15 period as the 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 18). This is important to ensure that the model is robust during different periods of water availability
- includes key benchmark years for the policy and the Basin Plan.

Table 18. Comparison of rainfall statistics (average, minimum and maximum) at climate site 53044 (Wee Waa at George Street) over the assessment period (2004 to 2015) to long-term record (1889 to 2020)

Metric	Long-term (mm) (1889–2020)	Short term (mm) (2004–2015)
Average	589	550
Maximum	1119	894

Numbers and distribution

Irrigation farms that were assessed as eligible for floodplain harvesting entitlements have been represented individually in the model. The remaining, generally smaller, farms have been aggregated in the model within the reach they are located. This resulted in 112 irrigator nodes, of which 92 represent individual eligible properties (or eligible enterprises consisting of several properties with one owner).

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 on-farm storage for each irrigator node, which represents all 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 to the model 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 had low sensitivity 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 might 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 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. ML/ha).

Upper Namoi

The smaller water users in the Upper Namoi system supplied from Split Rock Dam have an entitlement of about 10,000 ML over the model assessment period from 2004 – 2015 and irrigate a range of pasture and cereals. The allocations for this sub-system are more reliable than for the Lower Namoi, and the crop areas are not as variable across years.

Accordingly, a simplified crop area planting decision has been configured, with a fixed area configured to reproduce the same average water use over the model calibration period.

Lower Namoi

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 Namoi because floodplain harvesting is a significant component of water availability and we do not have recorded data for this. This means water availability needs to be simulated.

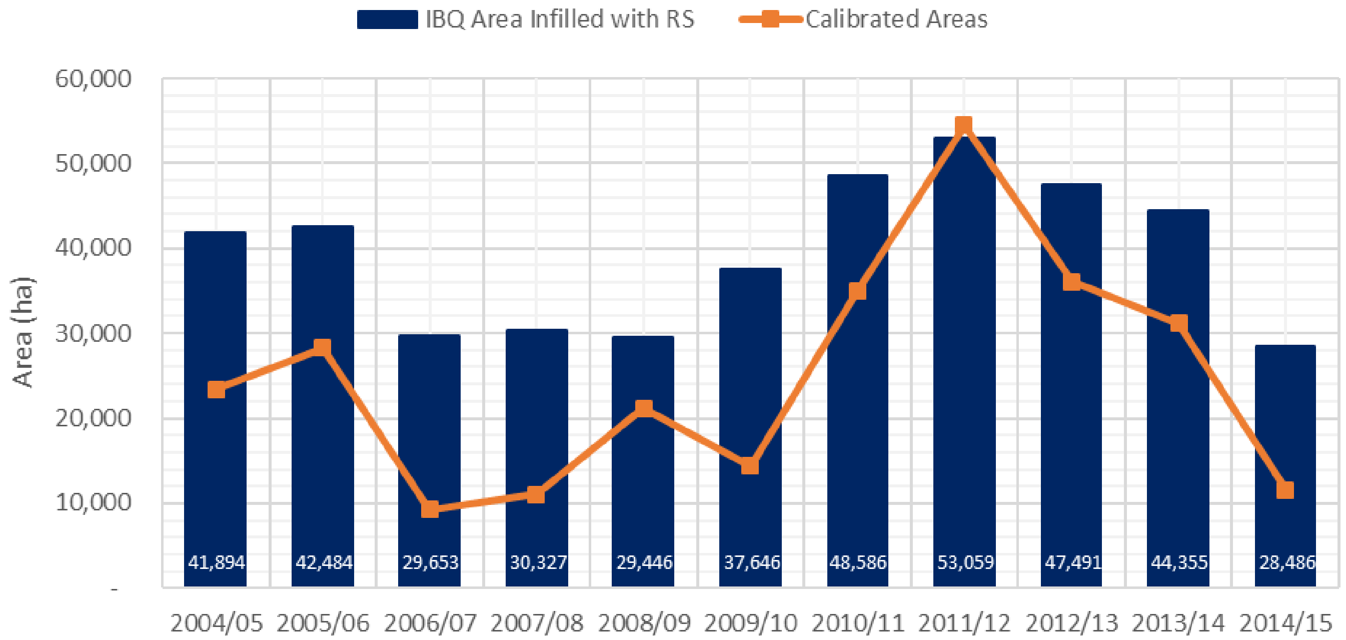
Table 19. Adopted crop planting decision rates, i.e. the volume of water required to be available before an irrigator decides to plant 1 ha of a given crop

Crop	Upstream Mollee Weir (ML/ha)	Downstream Mollee Weir (ML/ha)	Gunidgera-Pian system (ML/ha)
Winter wheat	1.0 - 2.0	1.0 - 4.0	1.0 - 2.0
Cotton	5.7 - 11.3	5.0 - 11.8	5.2 - 10.1

Modelling was initially configured with the planting decision application rate for cotton based on risk values reported in the farm surveys, which varied between 3–10 ML/ha between properties with the average being 6.3 ML/ha. 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. However, this approach resulted in difficulties reproducing metered diversions for many individual properties, and direct use of remote sensed crop areas did not reproduce metered diversions sufficiently.

To address these issues, crop areas were calculated for individual properties to better match observed diversions. An iterative process was used with a fully configured version of the model to determine a time series of crop areas that would reproduce metered diversions across the model assessment period. The resulting calibrated crop areas were then compared with the manually supervised remote sensed crop area data, and other factors such as known changes in infrastructure during the model validation period. The crop water efficiency parameter was adjusted within sensible bounds of 70%-85%,. This process produced a set of calibrated crop areas that were generally lower than the farm survey and remote sensing data.

Figure 21. Total farm survey crop areas compared to total calibrated crop areas



These derived crop areas were then used to configure a crop area planting decision for the model, using the following steps:

- Minimum planted area, defined based on driest year in the assessment period (2006)
- Maximum planted area, defined based on wettest years within the assessment period (2011), but constrained to the developed area for each property
- The planting decision was set to the average (ML/ha) based on all other years
- Some years were excluded such as years of zero metered diversions.

An intensive process was undertaken for approximately 20 properties, representing the larger water users, where the crop areas generated by the configured crop planting decision were compared with the various remote sensing data and farm surveys, and adjustments made to the planting decision where appropriate. For the remaining individual properties, the configured crop area planting decision was used directly.

The final planting decision application rates from this process varied from 5 ML/ha to 11 ML/ha across the valley for individually modelled properties, or groups of properties.

As noted in section 6.2.1, 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 constant 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:

A Source function was defined to calculate water availability as the sum of the volume currently stored in on-farm storages and licence account balances

This is then divided by the ‘risk factor’ which defines how many hectares to plant per ML of water available, constrained by a maximum area

The total area planted cannot be larger than the developed area. Where required, a smaller maximum area was specified for example if the maximum area historically planted was 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 crops which were planted in more than two years. This reduced the crop mix to largely cotton and winter wheat, with a few exceptions.

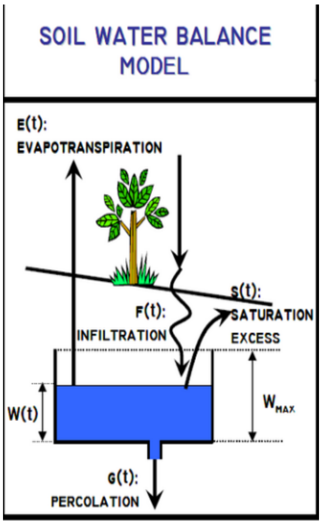
Crop water use

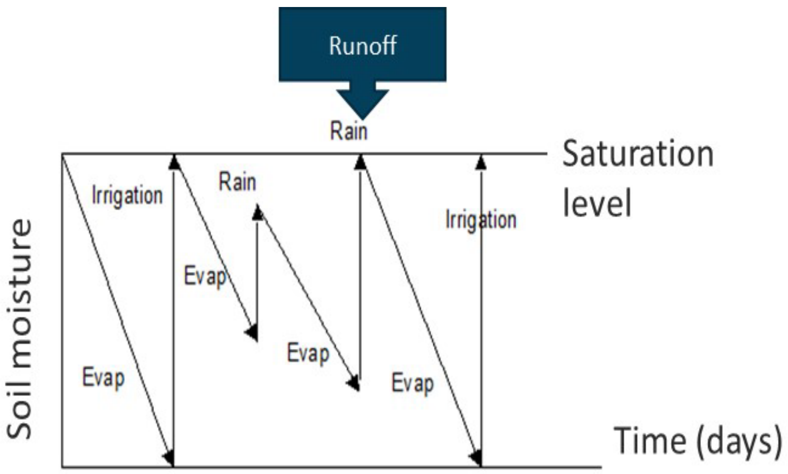
Crop models simulate the total water requirement of the crops being irrigated and are the core of the irrigator nodes in the model. The crop model uses recorded climate data and either recorded crop areas (for calibration) or simulated crop areas (validation and long-term scenario simulations) as primary 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. In the right-hand plot in Figure 22, 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[15].

Figure 22. Soil water balance model (left) with accounting for evapotranspiration, rain and irrigation (right)





15 This is the same approach used in IQQM.

Where possible, parameters in the crop model were pre-defined or narrowly bounded based on research and industry values or expert knowledge, some of which are detailed in Table 13. 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 (see Table 13). Surface water irrigation efficiency can vary widely. Gillies (2012) application efficiency results (cited in Wigginton, 2013, p26) 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 underestimate 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:

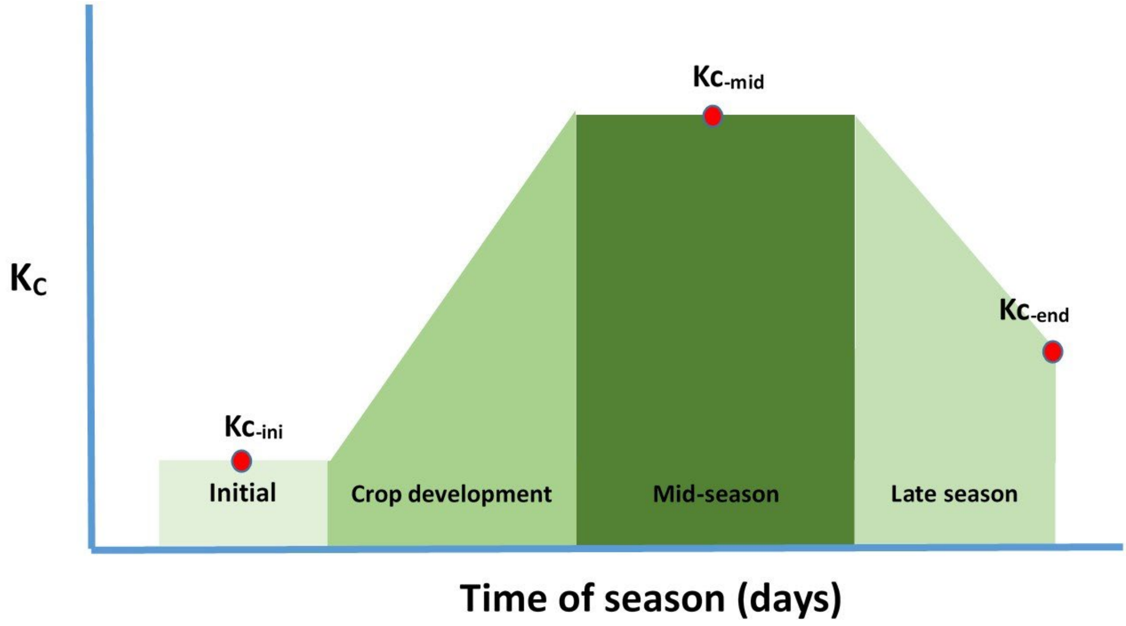
- 15% - 30% application loss for all scenarios. This is based on Gillies average result plus some allowance for channel losses.
- We propose that a 15% application loss be adopted for future versions of the Current Conditions Scenario; however, this will need to be considered along with other lines of 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.

Soil moisture capacity for crop and fallow crops are not defined directly in Source; they are a function of root depth and soil moisture capacity (%) and defined in Table 13. The product of the two equals the total available water (TAW); 112.5 mm and 45 mm respectively for cotton and fallow areas. Actual TAW will vary depending on soil type and farm management practices; however, the adopted values appear to be within a reasonable range for clay-based soils (e.g. 140-200 mm for 1 m of soil as cited in Larsen and Weir (2012)). While this is an average approximation, it is used in combination with other parameters to ensure that the generated demand is reasonable. This reduces the sensitivity of the results to this one parameter. Similarly, the TAW 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 23).

Figure 23. The relationship of Kc crop factors to time of season [adapted from Fig. 34, Allen et al. 1998]



Derivation of crop factor values, soil parameters and crop planting dates is provided in Table 13 and the adopted values are summarised in Table 20. Note that the late season cotton period is shorter than the likely actual period. This has been done to enable the simulation of depletion of soil moisture at the end of the season.

Table 20. Crop parameters used in the model: crop factors (Kc), length of period in season (days), periods and planting date

Crop class	Summer (cotton)	Winter (wheat)
Crop factor		
Kc-ini	0.35	0.30
Kc-mid	1.20	1.15
Kc-end	0.60	0.25
Period (days)		
Initial	30	16
Development	50	31
Mid season	60	67
Late season	20	41
Planting decision date	15 Oct	29 Apr

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 for the model parameters described above were tested in other valleys in northern NSW to ensure the set of parameters described above provided robust estimates of total water use by irrigation. This 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.

Rainfall–runoff harvesting

We simulate rainfall-runoff harvesting by floodplain harvesting water users using the soil water balance component of the crop model (Figure 17). The soil moisture profile is simulated separately for areas developed for irrigation (planted and fallow) and undeveloped areas. The model tracks the soil moisture of cropped, fallow and non-irrigable areas separately, enabling calculation of runoff following a rainfall event based on 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 representing other processes, percentage return efficiency parameter is applied to calibrate available runoff to pre-calculated long-term averages. The modelled annual variability was checked against nearby gauged inflows. The simulated runoff is collected in on-farm storage if the storage is not full; storage capture is constrained by the pump rate.

The parameters used for rainfall-runoff harvesting are summarised in Table 21. The supporting literature is further described in Appendix F.

No rainfall–runoff harvesting has been configured for the non-floodplain harvesting farms represented in the lumped Irrigator nodes in each river reach. There is only a small volume of on-farm storage capacity on these farms, and hence rainfall harvesting is expected to be relatively small.

Table 21. Calibration of parameters which control rainfall-runoff harvesting

Parameter	Adopted value	Comment
Fallow crop factor (for both developed and undeveloped areas)	0.25	Estimated and in conjunction with the other parameters produces the expected runoff response (Appendix F)
Rainfall–runoff return efficiency for fallow and winter irrigated areas	15–90%	Assumption that winter crops are often not fully irrigated. (Appendix F)
Rainfall–runoff return efficiency for summer irrigated areas	90%	Assumption of highest efficiency due to elevated soil moisture
Rainfall–runoff return efficiency for undeveloped areas	15%	Defined as lower than fallow rates, but within the bounds suggested by the Budyko framework (Appendix F) 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

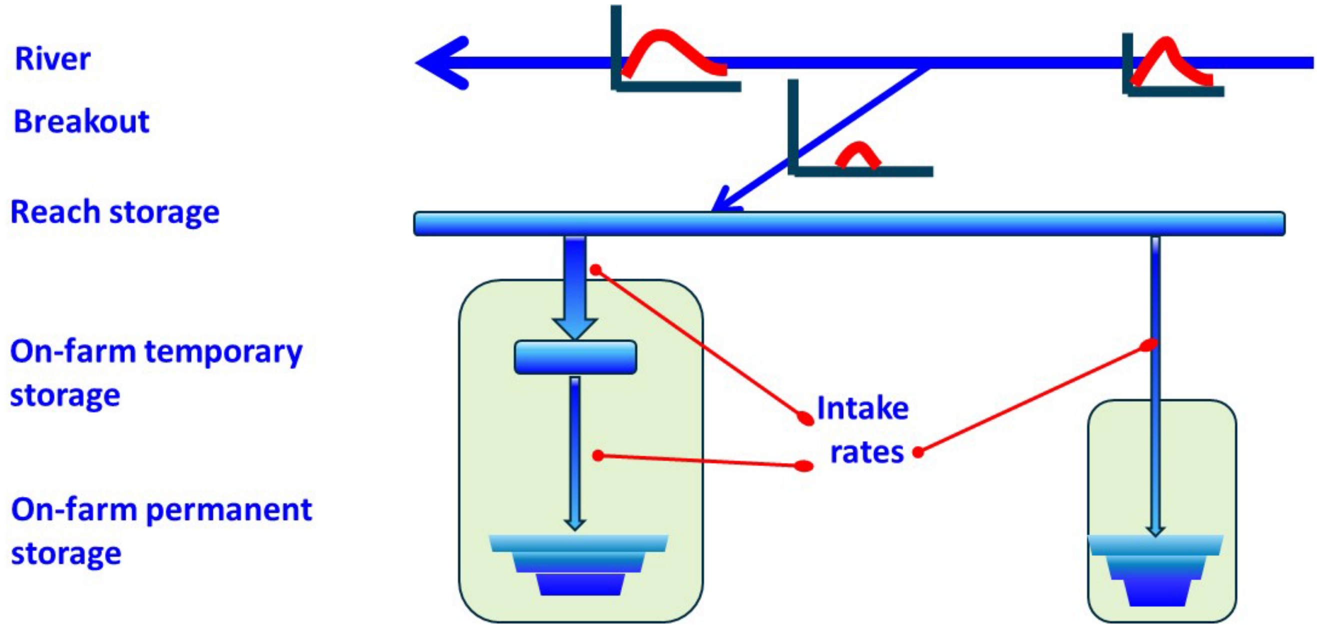
Overbank flow harvesting

The breakouts described in section 4.5 and Appendix D 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 occur in the same river reach, the returning flow 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 24.

Figure 24. 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 22.

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 advice from hydraulic modelling, farm survey information and Landsat data. 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 section G.5 provides an example of how we configured the breakout, floodplain storage and individual farm works.

Table 22. Setting of parameters which affect modelling of irrigator overbank harvesting

Parameter	Adopted value	Rationale
Days over which harvesting occurs	14 days	Selected to approximate the routing that is occurring on the floodplain. 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 virtual storage is sized based on 13 times the total of all downstream floodplain harvesting intake rates[16]. Likely to be an overestimate in the upper reaches
Release of water from the floodplain storage	Rate equal to 1 day's pumping for properties with access to that storage. Spills also occurring when the storage is filled	This means that in a small event, the water held in on-farm storage may be released quickly

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 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 subsequent slower transfer to permanent storage, this has been accounted for in the model where considered significant. This was configured by assuming a change in the floodplain harvesting rate into the permanent storage rather than explicitly modelling temporary storages.

Seepage from storages was not captured in the survey, 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 initially defined based on farm survey data. However, this was adjusted for water users in the Gunidgera-Pian Creek system to replicate early

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

delivery of water ahead of the peak irrigation season, when delivery of water is constrained by the channel capacity in that part of the system.

This information is summarised in Table 23.

In all cases the capacity of the storages has been defined such that it excludes a 1 m freeboard (airspace at the top of a storage).

Table 23. 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 1 m 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	Variable	Based on diversion data, with variable start dates across September and October. Limited to years where enough water available to plant crops.

Non harvesting properties

Each river reach has an Irrigator node to represent smaller farms that did not participate in the farm survey. The irrigated crop areas outside of the individually represented farms are predominantly in the upper reaches and are relatively small. There are no crop area data in the assessment period for these properties, and a planting decision was developed to achieve a match to recorded diversions only. These Irrigator nodes have been configured as set out in Table 24.

Table 24. 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	Summer (cotton) only	No significant winter crop areas
Developed area	Estimated maximum diversions	the developed area was based on the year of maximum diversions
Rate of river extractions	Based on authorised capacities	Taken from WAS

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 Basin Plan, the Commonwealth Government has purchased water licences 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 Held Environmental Water (HEW) licences linked to the WLS. At 31 May 2020, total Namoi holdings held by the Commonwealth Environmental Water Holder[17] comprise of 13,653 unit shares of general security licences. This represents around 3.5% of the total licences in the regulated Namoi river system as at 31 May 2020.

6.3.2 Modelling approach

Not enough is known regarding exactly how Held Environmental Water (HEW) is going to be used. The HEW portfolio has been modelled as a consumptive use that assumes an irrigation demand pattern. This issue has been addressed in other reporting for *Basin Plan* compliance. We plan to explicitly represent how HEW is used in future versions of the model.

For this model build process, we are using the 2008/09 water year as the base scenario. There was no HEW at this time in the Namoi Valley. HEW will only be represented in model scenarios for later periods (DPIE 2022a).

6.4 Stock and domestic use

Landholders in the Namoi 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 of up to 14 GL/year delivered at the end of the regulated section of the Pian Creek (see section 7.6).

6.4.1 Data sources

The department maintains records of stock and domestic water use in WAS.

Operational records of stock and domestic replenishment flows are maintained by WaterNSW. Flows delivered to the lower Pian Creek are measured at the gauging station on the Pian Creek at Dundee Weir and stored in WaterNSW Hydstra database.

No data is available on water use under Basic Landholder Rights. The Namoi WSP estimated water requirements of holders of domestic and stock rights at 1,936 ML/year at 1 July 2004.

6.4.2 Modelling approach

Stock and domestic replenishment flows are represented in the model, as a demand at the end of the regulated section of the Pian Creek, and is described in section 7.6.

The relatively small volumes of diversions by Basic Landholder Rights and other stock and domestic licences 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 (transmission losses are described in section 7).

[17] https://www.environment.gov.au/water/cewo/about/water-holdings

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 Namoi 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 Namoi WSP.

7.1.1 Available water determination

Announced AWDs are gazetted when made, and the results subsequently incorporated in the 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 25 (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 2017/18.

Table 25. Namoi announced allocations (%) for general security licences

Year	General security (%)
2003/04	46
2004/05	38
2005/06	7
2006/07	7
2007/08	28
2008/09	4
2009/10	99
2010/11	49
2011/12	111
2012/13	24
2013/14	0

Year	General security (%)
2014/15	0
2015/16	123
2016/17	9
2017/18	0
2018/19	46

Source: NSW water register, as at 9 July 2019

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 the next section.

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.

An annual accounting system is used in the Upper Namoi, with allocation to general security water users based on storage volumes in Split Rock Dam in accordance with clause 37 (2) of the Namoi WSP.

A **continuous accounting** system is used in the Lower Namoi regulated river system to allocate the water available for diversion by all licensed water users and 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. The transmission and operational loss (TOL) account receives 30% of the volume credited to the water user bulk accounts.
- If the 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 Namoi WSP, a **continuous accounting system** operates for general security, with individual accounts for each licence allowed to maintain up to 200% of their entitlement within their account at any one time. From the commencement of the Namoi WSP in 2004 to 2016 the annual water use limit was 125% of the share component, provided not more than 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.

Two key information sources were used to inform the modelling:

- the Namoi WSP
- 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 26.

Table 26. Key parameters for modelling of continuous accounting

Component	Comment
Debiting type	Water order
Timestep	Daily
Assigned storages	Split Rock and Keepit Dams. 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	General security licences – 30%
Usage limits	General security– 1 ML/year
Account limits	General security– 2 ML/share account limit
Allocation limit	Local water utility, domestic and stock, high security– 1 ML/year
Storage loss reserve	As per storage reserve calculations used in water allocation determinations
Essential supplies reserve (including delivery)	Included in the storage loss reserve calculation above

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 are a number of restrictions to trade to protect supply to all other water users, including between the Upper and Lower Namoi water sources, into the Pian/Gunidgera Creek system, and trade from above Mollee Weir to below Mollee Weir (for high security licences).

There is direct hydrologic connectivity between the Namoi and Peel regulated river systems, and inter-valley trade is permitted within the limits set in each river system's WSP.

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 25 and Figure 26 show permanent trading within the regulated Upper and Lower Namoi River system respectively. All entitlement categories (including supplementary) are included.

Figure 25. Annual permanent trade of licence shares in the Upper Namoi from 2004/05 to 2015/16 (DPI Water, 2017)

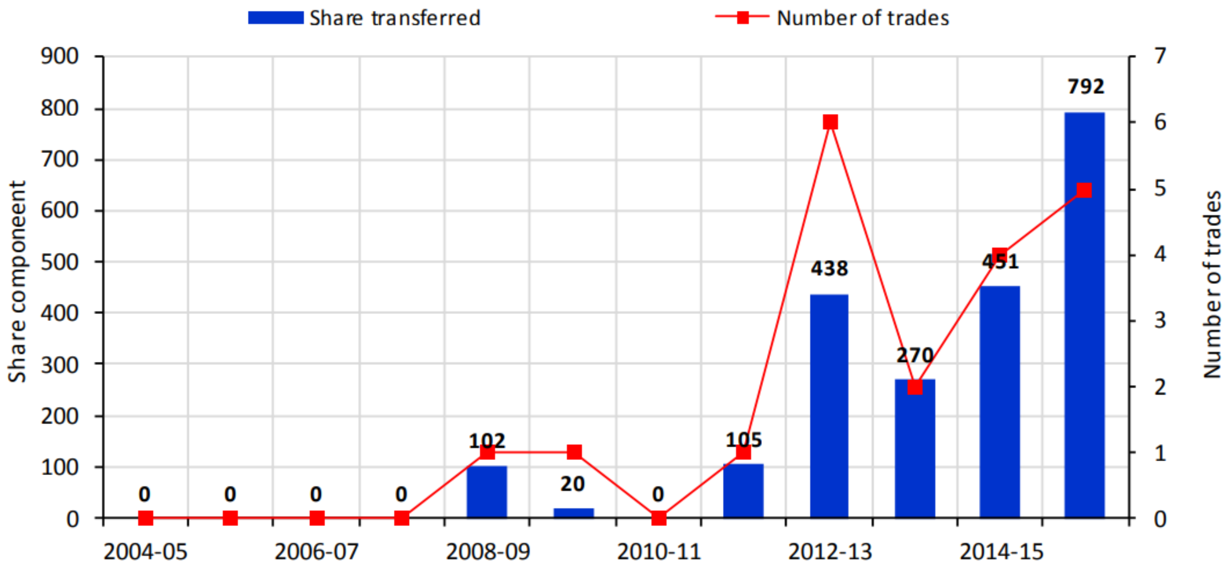


Figure 26. Annual permanent trade of licence shares in the Lower Namoi from 2004/05 to 2015/16 (DPI Water, 2017)

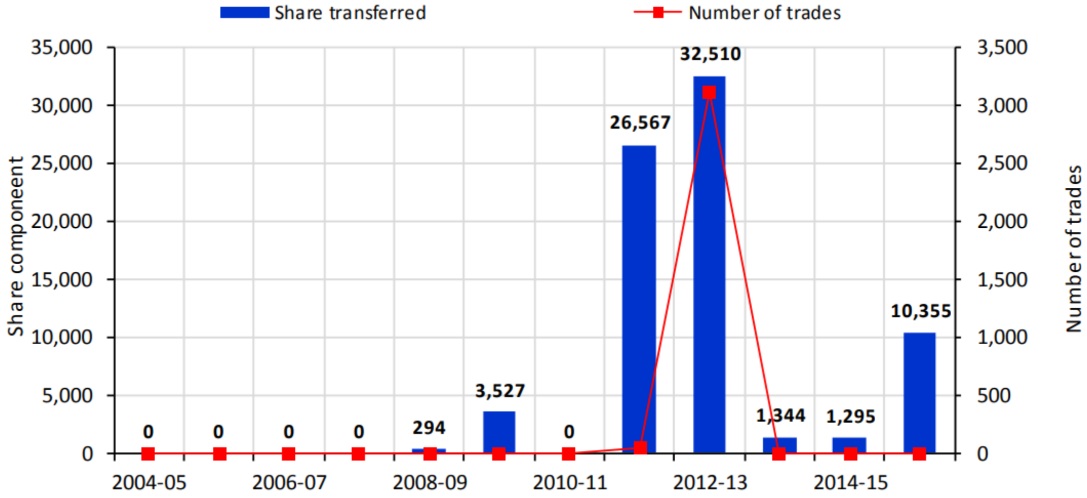


Figure 27 and Figure 28 show temporary trading within the regulated Upper and Lower Namoi River system respectively. All licence categories (including supplementary) are included.

Figure 27. Annual temporary (including intervalley) trade of allocations (volumes) in the Upper Namoi from 2004/05 to 2015/16 (DPI Water, 2017)

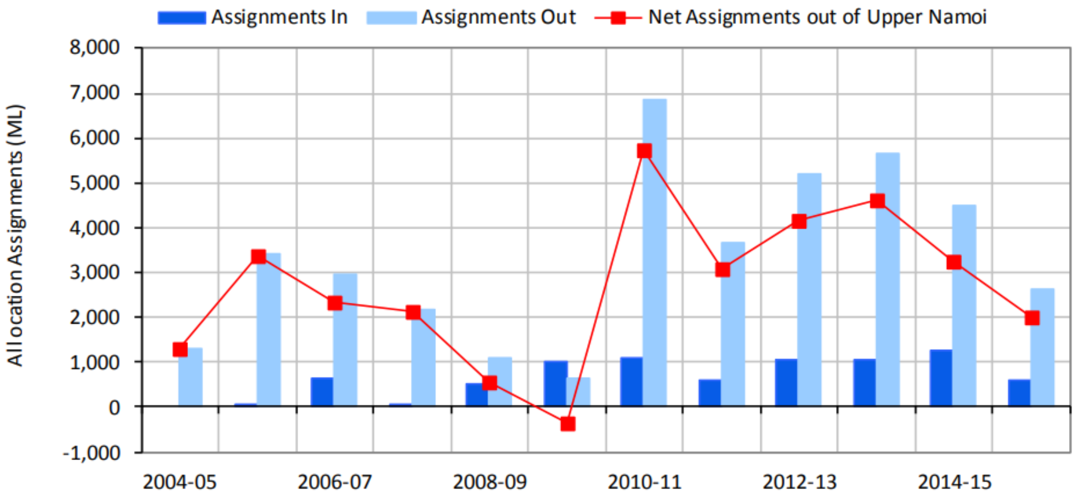
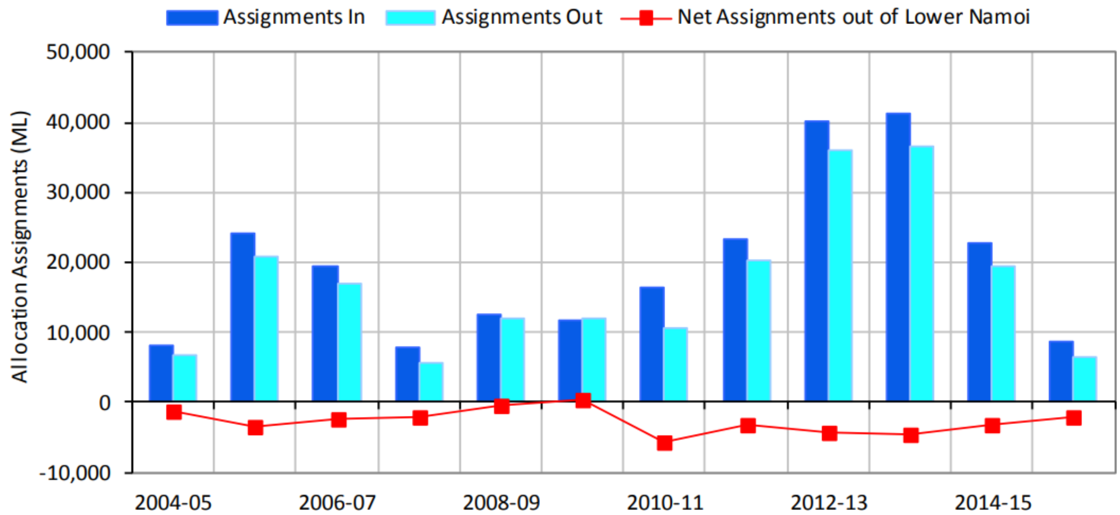


Figure 28. Annual temporary (including interstate) trade of allocations (volumes) in the Lower Namoi from 2004/05 to 2015/16 (DPI Water, 2017)



7.3.2 Modelling approach

Water trading is not explicitly represented in the model. The omission was necessary due to lack of trade data before 2004 and software limitations. When assessing the results of the model (section 8), any water trades that occurred are taken into account.

7.4 Planned environmental water

Supplementary flow sharing

The Namoi WSP requires that supplementary access is only available when flows exceed certain thresholds (shown in Table 11), and that a proportion of the volume of water above the flow thresholds is reserved from access to improve environmental outcomes along the Namoi River.

The proportion of the supplementary flow event volume available for access by licensed water users in any water year is

- from 1 July to 31 October, 10% of the event volume
- from 1 November to 30 June, 50% of the event volume

Minimum flow requirement

Clause 14(2) of the Namoi WSP requires that, in the months of June, July and August, a minimum daily flow which is equivalent to 75% of the natural 95th percentile daily flow for each month shall be maintained in the Namoi River at Walgett. However, if the sum of the water stored in Keepit Dam and Split Rock Dam is less than 120,000 ML, the flow requirement is not required to be met.

7.4.1 Data sources

WaterNSW prepares reports on compliance with rules set out in the Namoi WSP each year. These reports set out 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

Environmental flow rules to represent environmental releases described in Namoi WSP have been configured into the model as described in Table 27.

Table 27. Configuration of key environmental flow provisions in the model

Environmental flow provision	Configuration
Supplementary flow sharing	The flow available above the supplementary access flow thresholds in each river reach is calculated each day and reduced according to the flow sharing requirements set out in the Namoi WSP.
Minimum flow target at Walgett	An order for the required flow is generated at Walgett, and this is met when required with additional releases from Keepit Dam.

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.

In anticipation of Keepit Dam being drawn down, water is periodically transferred from Split Rock Dam down to Keepit Dam to ensure demand for allocated water can continue to be met. These bulk transfers of water are undertaken to maintain sufficient water in Keepit Dam to meet peak irrigation demands.

In general, the storages are operated to maintain Split Rock Dam as full as possible and transfer water to Keepit Dam as required until water must be retained to ensure regulated demands upstream of Keepit Dam can continue to be met. Keepit Dam is often unable to release the peak summer demands just using the valves (2 valves and hydroelectric station). Due to flow constraints in the Manilla River, operators are required to predict the peak demand on Keepit Dam, and the likely overall seasonal usage, and transfer the water down to Keepit Dam before summer begins.

Gunidgera Creek is a natural effluent of the Namoi River, with a regulator constructed across it adjacent to the Namoi River. The regulator and associated weir across the Namoi River are operated to divert water into the Gunidgera-Pian Creek system to meet water orders and provide access to supplementary flows. When high flows occur that exceed the capacity for the weir and regulator to control them, the gates are usually removed. Smaller surplus flows that are too small to be feasibly shared as supplementary access are often directed into the Gunidgera-Pian Creek system to provide a more equitable share of overall supplementary access, and to meet the requirements for stock and domestic replenishment flows in the lower Pian Creek where possible. Less frequently, additional flows are diverted into Gunidgera Creek and then allowed to flow along Gunidgera Creek back to the Namoi River to replenish the lower Gunidgera Creek.

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 takes into account forecasted inflows when determining how much water needs to be released from Split Rock and Keepit Dams to meet orders, reflecting operator practice. This part of the model is based on the existing IQQM parameters, which were configured using advice from WaterNSW river operators.

The model allows us to forecast a rate of inflow from an unregulated tributary based on the previous timestep flow. The forecast inflow is defined as yesterday’s inflow multiplied by a factor. The adopted values are summarised in Table 28. 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 28. Confluences with a forecast inflow of zero are not shown in Table 28.

Table 28. Adopted tributary recession factors to forecast rate of inflow from unregulated tributaries

Tributary	Tributary recession factor (trend forecast rate)
Peel River	0.9
Mooki River	0.9
Baradine Creek	1
Brigalow Creek	0.3
Coxs Creek	0.7
Manilla River	1
Maules Creek	1

Bulk transfer rules

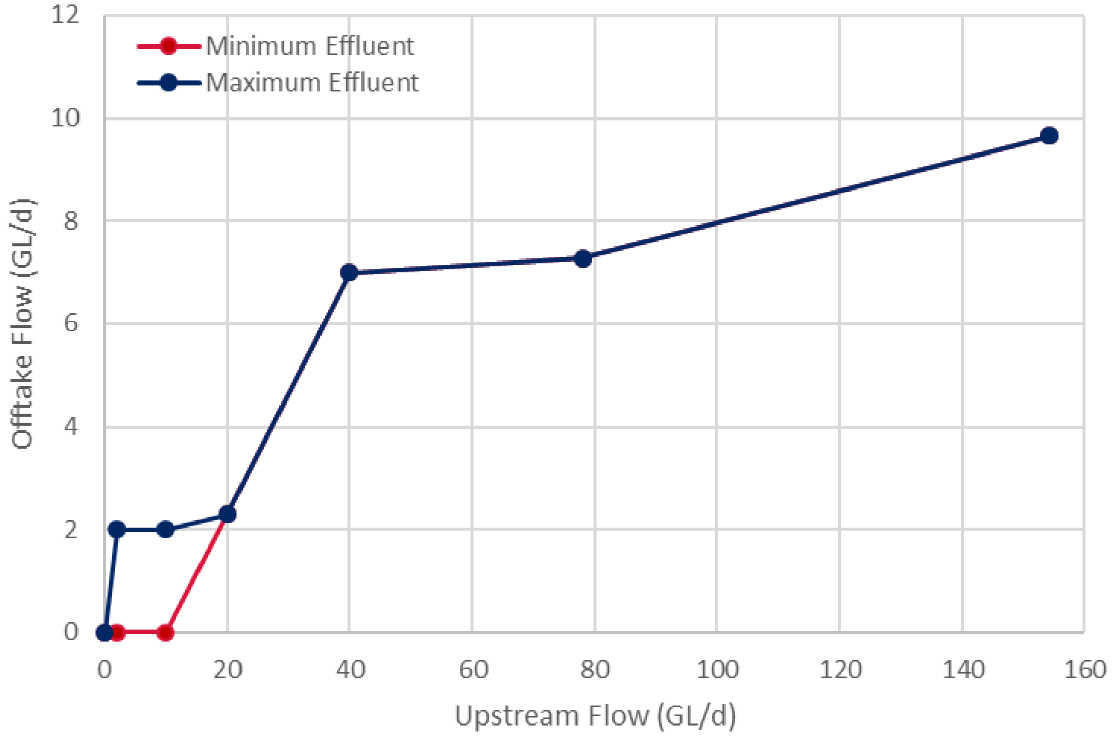
Transfers are undertaken when Keepit Dam is unable to meet downstream demands, with additional releases made at a constant rate of 2,000 ML/day, until inflows occur or demands reduce and Keepit Dam is able to meet downstream orders again, or Split Rock reaches the minimum reserve for ongoing supply to users in the Upper Namoi River system (19.4 GL + Upper Namoi general security account balance x 1.6).

Gunidgera Weir operation

Gunidgera Creek is a natural effluent of the Namoi River, with a regulator constructed across it adjacent to the Namoi River. When flows exceed the capacity for the weir and regulator to control them, an effluent flow relationship (i.e. a relationship between flows continuing down the main river and flows entering the creek system) is used. This regulator is represented through a regulated splitter node. These nodes allow water to be ordered from the Gunidgera-Pian Creek system bounded by a minimum and maximum flows shown in Figure 29.

The maximum flow relationship represents flows down the effluent when the gate is fully opened on the offtake regulator. The minimum flow relationship represents uncontrolled flows down the effluent when flows exceed the capacity for the weir and regulator to manage them (i.e. during high river flows). This relationship has been established by deriving a relationship between simulated flows upstream of the effluent and gauged flows at the offtake).

Figure 29. Maximum and minimum offtake flow relationship used at Gunidgera offtake



Diversions are made in the model to meet orders up to channel capacity, and supplementary flows are shared between the main river and the Gunidgera-Pian Creek system based on supplementary water access licence shares.

To simulate the diversion of smaller surplus flows that are too difficult operationally to share as general supplementary access into the Gunidgera-Pian Creek system, a relationship between river flows and offtake flows was calibrated based on observed flows. The model diverts the greater of the calibrated relationship or the modelled water orders in the Gunidgera-Pian Creek system.

At Knights Weir, all flows are directed into the Pian Creek, and a relationship was developed to simulate the small amount of flow that does pass the weir into the lower Gunidgera Creek.

Table 29. Model representation of operation of Gunidgera weir and regulator

Rule	Model parameterisation
Water is diverted from regulated flows into Gunidgera Creek to meet the greater of: • water orders, (including for domestic and stock replenishment), or • flows based on a relationship between observed flows into the Gunidgera Weir pool and flows into the Gunidgera Creek offtake.	Water orders: based on demand, limited to channel capacity Relationship between upstream flows and offtake flows developed using the FORS package.
When flows in the Namoi River are in excess of those required to meet water orders and other requirements under the Namoi WSP, flows are shared between the Namoi River and the Gunidgera-Pian Creek system to provide equitable supplementary access, up to the channel capacity limits in the Gunidgera-Pian Creek system.	Based on supplementary access shares, limited to channel capacity.

7.6 Replenishment flows

A volume of up to 14 GL/year is set aside in the major storages to provide a replenishment flow to the lower Pian Creek for stock and domestic purposes. If there are no naturally occurring high flow events to provide flows through the lower Pian Creek, a replenishment flow may be provided in up to two separate events, typically with one event in late winter/early spring, and another in late summer/early autumn. The timing of these flows is set by WaterNSW in consultation with local landholders.

Where possible, these flows are provided using supplementary flows. If supplementary flows do not occur, or are insufficient, additional releases are made from storage.

The objective for each event is to achieve a visible flow at the flow gauging station on the Pian Creek at Waminda for at least 5 consecutive days.

7.6.1 Data sources

Flow information is available for the flow gauging stations on the Pian Creek at Dundee Weir and Waminda. Water NSW also keep operational records of the volumes of water released from storage and diverted at Gunidgera Weir to deliver replenishment flows.

7.6.2 Modelling approach

A six-month flow volume target of 1,000 ML/day has been configured in the model. During August-September and February March each year, if the flow volume target has not been met over the previous 180 days, then a replenishment flow is ordered at the end of the regulated Pian Ck system (Waminda).

Replenishment flows are ordered at a daily rate of 50 ML/d over 12 days (~ 600 ML replenishment), to match observed replenishment flows.

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 Namoi Valley model.

For flow calibration, 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.

We measured whether there is sufficient water from all sources, including floodplain harvesting, to irrigate the historical crops, at valley, reach and property scale (some variation is allowed for given known differences in irrigation behaviour, potential inaccuracy of metered diversions and historic ineligible harvesting).

Appendix L details which version of the model has been used to report results in this section.

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, can determine whether model performance is better or worse than an alternate model
- 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 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 vs 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.

The assessment criteria/methods are summarised in Table 30.

Table 30. Overview of assessment criteria

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 Table 37)
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 Interannual variability in runoff depth
Overbank flow harvesting	How well frequency and volume of overbank flows are simulated	Observed vs modelled commence to flood and moderate flood events
Total irrigation water use (farm water balance)	How well metered diversions are reproduced at valley and reach scale and how well historic irrigation areas are reproduced	Observed vs modelled & measure of model bias (%) Sensitivity testing to variations in simulated crop water demand
Planted areas	How well historic irrigated areas are simulated	Annual total crop area compared to 2003–2016 farm survey data; filtered to exclude gaps in survey record
Metered diversions	How well general security and supplementary access metered diversions are simulated	Total, general security & supplementary access diversions over full 2004/05 to 2014/15 period (and first 4 and second 6 years of this period) compared to observed, model bias (%) metric
Supplementary access diversions	How well announced periods of supplementary access	Graphical comparison to announced periods
Storage operation & harmony management	How well storage volumes are simulated	Daily time series of storage volumes compared to observed
Weirs and regulators operation	How well flows into Boomi River are simulated	Monthly average flows compared to recorded lows

8.1.2 Model validation

The last step in the flow calibration process was to develop a validation model by amalgamating the individual reach models. The validation model is used to confirm the performance and accuracy of the model run as a complete system and provides a foundation for the development of scenario models.

The model that we have assembled using various calibrated model elements has been configured as a scenario that is representative of the assessment period. This allows us to evaluate the overall model performance by comparing model results with observed data over the period of calibration. For the Namoi Valley model, the diversions and water management components have been assessed over the period 2004 to 2015, which is a period that also includes key benchmark years for the policy and the Basin Plan. To ensure that our assembled model is able to simulate all of the key processes (flows, diversions, water management), a scenario has been configured to represent the 2008/09 level of development[18]. We refer to this as the 2008/09 Scenario.

The 2008/09 water year was selected for this validation scenario as it is in the middle of the assessment period for many of the model components, and it represents a key date for the issuing of floodplain harvesting licences (only floodplain harvesting works constructed or applied for by 3 July 2008 are eligible for consideration) and the Basin Plan (1 July 2009 is the baseline point from which the requirements of the Basin Plan were set).

We know that there were changes in irrigation infrastructure development over the assessment period. However, in the Namoi Valley, there was only minor change in irrigation development levels between 2008/09 and 2015/16 (generally less than 4% in this period). There was more significant irrigation infrastructure development between 2004/05 and 2008/09, mainly for floodplain harvesting activities, however, there are only small volumes of floodplain harvesting simulated in the first few years. It is likely that water availability, rather than infrastructure, is the constraint in this period.

We considered any changes in irrigation infrastructure and water management rules that actually occurred over the comparison period when reviewing results[19].

8.2 Flow simulation assessment

To assess flow simulation, releases from headwater storages are forced to recorded data and diversions are also forced using metered data.

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. The methods to calibrate the models are intended to reproduce those characteristics.

The NSW and Queensland departments have developed a workflow to standardise the reporting of results for all flow comparisons. The results include multiple metrics as no single metric alone can

[18] This scenario is configured with all eligible storages, which includes one storage built post 2008.

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

inform the suitability of a model result for a particular purpose. Key metrics are listed in Table 31. A subset of results from the workflow reporting is described below and summarised in Appendix K for all flow calibrations.

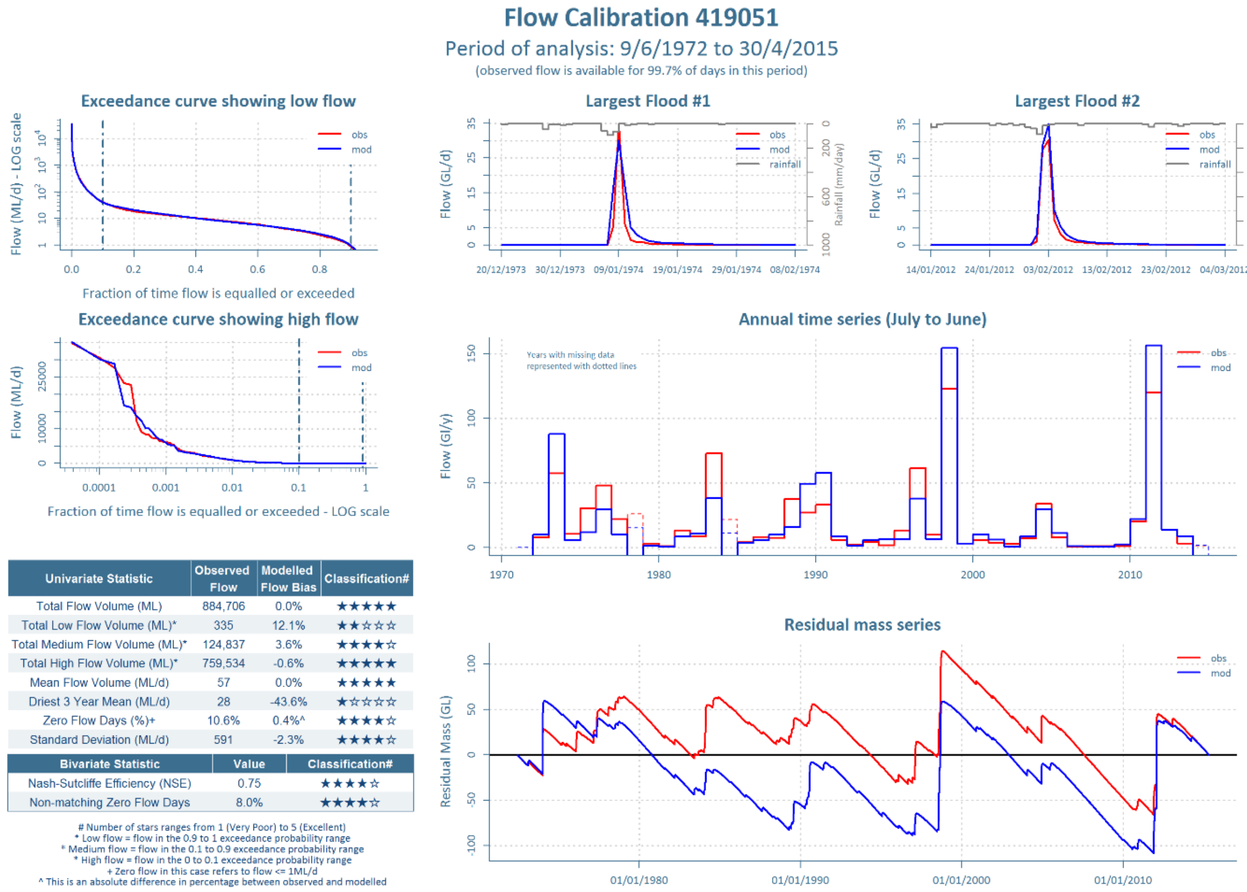
These multiple lines of evidence are presented as a report card (Figure 30) and show the degree to which the model has reproduced the quantity, distribution, and variability of streamflow that affects water availability for allocation, as well as instream variability for supplementary access, overbank flow harvesting, and environmental flows.

Headwater inflow rainfall–runoff modelling Further information on events is presented at section 8.3.1 for a key location at Gunnedah that demonstrates how well daily variability relevant to overbank flows has been reproduced.

Table 31. Flow metrics used to assess flow calibration

Metric	Importance
Tabular metrics	
Station Number	Identifier and location
Mean Annual Flow (MAF)	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 vs observed
Runoff % of rainfall	Confidence in water balance if spatially coherent and within published ranges for rainfall vs evaporation
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

Figure 30. Example of graphical comparison of flow calibration reported in Appendix J



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	884,706	0.0%	★★★★★
Total Low Flow Volume (ML)*	335	12.1%	★★☆☆☆
Total Medium Flow Volume (ML)*	124,837	3.6%	★★★★☆
Total High Flow Volume (ML)*	759,534	-0.6%	★★★★★
Mean Flow Volume (ML/d)	57	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	28	-43.6%	★☆☆☆☆
Zero Flow Days (%)+	10.6%	0.4%^	★★★★☆
Standard Deviation (ML/d)	591	-2.3%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.75	★★★★☆
Non-matching Zero Flow Days	8.0%	★★★★☆

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

8.2.1 Headwater inflow rainfall-runoff modelling

These results refer to Appendix J with reference to the flow metrics listed in Table 31. A separate model for the Peel River valley has been built, and the observed outflows from the Peel River at the Carroll Gap flow gauging station have been used in this assessment. The Peel Valley model has been used to provide modelled long-term flows as an input to the Namoi Valley model, with modelled flows at Carroll Gap taken from the Current Condition Scenario, which is reported separately (ref PeelE120.sqq). Within the period 2004-2020, there is an average of 140 GL/year of inflow into the Namoi from Carroll Gap.

Mean annual gauged inflows for the catchments range from 17–250 GL/y, and collectively account for 563 GL/year of inflow, with runoff coefficients in the range 3-12%. These runoff coefficients have a west–east increasing trend, reflecting the rainfall gradient. The spatial coherence of these demonstrates the robustness of the rainfall–runoff modelling process, as the major water balance components of rainfall and evapotranspiration are varying in a structured way.

Daily Nash-Sutcliffe values ranged from 0.59 to 0.75. These results are influenced most of all by the representativeness of the rainfall data used, which may mean that individual events are not well represented. Importantly, the distribution of flows is well represented. In the case of the smaller catchments below the headwater storages, the Nash-Sutcliffe values tend to be lower, as flows tend to be susceptible to local variations in rainfall that are not reflected in nearby rain gauging stations as well as quality of flow gauge data. However, this is not likely to be significant for larger flow events that result in overbank flows.

Flow biases across the full flow range are in all cases zero. This close match is not surprising as flow bias has a high weighting in the automated process. The distribution across the flow ranges varies considerably more, with biases of up to ±31% for the low flow range, and a number of instances where the low flow range is dominated by zero flow days and the volumetric comparison was not meaningful. The discrepancies are much less for the medium flow range (mostly less than ± 4%) and for the high flow range (less than -0.6%). The larger discrepancies in the low flow range are not a great concern in the context of the model suitability. In most cases, this describes flows less than 5 ML/day for a tributary in the lower reaches and would not affect operational decisions or water availability calculations.

There is good agreement in the **flow exceedance** graphs, however some divergence does occur for extreme high flows (Figure 54 to Figure 59). The matching of the highest flows is difficult as it is particularly sensitive to rainfall totals on rare events. The inter-annual 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

These results refer to Table 50 and Figure 60 to Figure 71 in Appendix J with reference to the flow metrics described in Table 31. The results are for the fully assembled flow calibration model. This is referred to as the Validation model as described earlier.

Mean annual flows at these gauging locations vary in the range 49 to 505 GL/year. These values are higher than for headwater inflows but represent larger catchment areas as flow accumulates along the system, as well as the effect of transmission losses and effluents in the reaches.

Daily Nash Sutcliffe values range from 0.72–0.98, with mean value of 0.87. These high values are one line of evidence that provides us with confidence that mainstream flows are simulated well.

The flow gauge at the bottom of the Namoi River at Walgett (419091) is affected by flows in the Barwon-Darling River, and by flows returning from the floodplain during larger flood events. This has caused poorer results for this flow gauge in most of the metrics. No overbank flow relationships use this flow gauge, and the next upstream gauge at Goangra (419026) performs satisfactorily.

Overall **flow bias** is within ±5%, with the exception of the last flow gauging station at Walgett, (419091) which is affected by flows in the Barwon River. Examination of the related **graphs** indicate that this is heavily weighted to the medium and high flow periods.

The **medium range flow** results are generally within ±5%, with the exception of the second-last flow gauging station along the Namoi River at Goangra (-7%) and the last station at Walgett (-24%). The significant underestimation for Walgett is related to flow measurement uncertainty at that location due to backwater effects from the Barwon River. However, it is not likely to have an influence on simulated water use as this gauge is at the end of the Namoi regulated river system.

The graphical comparisons in Figure 60 to Figure 71 provide a summary of model performance. **Interannual variability** is closely reproduced in all cases. There is good agreement in the **flow exceedance** graphs, except at the extremes which diverge in some cases.

8.3 Water use simulation assessment

8.3.1 Irrigation

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 highly uncertain data for each individual property or group.

The available literature on average irrigation requirements uses variable definitions (i.e. whether it includes some or all losses) which makes comparison difficult. Publications which 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 taken into account in order to compare to model assumptions

For the first floodplain harvesting models developed in the Border and Gwydir Valleys, four independent data sources or methods were used to assess the model estimates; farm surveys, WaterShed Pro software, IrriSAT remote sensed data, and Australian Bureau of Statistics (ABS) data. These tests are described in more detail in the model build reports for those valleys (DPIE Water 2020, 2021). The tests found that the independent methods described above have their own sources of uncertainty as truly representing crop water use for both specific periods and long-term averages. Overall, the testing of the approach taken to model irrigation crop demands for the Border and Gwydir indicated that modelled results compared reasonably well to the other methods.

The Namoi Valley model has used the same approach to configure crop water demands, using climate data in the Namoi Valley, and these earlier test results provide confidence that this is a robust estimate.

Rainfall-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 crop water model used to determine irrigation application rates. This was described in section 5.4.2.

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 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 do not appear to be a significant issue for a long-term simulation period. These considerations led to our decision to match these long-term averages to the best available data sources available.

Simulated **rainfall–runoff rates** are summarised in Table 32. The runoff rates from both fallow and irrigated areas are in line with the results from the literature review described in Appendix F.

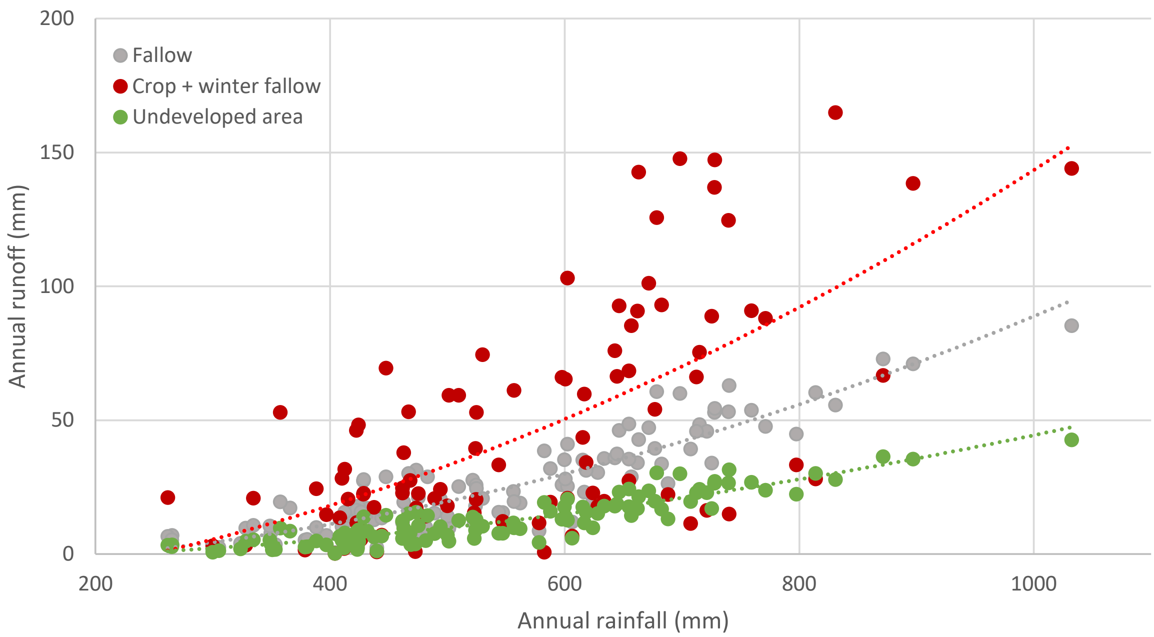
The **interannual variability in runoff depths** from climate variability is well represented (Figure 31). As well as reinforcing the relative rates of runoff response summarised in Table 32, this also shows a clear relationship of higher annual runoff depths with more annual rainfall for each land use type.

Table 32. Rainfall-runoff rates for Boggabri climate (calculated as total runoff over the period divided by total rainfall)

Area	1950 to 2000
Summer irrigated + winter fallow	8.7%
Continuous fallow	4.8%
Undeveloped	2.4%

Note: The same parameters are applied for other climate stations however a small amount of variation occurs due to differences in rainfall characteristics.

Figure 31. Annual runoff depth (mm) compared to annual rainfall (mm) for 3 on-farm land area types: fallow, crop + winter fallow and 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 a number of 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.
- bias in rainfall–runoff rates may be in part offset by a bias in overbank harvesting estimates. Any revision should consider data for both sources.

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 as described in section 6.2. The opportunity to harvest overbank flows depends in part on their frequency and volume. This ability of the model[20] to reproduce these is shown at Figure 32, with summary statistics reproduced at Table 33.

These show that the modelled **frequency of overbank flow events** closely matches the observed behaviour, particularly for the more recent 32 years. The number of **moderate flood events** since 1981 is close to observed and the number of **events above the commence to break flow** is the same as observed (Table 33). Prior to this period the modelled data has fewer events than observed flow data would indicate, however more weighting would be given to the more recent behaviour as there are better data for this period.

The analysis depends on what assumption is made about how to define separate events; this analysis used a 5 day interval (i.e. if 5 days separate flow above the threshold, they are defined as separate events). If two events occur within a few weeks of each other, it may make no difference to results as the storages may have already been filled. If a larger interval between events were assumed in this analysis, then the simulated and observed results would be a closer match.

Volumes above the commence to break flow threshold are close, with a -1% bias overall.

Figure 32. Annual modelled vs observed events at Gunnedah above moderate flood threshold

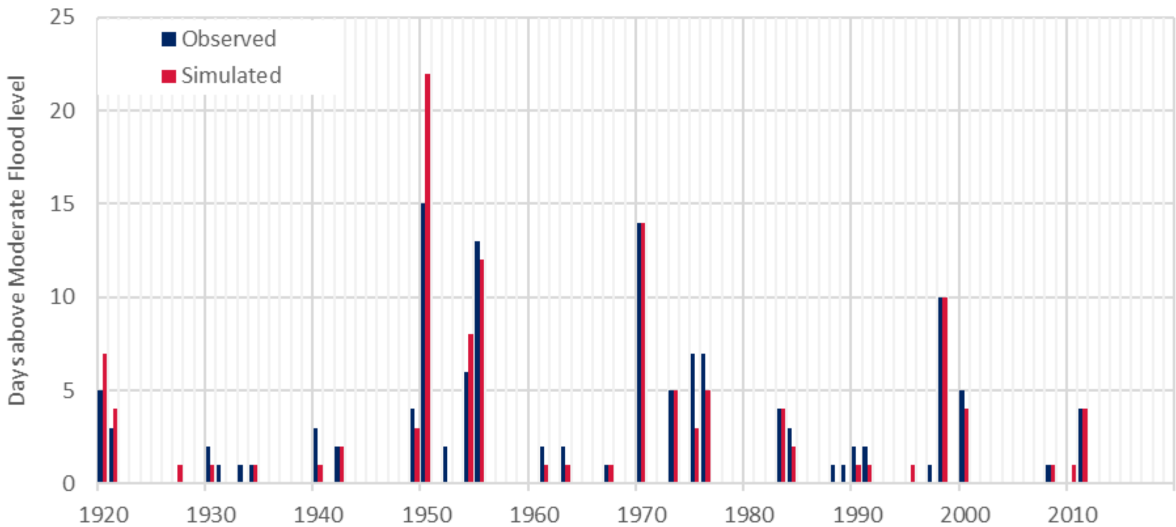


Table 33. Total observed vs modelled events at Gunnedah above flood thresholds (1920-2020)

Periods	Observed	Modelled	Bias
Minor flood events (>40,000 ML/day)			
Total days above threshold	181	173	-4%
Moderate flood events (>50,500 ML/day)			
Total days above threshold	130	121	-7%

[20] The flow validation model is used for this purpose as described in Appendix M

Apart from the data that were analysed to form the breakout relationships, there are no other data that can be used to validate the volume on the floodplain during an event[21]. We have investigated whether it will be possible to use remote sensing data to estimate change in on-farm storage volumes during an event. This type of data could provide more confidence than looking at volumes on the floodplain, as not all water can be and is diverted[22]. 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. 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 crops may not always be fully irrigated, and this is evident in the comparison between the two test models described earlier.

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

These checks were performed at 3 scales:

- whole-of-valley scale
- reach scale
- property scale.

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. Table 34 shows that valley total results are close to the observed data, with no overall bias in estimating diversions.

Table 34. Total metered diversions for floodplain harvesting properties (GL) (7/2004-6/2014)

Sub-region	Observed (GL)	Simulated (GL)	Model bias (%)
Namoi River upstream Gunidgera Weir	551	576	4%
Namoi River d/s Gunidgera Weir	320	359	12%
Gunidgera-Pian Creek system	529	462	-13%
Total	**1,401**	**1,396**	**0%**

[21] 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.

[22] Our long-term model results indicate that the proportion of breakout water harvested are generally not a limiting factor in determining overall volumes harvested.

Reach scale results should be reasonable to indicate that the distribution between reaches is consistent. Table 34 shows that there is a bias towards the main river stem compared to the Gunidgera-Pian Creek system. The flow constraint at the Gunidgera Creek offtake significantly limits water use in the Gunidgera-Pian Creeks system at times, and there are operational practices that occur in practice to manage the impacts, such as rostering, pre-ordering and sharing strategies to make supplementary access more equitable. The model represents some of these management practices, however, there remains a moderate bias in diversions.

This water balance check at 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 is also assessed – comparison to farm surveys, nearby properties, remote sensing etc.

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 is made for some variation in water balance results at individual properties. The accuracy of metered water use is also expected to vary and this may cause differences in the water balance result, as will any ineligible historic harvesting.

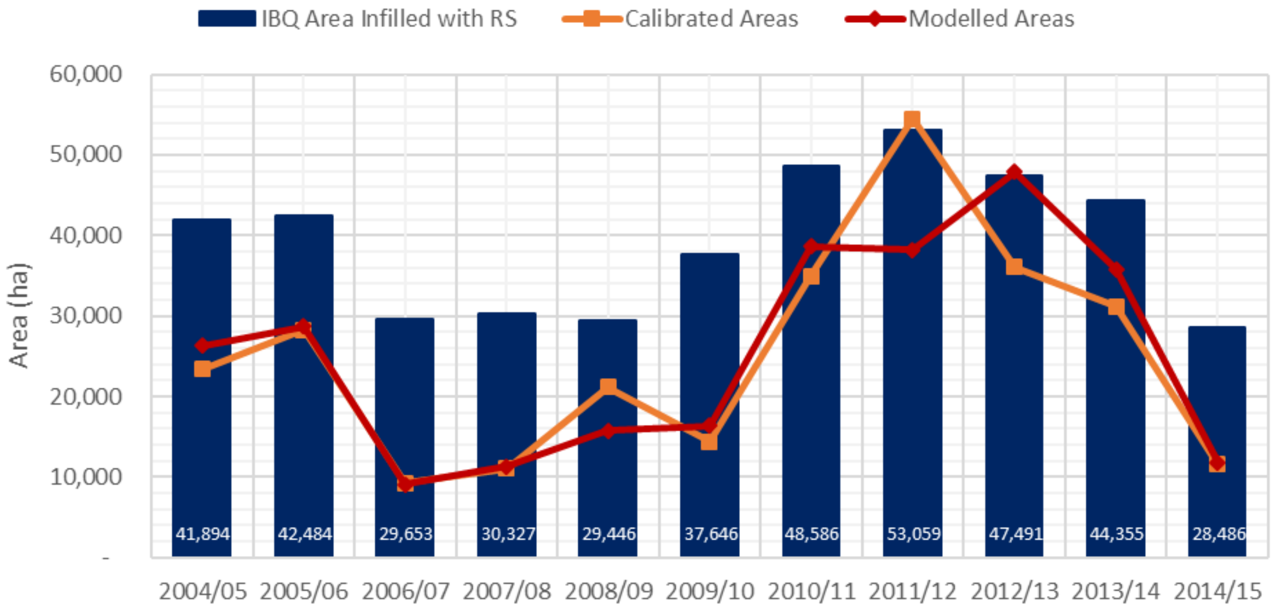
8.3.2 Planted areas

The Namoi 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 crop areas from the final fully assembled Source calibration model using 2008/09 conditions were compared to the observed data over the 2004–2015 period.

The modelled **planted areas for individual properties** are in reasonable agreement with those reported in farm survey data (Figure 33). There are some gaps in the farm survey record, and it is not clear whether no irrigated crop was grown or whether the area was unknown. For this reason, the modelled data have been presented for both total crop area and for area filtered to exclude gaps in farm survey records.

Figure 33. Observed (farm survey total) and modelled total and total filtered for gaps in the farm survey data for summer crop areas for floodplain harvesting properties



The calibrated model represents well the **seasonal variability in the area planted** in response to water availability. There are no individual years where there is a significant mismatch between observed and modelled crop areas and the overall bias between observed and simulated areas over the validation period is 2%. In some of the earlier years, it appears that the model is slightly underestimating planted areas. This may be offsetting possible over-estimating of application rates in those years.

8.3.3 Metered diversions

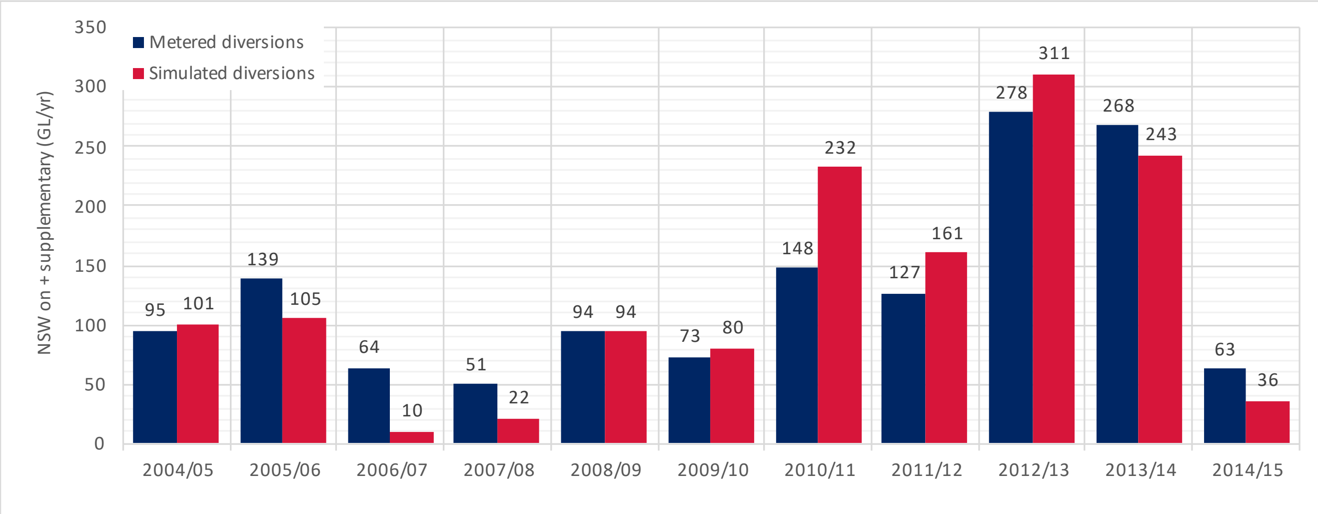
Results of simulated diversions from the fully assembled, calibrated model for the 2008/09 Scenario were compared with recorded diversions. This scenario simulates all system operations and management rules such as supplementary announcements and general security allocations. The totals for the 2004/05 to 2014/15 comparison period are illustrated in Figure 34 with summary results reported in Table 35.

The model under-simulates **total diversions** from the river by less than 1% over the assessment period. The model slightly over-simulates **general security diversions and** slightly under-simulates **supplementary access diversions for the period as a whole.**

Table 35. Total simulated and observed metered diversions from 2004/05 to 2014/15

Diversion type	Observed diversions (GL)	Simulated diversions (GL)	Bias (%)
General security	1,010	1,021	1%
Supplementary access	391	375	-4%
Total	**1,401**	**1,396**	**0%**

Figure 34. Annual modelled and observed (metered) diversions from 2004/05 to 2014/15



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 subjectivity to forecasting orders and flows made by river operators when assessing whether flows will be supplementary to requirements.

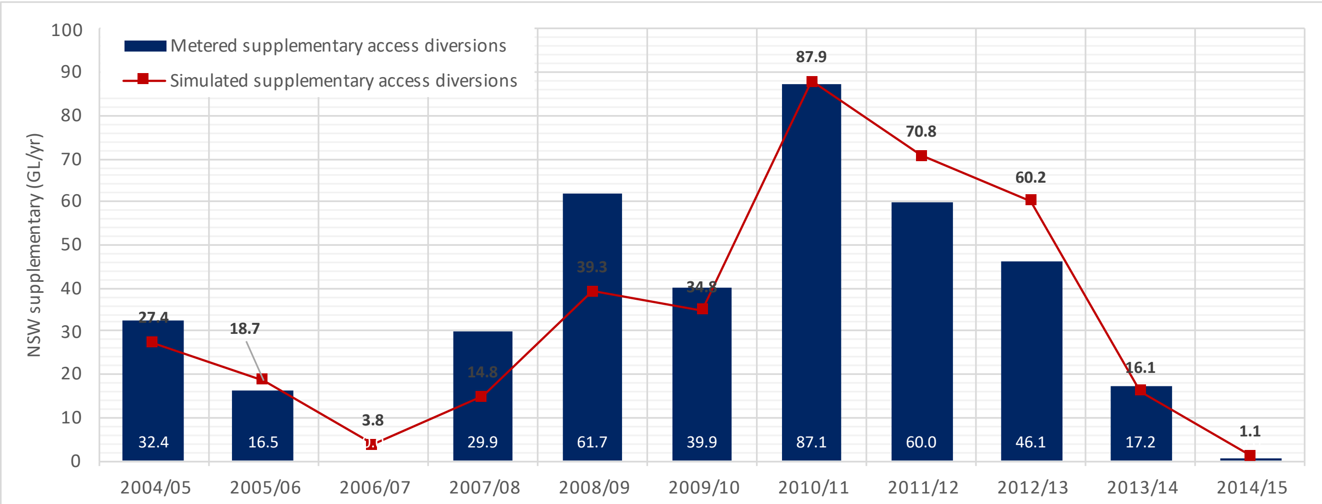
The results of the supplementary access diversions were reported as part of metered diversions in the previous section and show a slight underestimation of -4%. This section examines the announced periods of supplementary access in the model compared with data. The corresponding graphs are in Appendix K.

An examination of the model results indicates that actual announced periods of supplementary access are less frequent, but last longer than those modelled. The greater frequency of modelled supplementary access periods is likely due to the model not representing operational forecasting, instead responding to flows on a daily basis.

At times there can be mismatches in time due to smaller tributary inflows that are more difficult to simulate closely.

The model slightly underestimated **total** supplementary access diversions (Table 35). The modelled and observed **annual** supplementary access diversions in Figure 35 show that **inter-annual variability** is reproduced reasonably well. However, there is a tendency for the model to over-estimate supplementary access in wetter conditions (2010-2013) and underestimate it in the drier periods (2004-2009).

Figure 35. Annual simulated and observed (metered) supplementary access diversions from 2004/05 to 2014/15



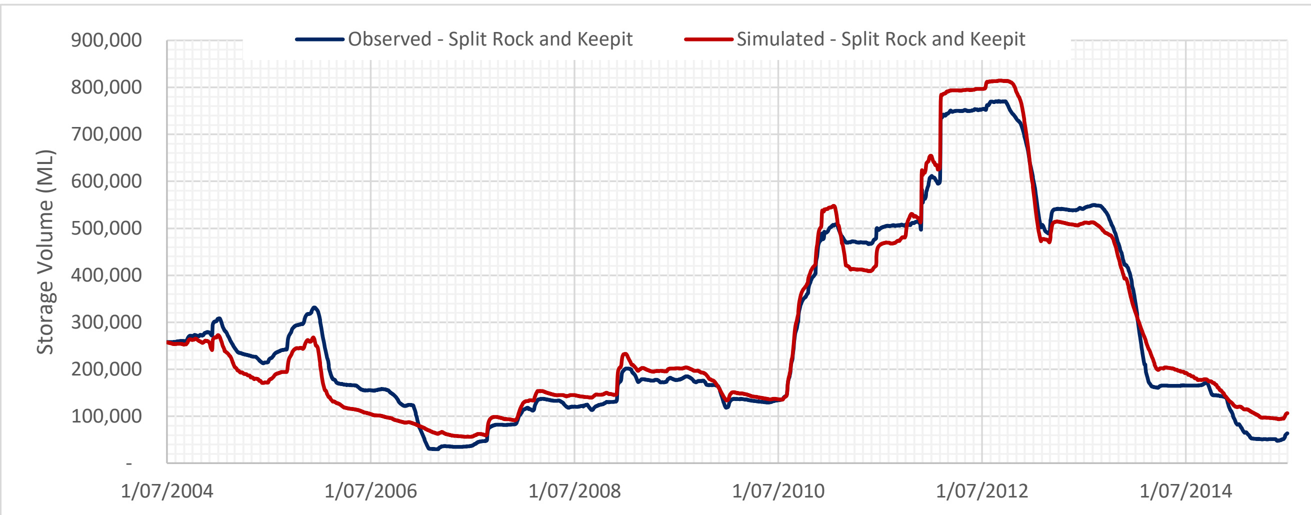
8.4 Water management rules

8.4.1 Storage and weir operation

Storage operation

The simulated combined storage volume from the 2008/09 Scenario for Split Rock and Keepit dams matches the observed combined storage volumes well over the assessment period (Figure 36).

Figure 36. Time series of observed vs simulated total storage volume at Split Rock and Keepit dams from 2004/05 to 2014/15



There can be multiple causes for variations in headwater storage volumes, including variations in annual planted areas, differences in management (e.g. supplementary announcements or block releases), and differences in inflows and in estimates of unmetered water use including floodplain harvesting.

A localised inflow event in 2004/05 downstream of Keepit Dam was not fully represented in the model, resulting in slightly lower modelled storage volumes for a few years. Block releases from storage were made in 2006 and 2014, which the model does not represent. This combined with small mismatches in the resource assessment led to a small storage drawdown that the model did not replicate.

Periodic differences in headwater storage volumes are to be expected, however if systematic issues emerge in future assessments, this will require amendment to be suitable for planning and compliance purposes.

Storage bulk transfer management

The simulation of storage volumes at each storage has also been compared to observed storage levels over the assessment period.

Figure 36 shows that the **bulk transfer** appears to be well represented by the model, although a smaller transfer in 2006 was not simulated, and the 2014 transfer was under-simulated. This was associated with the block releases not simulated by the model in those years.

Figure 37. Time series of Keepit Dam observed and simulated storage volumes from 2004/05 to 2014/15

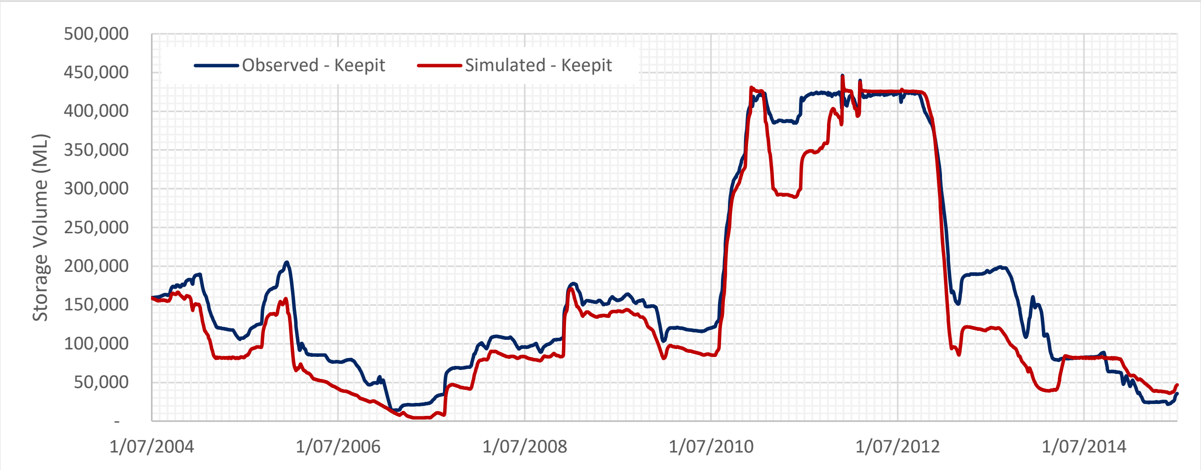
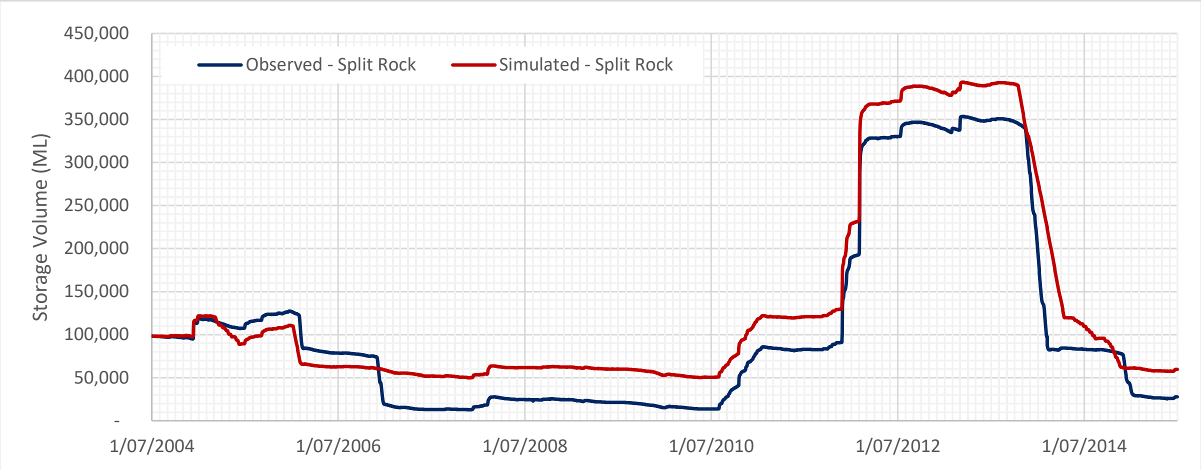


Figure 38. Time series of Split Rock Dam observed and simulated storage volumes from 2004/05 to 2019/20



8.4.2 Weirs and regulators operation

Gunidgera Creek offtake

Diversion of water into the Gunidgera-Pian Creek system is controlled by the operation of the regulator at the offtake. Simulated **monthly average flows** at the Gunidgera offtake regulator (419059) are compared to recorded flows in Figure 39. It shows that simulated flows are close to the recorded flows over the assessment period (+1.5% bias). Figure 40 show the simulated and recorded **daily flow** time series.

Figure 39. Monthly average Gunidgera Creek flows 2004-2015

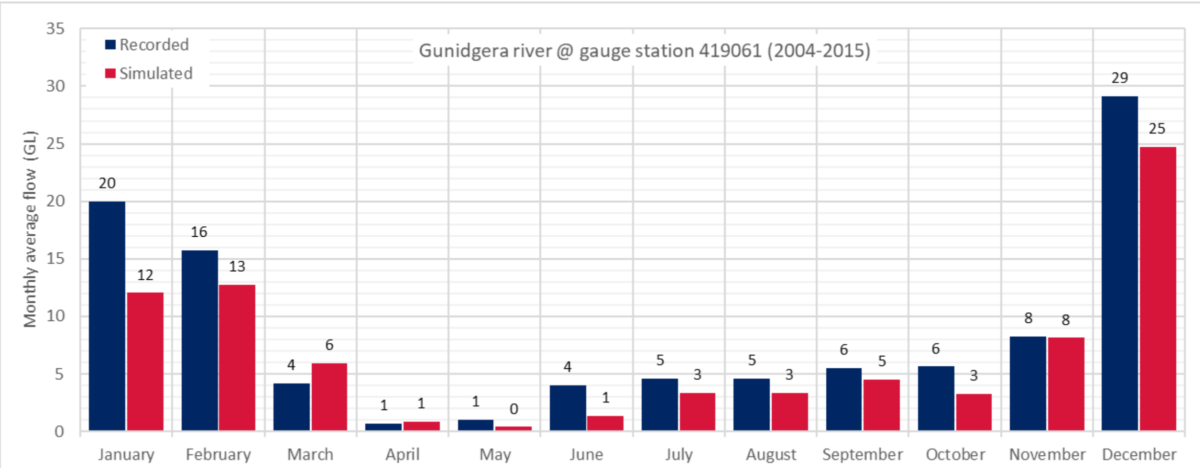
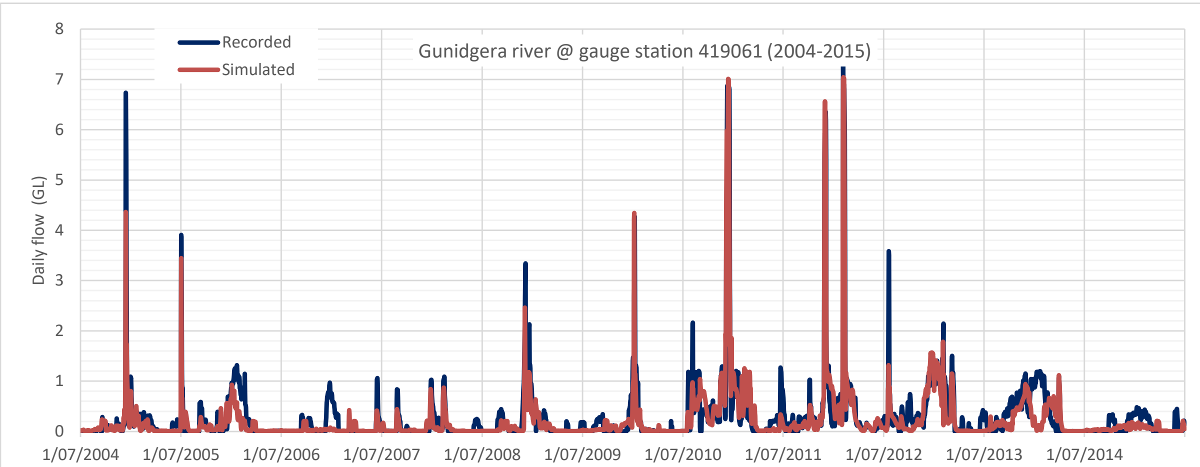


Figure 40. Daily time series of Gunidgera Creek flows 2004-2015

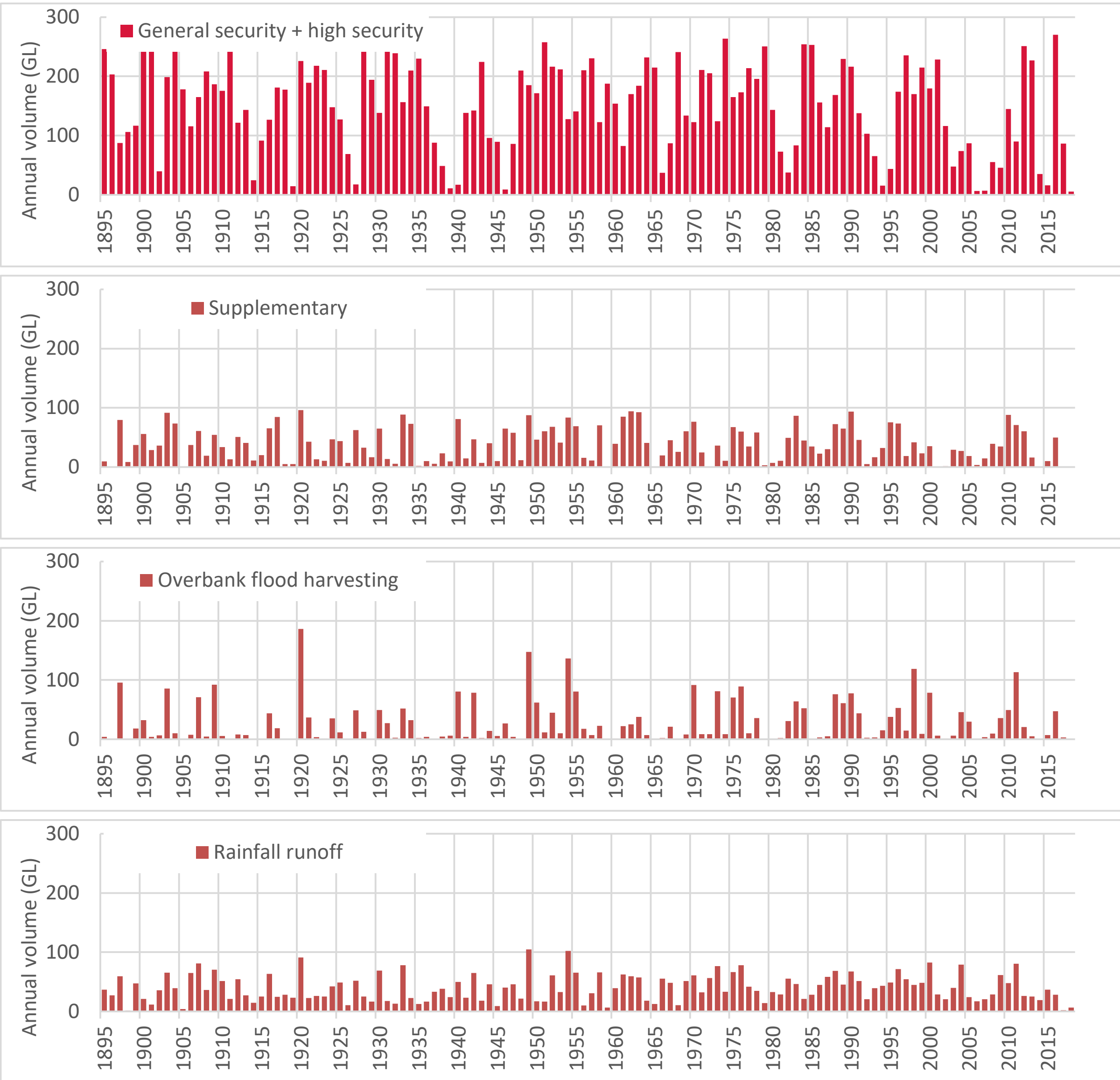


8.5 Long-term annual diversions

River system models are used to create a number of scenarios, which reflect different levels of development and management rules in the river system. For example, the *Namoi WSP* describes two scenarios which are used to determine the Plan Limit. We describe how we have updated the Plan Limit estimate in the companion Scenarios report (DPE Water 2022a) by modifying the baseline 2008/09 Scenario to reflect the scenarios required under the policy.

We have included some long-term results from the updated Plan Limit Scenario here (Figure 41) to illustrate 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 rainfall–runoff harvesting. **General security diversions interannual variability** reflects the impacts of climate and headwater storage. **Supplementary diversions show less interannual 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 interannual variability and reflects the occurrence of flow breakout events in Figure 32. **Rainfall–runoff harvesting** occurs more frequently, but generally at a reduced scale.

Figure 41. Simulated annual volumes of high and general security, supplementary access, floodplain and rainfall harvesting flow diversions over the period 1895 to 2009



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 below 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.

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 36 and Table 37 summarise the significance of a range of sources of uncertainty on the modelling of floodplain harvesting and the Plan Limit based on work undertaken in the NSW Border Rivers Valley and the Gwydir Valley. The summary below draws on the sensitivity testing undertaken for these other valleys.

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 37. 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 36. 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	n/a

Table 37. 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.	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 diversions have known uncertainties of up to 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
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

Source of uncertainty	Comment	Significance rating
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. 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. The sensitivity may be higher when considered in conjunction with other issues. Reducing this uncertainty further would require significant new datasets and investment in model refinements (which we are not planning to undertake)	Low
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 (1 m 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	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.	Medium for valley total Low for distribution

Source of uncertainty	Comment	Significance rating
	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. 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	
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, these 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 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 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[23]. These models were calibrated to several flood events against gauged flows, remote 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	Medium

[23] The FMP 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
	actual volume harvested will be sensitive to the breakout relationship and access to this flow. This will be reviewed using information from the floodplain harvesting measurement requirements.	
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. 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

9.2 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 have to access floodplain flows based on their location and climatic variability. The key components of the capability assessment are detailed in Table 38. The appropriateness of the adopted methodology in addressing each criterion relies on the conclusions made in Table 38.

Table 38. 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 have 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 five 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 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 6 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 Namoi Valley model is the primary tool that will be used for the NSW Government to provide the technical information about the Namoi regulated 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 Namoi 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 to simulate flow and water use for water planning purposes and estimate 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:

1. 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; and
2. 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 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 six criteria, and how they were met is discussed below.

10.2.1 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 Modelling flows 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 sources and licensing, section 6 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
- diversions, both metered and unmetered
- water accounting

- environmental watering.

10.2.2 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 30/06/2020 and includes this period.

The calibration period varies depending on the component. The flow calibration uses the period of flow record. Various components of the farm scale models were calibrated over different periods of time e.g. rainfall–runoff rates were calibrated using a long period of time to match published information while winter cropping was calibrated using an 11-year period from 2003/04 to 2013/14. Floodplain harvesting was initially assessed using a shorter period (2007/08 to 2012/13 based on crop area data). The period 2003/04 to 2013/14, which was also used as a calibration period for some components of the model, was used as the assessment period for the fully configured model (e.g. diversions and headwater storage volumes).

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. A climate risk dataset has been developed for that purpose which includes: a stochastic element derived from historical climate observations, and a paleological climate signal; and combines this with future climate projections from dynamically downscaled climate models.

10.2.3 Criteria 3: spatial resolution sufficient for multi-scale analysis

The spatial detail in the Namoi Source 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 a large number of rainfall stations, allows 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 detailed 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 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 would enable an **individual farm water balance** to be estimated under different scenarios. We used eligible works information to estimate how the allowable total floodplain harvesting volume is shared between individual properties.

The model includes all significant breakouts based on multiple lines of evidence, and the flow rates down these breakouts are based on local knowledge, farm surveys, flow change analysis, hydraulic modelling and remote sensing.

The uncertainty in this regard is significant. This is not necessarily because of spatial detail. The 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 presents challenges for the equitable distribution of entitlements.

The model uncertainty is much better resolved where there are data to inform the parameterisation of 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.

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

The standard time step for calculation in the Source Model 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 annual** simulation results in section 8.5 This capability will be further tested in the annual diversion compliance for the Basin Plan.

10.2.5 Criteria 5: supports replication of historical usage

The replication of historical usage has been undertaken using both crop areas forced to historical data (section 8.3.1) and simulation of crop areas (section 8.3.3). Both tests show that historical **metered usage** is well represented. Total simulated metered diversions had a -1% bias when using historical crop areas and a similar bias when using a planting decision. The model replicated inter-annual variability well.

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 less than 1%, with some underestimation during the earlier drier periods. Some potential reasons for the underestimation in the earlier period include variations in planted area, efficiency and application rates and limitations in rainfall data.

Supplementary access diversions were slightly underestimated, 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. There are insufficient data to represent variations in efficiency at property scale, however sensitivity testing shows that the determination of entitlements is not highly sensitive to changes in this parameter. In the future, we will use data from the floodplain harvesting measurement requirements to review and verify our assumptions about application rates and reduce uncertainty in floodplain harvesting estimates.

10.2.6 Criteria 6: pathway for upgrades

River system models in the department have been and will continue to be used to inform water management in the Namoi Valley. The previous models are about two decades old, and it is foreseeable that the Namoi Valley Source model will likewise be around for at least a generation. The Source platform has been designed for models built with it to be easily updated and extended, through inclusion of more data and/or new or improved component models.

Good modelling practice requires that 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. Improvements arise from the inclusion of additional data, particularly where previously sparse, better methods, and more time.

In the case of the Namoi Valley model, additional on-farm water harvesting and use data provide 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 policy. The additional data can be used within the existing model framework to better parameterise components of the farm models. The Source software platform has sufficient onboard capability to customise components where needed.

The other significant limitation of the Namoi 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, rather than a new model.

10.3 Conclusion

The updated Namoi Valley model represents floodplain harvesting much better than previous models and is capable of providing 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 have also used a water balance assessment based on 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.

We contend there is sufficient evidence to conclude the model meets design criteria 1–4 with low uncertainty. Meeting these is important for meeting the remaining design criteria and objectives.

With respect to criteria 5, we consider 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 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. The model also provides a more realistic representation of supplementary access diversions in comparison to the previous IQQM.

In conjunction with more accurate infrastructure data, the model is now able to provide a more robust estimates of floodplain and rainfall harvesting diversions. However, for components with only surrogate data such as on-farm water balance, 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 in the future through adaptive management 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. While return flows are implicit in the flow calibration, lack of direct accounting is 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 recommendations.

We contend the model is suitable to upgrade for accuracy and capability (design criteria 6). 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 these 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 seven recommendations listed in Table 39 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 39. 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 underestimating diversions in the Gunidgera-Pian Creeks system
5	Determine the impacts of future climate on diversion and flows for consideration during 5 yearly reviews of NSW water sharing plans and the development of the department's regional water strategies
6	Including stock and domestic entitlements and usage within the model (where significant)
7	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

References

NSW legislation and policies

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

NSW Floodplain Harvesting Policy. First published May 2013, updated September 2018. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0017/143441/NSW-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

(Draft) Floodplain Management Plan for the Namoi Valley Floodplain 2018. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0003/146307/Draft-floodplain-management-plan-lower-namoi-background.pdf

Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources 2016 (2015 SI 361). Last updated 2018. https://legislation.nsw.gov.au/view/html/inforce/current/sl-2015-0631. Referred to in this report as the Namoi WSP.

Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012. https://legislation.nsw.gov.au/view/pdf/asmade/sl-2012-493.

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. A report for the NSW Department of Planning, Industry and Environment Water, Sydney. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0004/272146/Final-floodplain-harvesting-independent-review.pdf

Alluvium (2020) Namoi Model Build Report – Independent Reviewer Comments. A memo for the NSW Department of Planning, Industry and Environment Water, Sydney.

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, Industry and Environment.

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

DPI Water (2017) Burrell M., Moss P., Petrovic J., Ali A.,General Purpose Water Accounting Report :Namoi Catchment, NSW Department of Primary Industries, Sydney

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.

DIPNR (2005) Namoi River Valley IQQM Cap implementation summary report, NSW Department of Infrastructure Planning and Natural Resources.

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

DPE Water (2022a) Floodplain *Harvesting entitlements for Namoi Valley river system: model scenarios*. NSW Department of Planning and Environment

DPE Water (2022b) *Environmental Outcomes of implementing the Floodplain Harvesting Policy in the Namoi Valley*. NSW Department of Planning and Environment.

DPIE Water (2021) Building the Gwydir Valley river system model: Conceptualising, constructing and calibrating the DPIE Water river system model for the Namoi Valley. NSW Department of Planning, Industry and Environment – Water.

DPIE Water (2020) Building the Border Rivers Valley river system model: Conceptualising, constructing and calibrating the DPIE Water river system model for the Namoi Valley. NSW Department of Planning, Industry and Environment – Water.

DPI Water(2017) Namoi Alluvium Water Resource Plan, Status and Issues paper . NSW Department of Primary Industries.

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.

Kavetski D, Kuczera G, Franks SW (2006) Bayesian analysis of input uncertainty in hydrological modelling: 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: CRDC (2012) WATERpak – a guide for irrigation management in cotton and grain farming systems, 188–195, https://www.cottoninfo.com.au/sites/default/files/documents/WATERpak.pdf.

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

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

Morrison Tim, 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.

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

NSW DPIE (2020) Guideline for the implementation of the NSW Floodplain Harvesting Policy. June 2020. NSW Department of Planning, Industry and Environment. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0007/272338/guideline-for-implementation.pdf

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: CRDC (2012) WATERpak – a guide for irrigation management in cotton and grain farming systems, 40-58, https://www.cottoninfo.com.au/sites/default/files/documents/WATERpak.pdf.

Appendix A Quality assurance

A.1 Quality assurance practices

The department has 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 the department's 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[24] 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 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. For further information on this review and our action plan to respond to the recommendations, refer to our website[25].

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*". We have undertaken this review process as described below.

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 are 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

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

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

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 is 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.

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 model development 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 is provided in the companion Scenarios report (DPE Water 2022a).
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 IBQ 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 Namoi 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 an independent Floodplain Harvesting Review Committee.

In conjunction with NRAR, we reviewed all submissions and presented the results of the review to the Review Committee. Where submissions supported changes to the model, the proposed changes were presented to the Review Committee for endorsement before inclusion in the final Namoi Valley model used to determine floodplain harvesting entitlements.

Further information on the function of the review committee, and the overall implementation of the policy, can be found in the 2020 *Guideline for the implementation of the NSW Floodplain Harvesting Policy* (NSW DPIE 2020).

A.4 Report review process

This report has gone through an internal review and editorial process, and will be subject to external review as part of an independent peer review of the Namoi Valley model. 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, with 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 this report for review (Alluvium, 2020), as was the case for similar reports prepared by the department and reviewed by Alluvium for the NSW Border Rivers, Gwydir, Macquarie, and Barwon-Darling valleys.

This report addresses those previous review comments, either through adding more explanatory material to this report, or through adding material to the companion Scenarios report (DPE Water 2022a). This series of reports has been developed with an external editor working with the model development team.

Appendix B Climate stations

Table 40. Rainfall stations used in headwater inflow calibration, their station numbers, location (latitude/longitude) and mean annual rainfall. Asterisk (*) against a station # identifies those shown in Figure 9

Station #	Station name	Start	End	Lat (°S)	Long (°E)	Mean annual rainfall (mm)
52023	PILLIGA POST OFFICE	1883	Current	-30.3515	148.8843	556.6
52026	WALGETT COUNCIL DEPOT	1878	Current	-30.0236	148.1218	466.9
53002	BARADINE FORESTRY	1944	Current	-30.9469	149.0654	593.6
53026	NARRABRI (MOLLEE)	1926	Current	-30.2552	149.6789	602.4
53034	WEE WAA (PENDENNIS)	1890	Current	-30.1187	149.3232	559.3
53044	WEE WAA (GEORGE ST)	1884	Current	-30.2257	149.4452	588.4
53045	WILUNA	1901	1943	-30.3	149.5	587.9
54003	BARRABA POST OFFICE	1881	Current	-30.3781	150.6096	681.9
54020	MAY VALE	1888	1962	-30.4	150.4	787.9
54021	BARRABA (MOUNT LINDESAY)	1886	Current	-30.3209	150.2734	991.8
54023	BARRABA (NERANGHI)	1908	Current	-30.2948	150.8103	700
54105	BUNDARRA (GRANITE HEIGHTS)	1965	Current	-30.3354	150.9338	794.9
54120	NARRABRI BOWLING CLUB	1870	Current	-30.3222	149.782	641
55002	MULLALEY (BANDO)	1883	Current	-31.2342	149.8345	640.4
55004	BENDEMEER (CAROLINE ST)	1879	Current	-30.8833	151.1546	809.8
55007	BOGGABRI POST OFFICE	1884	Current	-30.7056	150.0458	588
55017	PREMER (EDEN MOOR)	1887	Current	-31.5711	149.7762	634.1
55018	MULLALEY (GARRAWILLA)	1884	Current	-31.1711	149.6456	641.4
55023	GUNNEDAH POOL	1876	Current	-30.9841	150.254	614.4
55031	MANILLA POST OFFICE	1883	Current	-30.7477	150.7196	646.6
55037	PINE RIDGE (MOOKI SPRINGS)	1886	2012	-31.5077	150.3986	593.9
55044	BOGGABRI (RETREAT)	1899	Current	-30.7044	150.2767	586.1
55049	QUIRINDI POST OFFICE	1882	Current	-31.5086	150.6792	677.1
55057	WILLOW TREE (VALAIS)	1881	Current	-31.7731	150.2856	729.6
55058	TURRAWAN (WALLAH)	1910	Current	-30.4445	149.939	599.6
55066	WALLABADAH (WOODTON)	1892	Current	-31.6218	150.8437	767.3
55076	BOGGABRI (KANOWNDA)	1899	Current	-30.5121	150.2119	588.8

Station #	Station name	Start	End	Lat (°S)	Long (°E)	Mean annual rainfall (mm)
55103	WATSONS CREEK (TILMUNDA)	1959	Current	-30.6929	151.1214	768.7
55105	ATTUNGA (TARANA)	1958	Current	-30.7966	150.8643	726.6
55122	ATTUNGA (MINDEROO)	1958	Current	-30.8415	150.9097	743.7
55273	BOGGABRI (NEOTSFIELD)	1968	Current	-30.8202	149.8366	592.6
55274	KELVIN (CARELLAN)	1909	2013	-30.7783	150.4339	584.6
55276	KEEPIT DAM	1955	Current	-30.8828	150.4928	598
56075	WALCHA ROAD (BOXLEY)	1959	Current	-31.034	151.4409	768.4
56083	GLEN MORRISON (BRANGA PLAINS)	1940	Current	-31.2642	151.5465	918.1
64008	COONABARABRAN (NAMOI STREET)	1879	Current	-31.2712	149.2714	741.8
64046	COONABARABRAN (WESTMOUNT)	1965	2013	-31.2886	149.0687	987.8

Table 41. Evapotranspiration stations used in headwater inflow calibration, their station numbers, location (lat/long), mean potential evapotranspiration (PET) and mean lake evaporation. Asterisk (*) against a station # identifies those shown in Figure 10

Station #	Station name	Start	End	Lat (°S)	Long (°E)	Mean PET (Mwet) (mm/y)	Mean lake evap (MLake) (mm/y)
52026	WALGETT COUNCIL DEPOT	1878	Current	-30.0236	148.1218	1542.4	1633.9
53030	NARRABRI WEST POST OFFICE	1891	Current	-30.3401	149.7552	1559.6	1585.3
53044	WEE WAA (GEORGE ST)	1884	Current	-30.2257	149.4452	1579.4	1605.6
54003	BARRABA POST OFFICE	1881	Current	-30.3781	150.6096	1444	1469
55004	BENDEMEER (CAROLINE ST)	1879	Current	-30.8833	151.1546	1317.3	1339.4
55018	MULLALEY (GARRAWILLA)	1884	Current	-31.1711	149.6456	1450.3	1475.4
55023	GUNNEDAH POOL	1876	Current	-30.9841	150.254	1504.2	1528.6
55037	PINE RIDGE (MOOKI SPRINGS)	1886	2012	-31.5077	150.3986	1406.2	1429.9
55076	BOGGABRI (KANOWNDA)	1899	Current	-30.5121	150.2119	1501.8	1527.4
64008	COONABARABRAN (NAMOI STREET)	1879	Current	-31.2712	149.2714	1416.3	1441.2

Appendix C Streamflow gauges

Table 42. Inflow headwater gauges used in Namoi Valley model, their station number and name, catchment area (CA), start and end dates of gauge, highest recorded and highest gauged flows. – in End date indicates that the station is still active

Station #	Station name	CA (km²)	Start date	End date	Highest recorded flow (m³/s)	Highest gauged flow (m³/s)
419005	Namoi River @ North Cuerindi	2,536	10/12/1915	Current	93,439	27,555
419027	Mooki River @ Breeza	4,942	3/09/1957	Current	134,047	128,000
419029	Halls Creek @ Ukolan	357	22/05/1965	Current	10,456	25,22
419032	Coxs Creek @ Boggabri	4,040	5/06/1965	Current	98,478	95,000
419051	Maules Creek @ Avoca East	661	8/06/1972	Current	34,800	4,390
419072	Baradine Creek @ Kienbri No.2	985	8/05/1981	16/11/2011	16,500	1,490
419083	Brigalow Creek @ Tharlane	259	13/10/1993	Current	12,283	6,948

Table 43. Stream gauges used for reach calibration in Namoi Valley model, their station number and name, catchment area (CA), start and end dates of gauge, and highest recorded and highest gauged flows. – in End date indicates that the station is still active

Station #	Station name	CA (km²)	Start date	End date	Highest recorded flow (ML/d)	Highest gauged flow (ML/d)
419001	Namoi River @ Gunnedah	,6654	27/11/1891	Current	70,7060	18,9000
419003	Narrabri Creek @ Narrabri	25,120	1/01/1891	Current	182,766	150,000
419007	Namoi River @ Downstream Keepit Dam	5,733	14/01/1924	Current	182,228	61,035
419012	Namoi River @ Boggabri	22,79 8	16/11/1911	Current	314,402	175,000
419020	Manilla River @ Brabri (Merriwee)	2,047	18/08/1942	Current	75,844	66,057
419021	Namoi River @ Bugilbone (Riverview)	334	9/04/1951	Current	106,627	75,900
419022	Namoi River @ Manilla Railway Bridge	5,126	19/03/1941	Current	22,7532	182,025
419026	Namoi River @ Goangra	35,74 0	5/08/1954	Current	109,948	67,900
419039	Namoi River @ Mollee	27,76 4	30/09/196 5	Current	194,626	136,000
419043	Manilla River @ Downstream Split Rock Dam	1,642	27/05/196 8	Current	56,850	49,100
419049	Pian Creek @ Waminda	1,453	28/03/197 2	Current	36,521	24,250
419059	Namoi River @ Downstream Gunidgera Weir	28,50 0	7/04/1976	Current	144,550	28,100

Station #	Station name	CA (km²)	Start date	End date	Highest recorded flow (ML/d)	Highest gauged flow (ML/d)
419061	Gunidgera Creek @ Downstream Regul@or	28,006	29/07/1975	Current	10,719	5,550
419063	Gunidgera-Pian Cutting @ Merah North	28,400	6/01/1978	Current	1,375	1,090
419064	Pian Creek @ Rossmore	771	5/01/1978	Current	2,670	1,090
419068	Namoi River @ Downstream Weeta Weir	734	26/10/1978	Current	64,038	28,200
419091	Namoi River @ Upstream Walgett.	39,236	10/11/1996	Current	159,595	90,400

Appendix D Sources of flow breakout information

Multiple sources of information have been used to define within channel breakouts to creeks and overland flow breakouts (Table 44).

For Reaches 4 and 5 results from a Carroll to Boggabri Mike11 model and flood study were used to configure the effluent breakout relationships. For Reaches 6 and 7 the effluent breakout relationships were calibrated based on the flow from reaches gauges and overbank thresholds from reach cross sections. For Lower Namoi effluent breakout relationships were supplied by Morrison Water and Spatial based on numerous MIKE21FM hydraulic models prepared by the department's Environment Energy and Science division. Only the rising limbs of these relationships were used as Source does not allow upstream flow to decrease and therefore the hysteresis curve is left off. It was found that these effluent relationships were based on sub-daily flow time series. Therefore, when used in a daily Source model the breakout thresholds missed observed events due to differences between daily and sub-daily time series.

Modelled overbank events where then checked against multiple lines of evidence such as historical flood data at certain gauges, satellite imagery and remote sensing data found during large flood events.

Table 44. Namoi Basin known effluents and breakouts: their name, location (reach) and downstream gauge. Those with an ID are the NSW breakouts that are depicted in Figure 14.

Reach	Downstream Gauge	Effluent Name in model	ID	Comments
4	419001	Namoi_South_Split	Namoi_South_Split	Mike11, Carroll to Boggabri flood study134134 of data
		Carrolls_Gap_Split	Carrolls_Gap_Split	134134Mike11, Carroll to Boggabri flood study of data
		Namoi_North_Split	Namoi_North_Split	134134Mike11, Carroll to Boggabri flood study of data
		Mooki_Split	Mooki_Split	134134Mike11, Carroll to Boggabri flood study of data
5	419012	Deadmans_Gully_Split	Deadmans_ Gully_Split	134134Mike11, Carroll to Boggabri flood study of data
		US_Boggabri_Split	US_Boggabri_Split	134134Mike11, Carroll to Boggabri flood study of data
6	419003	NAMO_Reach06_FPH_offtake	NAMO_Reach06_FPH_offtake	Calibrated based on Reach gauge data.
7	419039	NAMO_Reach07_Effluent_Breakout	NAMO_Reach07_Effluent_Breakout	Calibrated based on Reach gauge data.
8	419059	NAMO_Effluent_Breakout_1A	A	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_2B	B	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_3C	C	MIKE21FM hydraulic model results

Reach	Downstream Gauge	Effluent Name in model	ID	Comments
		NAMO_Effluent_Breakout_4D	D	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_5E	E	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_6F	F	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_7G	G	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_8H	H	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_9I	I	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_12L	L	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_15O	O	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_16P	P	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_17Q	Q	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_18R	R	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_19S	S	MIKE21FM hydraulic model results
9	416068	NAMO_Effluent_Breakout_10J	J	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_11K	K	MIKE21FM hydraulic model results
10	419095	NAMO_Effluent_Breakout_20T	T	MIKE21FM hydraulic model results
11	419021	NAMO_Effluent_Breakout_21U	U	MIKE21FM hydraulic model results
13	419094	NAMO_Effluent_Breakout_24X	X	MIKE21FM hydraulic model results
14	419079	NAMO_Effluent_Breakout_14N	N	MIKE21FM hydraulic model results
		NAMO_Effluent_Breakout_13M	M	MIKE21FM hydraulic model results

Appendix E Major storage characteristics

Table 45. Split Rock storage curves (level, volume, surface area relationships)

Level (m)	Volume (ML)	Surface area (km^2)
0	0	0
0.96	24	4
2.995294	197	13
4.916506	514	20
6.916506	1,064	35
8.857683	1,889	50
10.80691	3,156	80
12.79072	5,239	130
14.79072	8,439	190
16.79072	12,839	250
18.7668	18,372	310
20.77152	25,589	410
22.77526	34,706	500
24.77526	45,506	580
26.77251	57,889	660
28.76783	71,956	750
30.76572	88,039	860
32.76757	106,456	980
34.76911	127,172	1,090
36.76622	149,939	1,190
38.76622	174,939	1,310
40.76622	202,339	1,430
42.76622	232,139	1,550
44.76516	264,322	1,670
46.76516	299,022	1,800
48.7643	336,306	1,930
50.7626	376,272	2,070
52.7626	419,272	2,230
54.76191	465,456	2,390
56.76122	514,939	2,560
58.75998	567,906	2,740
60.76054	624,722	2,940
62.7611	685,439	3,130
63.66145	713,980	3,210

Table 46. Keepit storage curves (level, volume, surface area relationships)

Full Supply Level = 36.568m (425512 ML)

Level (m)	Volume (ML)	Surface area (km^2)
0	0	0
1.52	75	10
3.04	286	19
4.56	663	32
6.04	1,263	49
7.61	2,195	74
9.14	3,496	98
10.56	5,217	131
12.18	7,600	185
13.71	10,953	259
15.23	15,646	357
16.76	21,801	455
18.28	29,617	578
19.8	39,659	740
21.33	52,068	902
22.852	67,656	1,147
24.376	87,149	1,411
25.9	110,603	1,675
27.424	138,476	1,992
28.948	171,705	2,365
30.472	210,427	2,719
31.996	254,586	3,088
33.524	305,005	3,526
35.044	361,940	3,948
36.568	425,512	4,386
39.616	578,379	5,111
42.664	736,599	5,787

Appendix F Irrigation farm runoff: data review

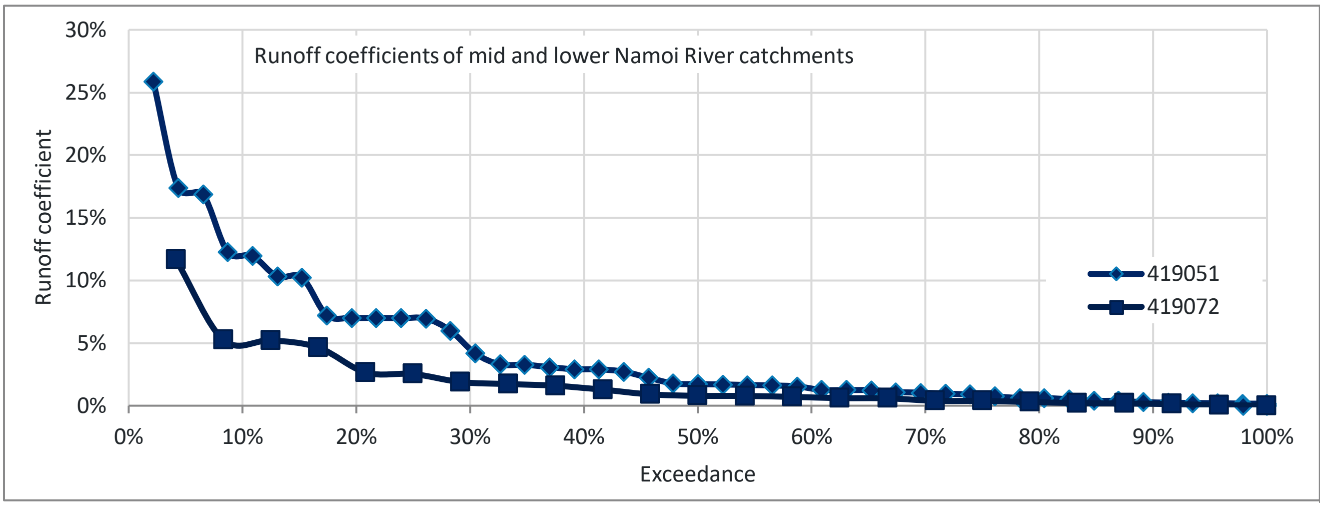
F.1 Background

The irrigator nodes in the Source model 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 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 to 800 mm/year, and 8–16% for average annual rainfall from 800 to 1,100 mm/year.

Two gauged catchments[26] in the Namoi 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 42. 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 25% of annual rainfall volume with a long-term average of about 4% and 2% respectively.

Figure 42. 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]

[26] 419051: Maules Creek @ Avoca East, and 419072: Barradine Creek @ Kienbri

developed by modellers across the MDB 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 a number of 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 small component of total valley diversions.

A small amount of relevant farm scale data were available and are summarised below.

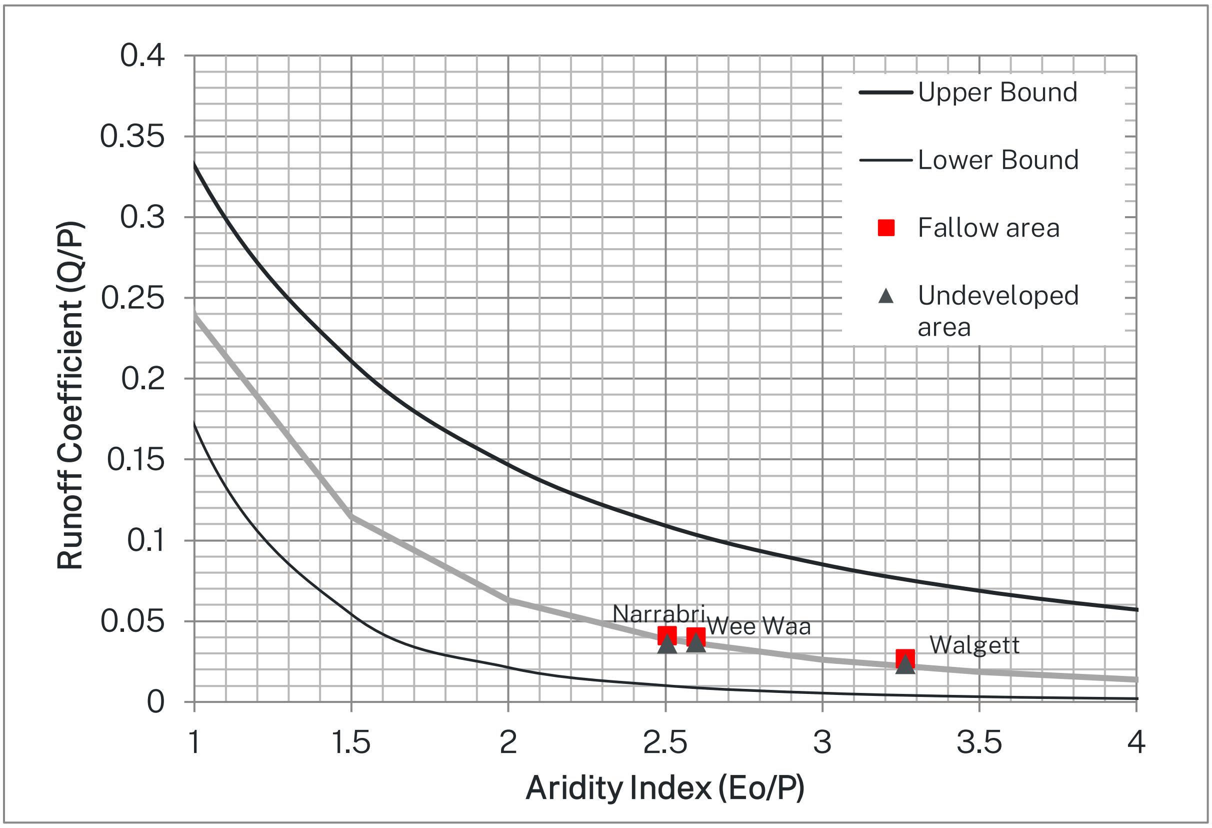
- In-field data for furrow-irrigated cotton fields were collected by Connolly et al. (2001) to calibrate a daily water balance model (GLEAMS). This has been used to assess runoff values from both un-irrigated and irrigated areas over a relatively long period (e.g. 30 year simulation in Connolly et al. (2001)). They measured 16 mm runoff for a dryland cotton site on black vertosols in Emerald, Qld with 600 mm rainfall (~3% of rainfall), whereas an irrigated field with the same rainfall generated 42 mm of runoff (cited in Silburn et al., 2012). Their results, for a site near Warren in NSW with 625 mm of rainfall, indicate 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. The overall average is a little higher than our adopted approach. Six properties provided estimates on rainfall–runoff harvesting in the farm surveys. The estimates had ranges from 0– 20% for the same annual rainfall, with an average of 9%. 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 was 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.

F.2 Further information on Namoi Valley model development

The parameters for the rainfall–runoff model in the Namoi Valley model were developed using rainfall at Narrabri, Wee Waa and Walgett. The final fallow and undeveloped area runoff rates appear to be reasonable compared to the median values in the Budyko framework (Figure 43).

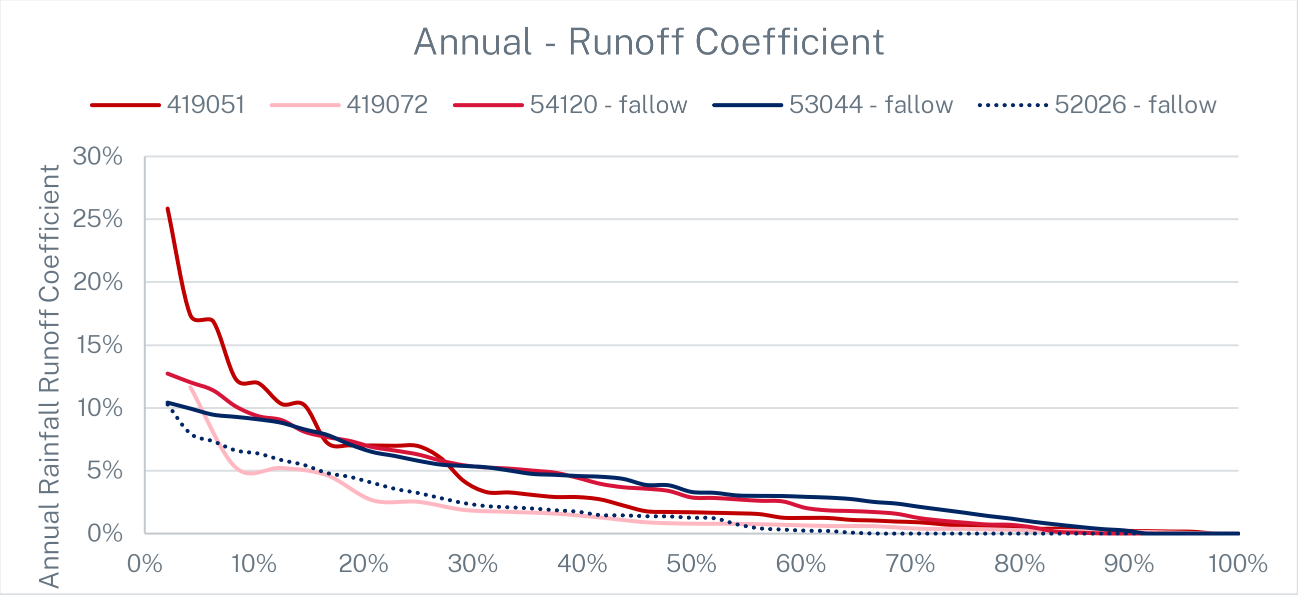
The parameters were defined such that runoff from fallow areas was greater than from undeveloped areas. The undeveloped runoff rates were assumed to be lower, in part because the efficiency of harvesting runoff from these areas is not known. The models have adopted the undeveloped farm catchment areas claimed in the farm surveys, with review only where issues were raised as part of the farm scale validation process. In most instances the areas were 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 volumes, the assumptions for undeveloped areas would be reviewed.

Figure 43. Runoff and aridity results for Namoi (1965–2009 as per Neumann et al. (2017))



As the runoff coefficient in any one year can be quite variable, a check was also made to ensure the range of annual values and general pattern are reasonable, when compared to a nearby gauge (Figure 44).

Figure 44. Range of annual runoff coefficients compared to gauged inflows; ranked data from 1969–2015



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

As part of implementing the policy, there has been unprecedented 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.

G.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 SBM was based on 5 empty storages with a range of volumes and surface areas. The SBM was validated using an additional 6 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[27]. A 1 m 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.

G.2 Verification and representation 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 Landsat data from 30 January 2011 following a very large event,

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

which peaked at Goondiwindi on 15 January. Assuming a depth of 1 m, it is estimated that less than 1.5 GL was held in temporary storages on 30 January.

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.

We include these in the model where:

- the storage is either a properly constructed buffer storage mapped by NRAR or remote sensing evidence prior to 2008 confirms that it was used to hold overland flow
- the storage is significant; it is greater than 20 ML and greater than 5% of eligible on-farm storage capacity.

Small surges, or surges that do not allow a much faster intake rate compared to the on-farm storage pumps, will have little impact on modelling results. Adding the temporary storages adds significant complexity to the modelling (particularly in IQQM) and hence we developed this approach to avoid unnecessarily complicating the modelling.

G.3 On-farm storage pump rate

NRAR has 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 45 and Figure 46. The adopted flow rates have also been compared to check for consistency (Figure 47).

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

Figure 45. Centrifugal pumps flow rate analysis

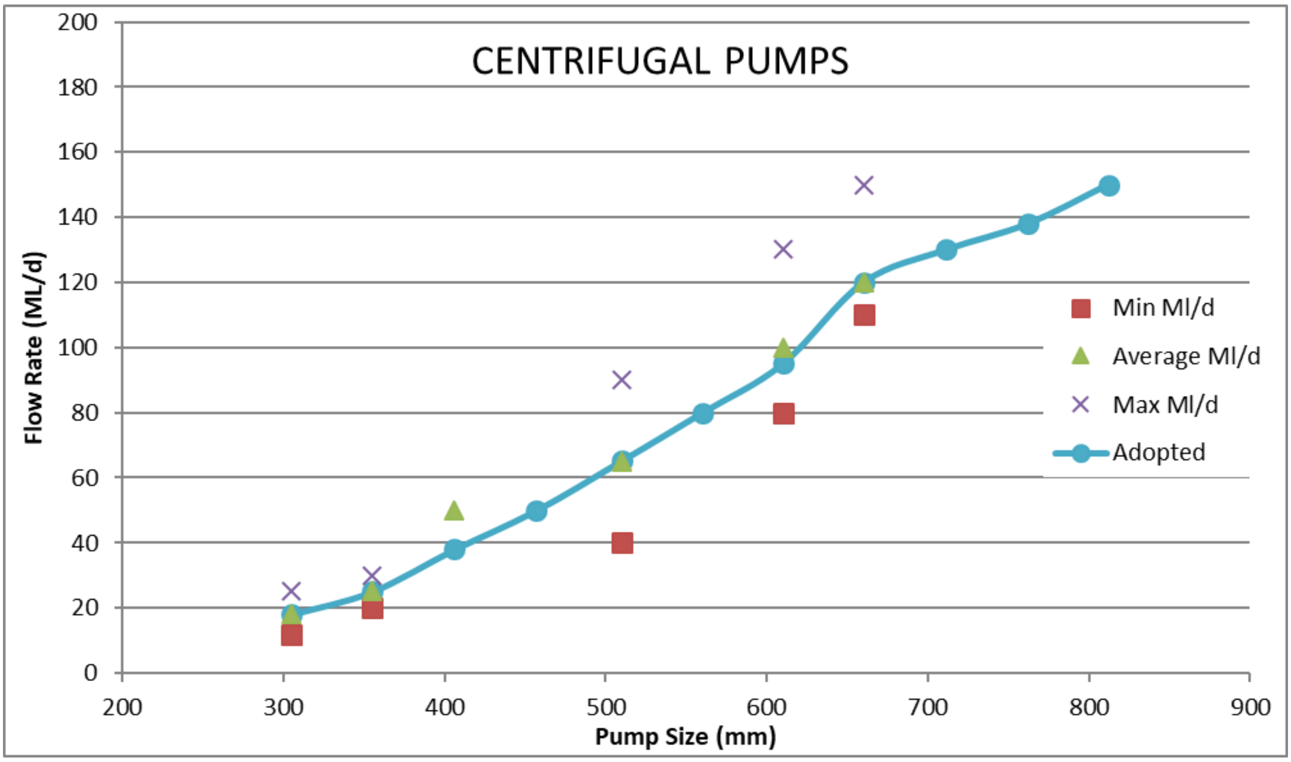


Figure 46. Axial flow pumps flow rate analysis

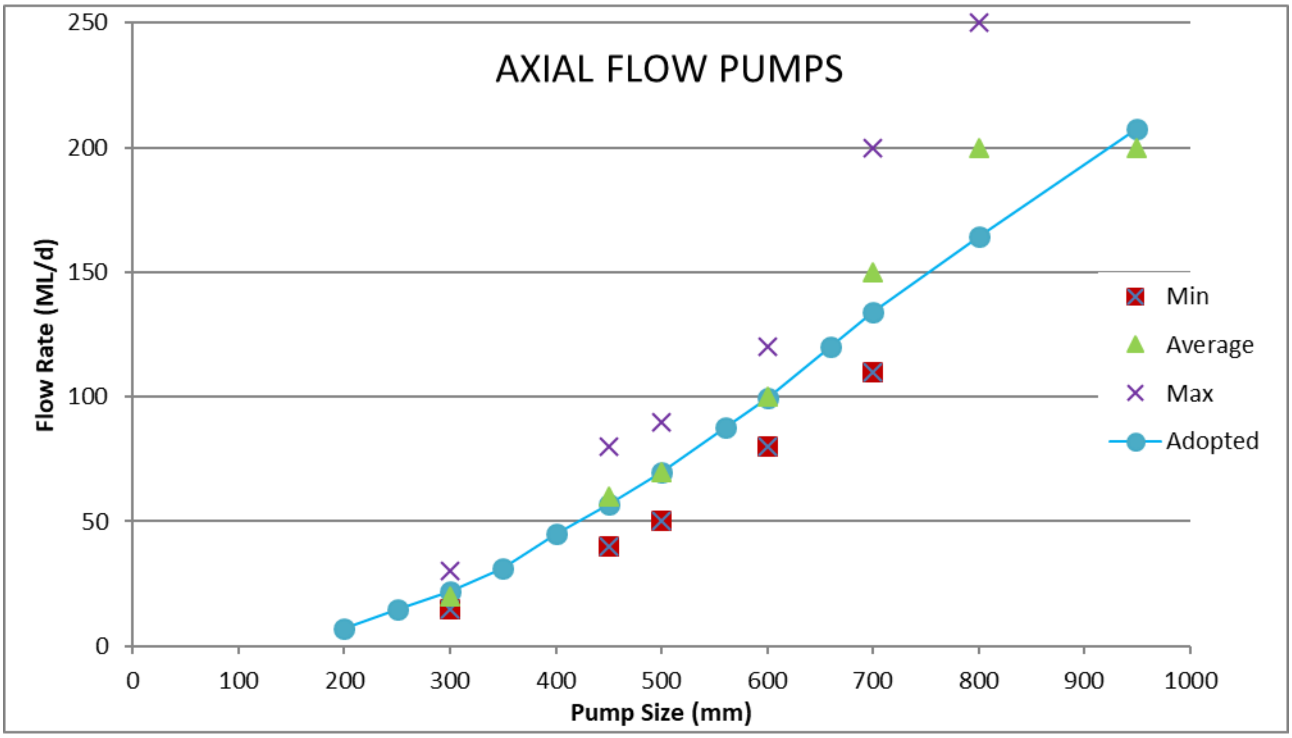
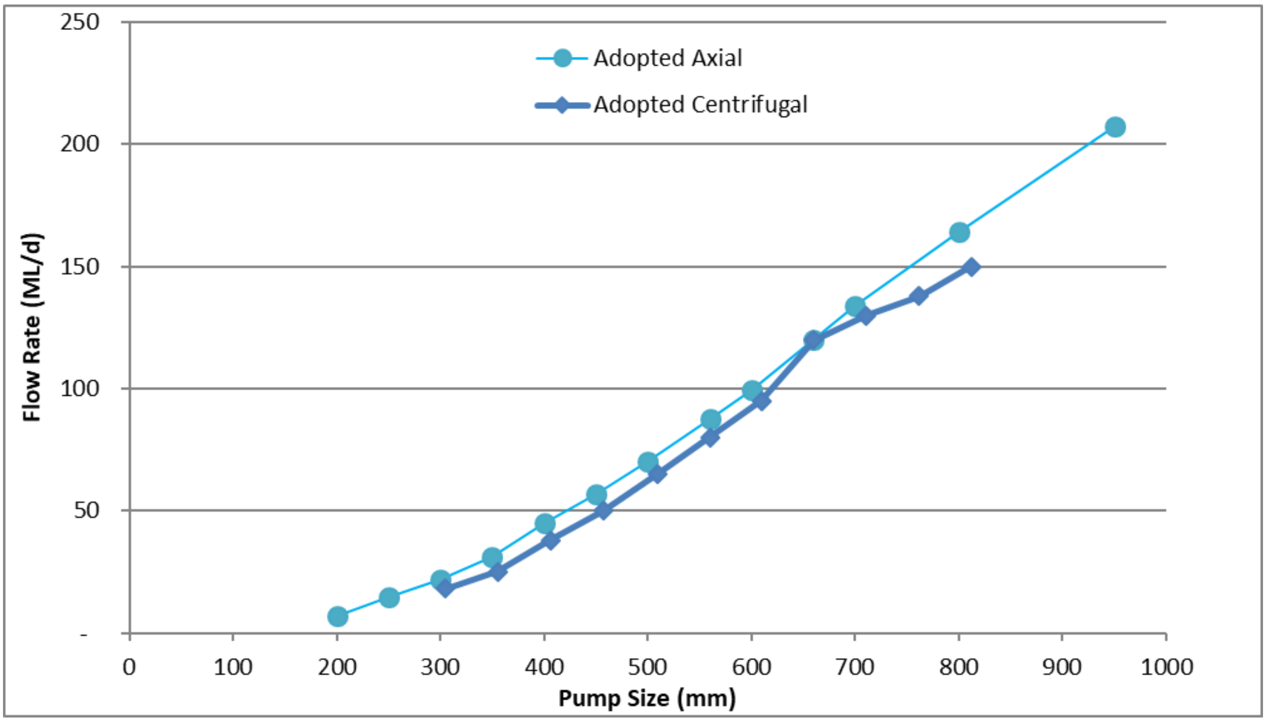


Figure 47. Comparison of adopted centrifugal and axial flow rates



G.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 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 the on-farm storage pumps were considered the limiting factor and the capacity of the pipes was generally not used in the modelling. There were only a few exceptions to this as discussed in section 6.2.2.

The flow rates assumed in the review of pipes are set out in Table 47.

Table 47. Pipe diameter and estimated flow rate at 0.2m head

Diameter (m)	Flow rate (ML/d)
1.8	264
1.5	183
1.2	117
1.05	92
0.9	66
0.75	48
0.6	29
0.5	20

G.5 Worked example for representing floodplain harvesting works including temporary storage

This section describes an example property where allowance for temporary storage has been included in the modelling. All data in this example are draft, for the purposes of illustrating the modelling methodology.

The property can access overbank flow in the following way:

- one eligible storage with a relatively small total lift pump capacity estimated at 240 ML/d
- one surge area which is able to take water in at a much higher rate through three pipes. While the head will vary in practice, we adopt a simplified approach and assumed a head of 0.2 m is representative. In larger floods, the head may be higher, however this is not relevant where the model is filling storages regardless. Assuming a head of 0.2 m, we estimated a representative rate of around 813 ML/day through the pipes to both the temporary storage and direct to the permanent storage.

Using LIDAR, we estimated the surge capacity at 770 ML.

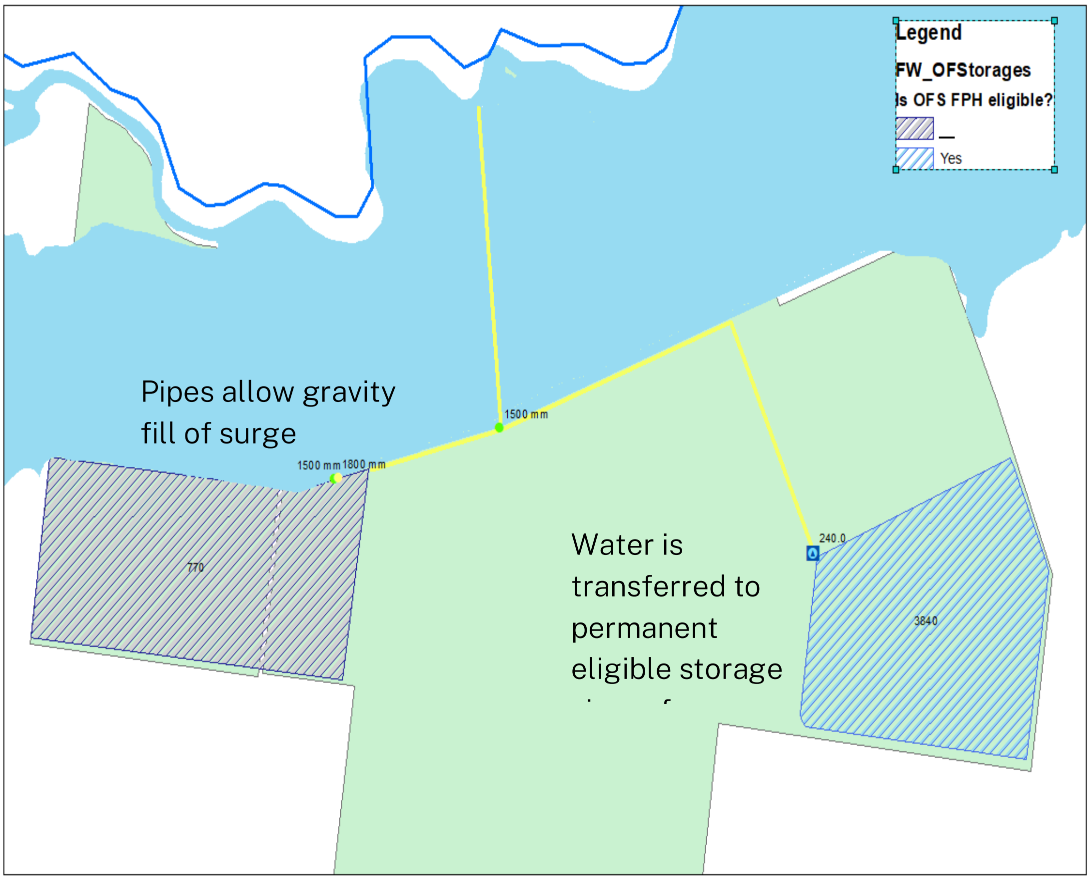
If we were to represent the temporary storage and transfer to permanent storage, this would require a complex model arrangement with several additional nodes. A much simpler approach is to account for the temporary storage by adjusting the pump rate on the permanent eligible storage. This approach assumes that the water in surge is immediately put into the permanent storage.

The model initially assumes that water is put into the on-farm storage at the maximum rate of total harvesting. This is estimated as 630 ML/day into the surge plus 183 ML/day direct to the on-farm storage via a single 1500 mm diameter pipe. However, this high rate cannot continue if the surge is filled. To represent this, the model uses a function on the on-farm storage pump as follows:

- If the total volume pumped in the last 10 days is less than the capacity of the surge (770 ML), the maximum rate of 813 ML/day is assumed to be the permanent on-farm storage pump capacity
- Otherwise, the surge is assumed to be filled and the on-farm storage pump rate drops to 240 ML/day.

Figure 48 illustrates this example.

Figure 48. Example property with temporary storage



G.6 Worked example for representing floodplain harvesting works where multiple storages and intakes

This section describes an example property from the Macintyre River catchment where there are multiple storages and floodplain harvesting intake points. The data are draft and used here to illustrate the modelling approach.

The property can access overland flow in the following way:

- overbank flow from the Macintyre 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; we have estimated overbank flow in this region and included.

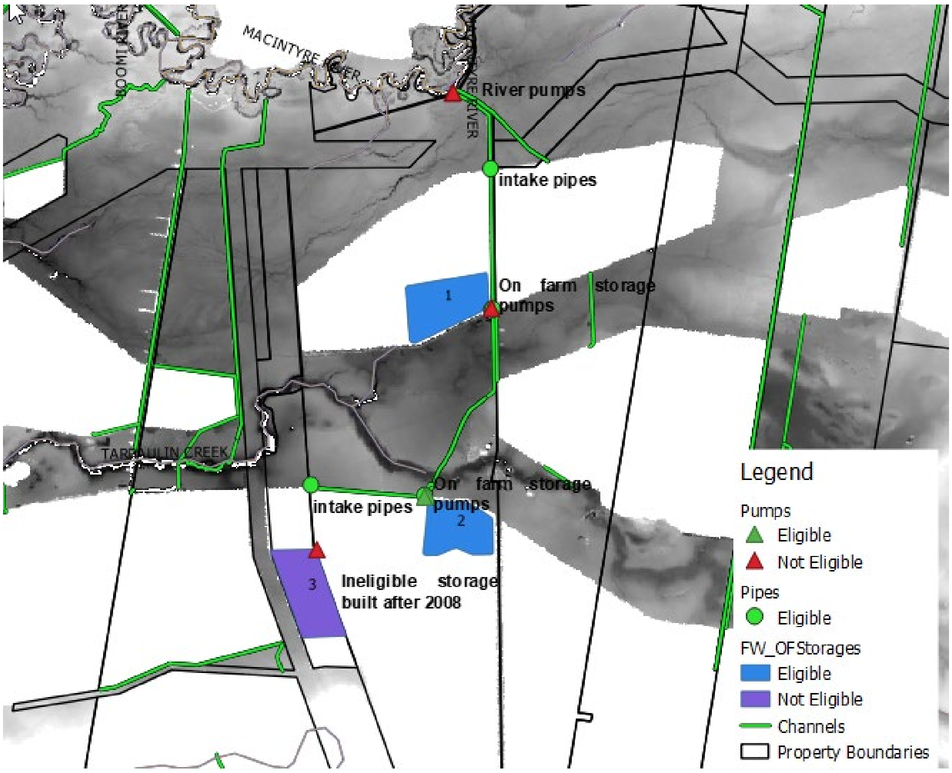
The property has multiple works:

- two eligible storages with a total estimated pump capacity of 720 ML/day
- one ineligible storage. This storage is not included in the assessment of eligible floodplain harvesting. The storage is included in the Current Conditions Scenario, however.

- 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 these pipes was estimated to be greater than 720 ML/day. Hence the on-farm storage pumps were 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 720 ML/day.

Figure 49 demonstrates this example.

Figure 49. Example property with multiple storages and intakes



Appendix H Crop area verification

H.1 Completeness of survey crop area data

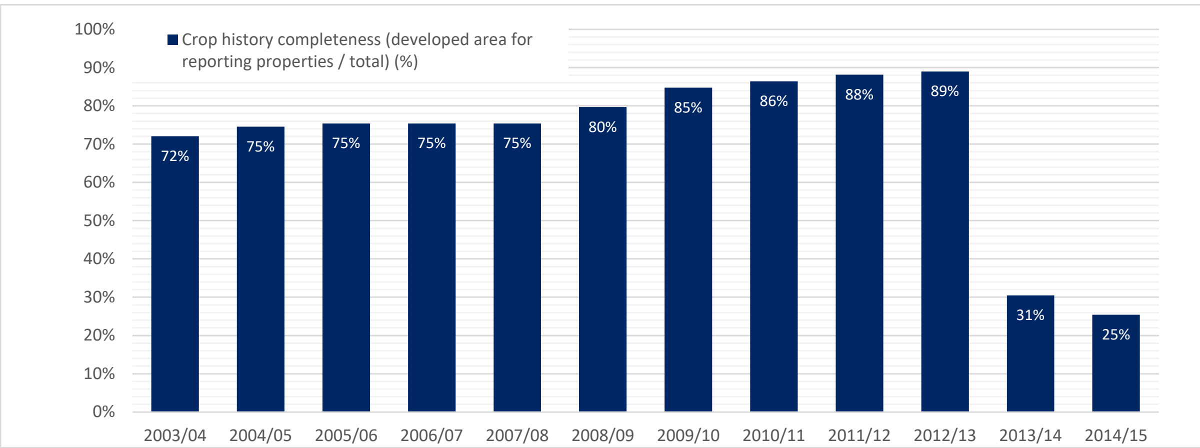
Survey data on crop area and crop type were supplied by most floodplain harvesting properties.

Not all properties filled in 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. An analysis of the completeness of the planted areas was undertaken as follows:

- properties were classified based on year in which crop areas were originally reported
- the sum of the developed area was determined for all properties with records (i.e. they started recording in that year or in an earlier year)
- this area was divided by the total developed area for all floodplain harvesting properties.

Results are presented in Figure 50.

Figure 50. Completeness of reported crop area records



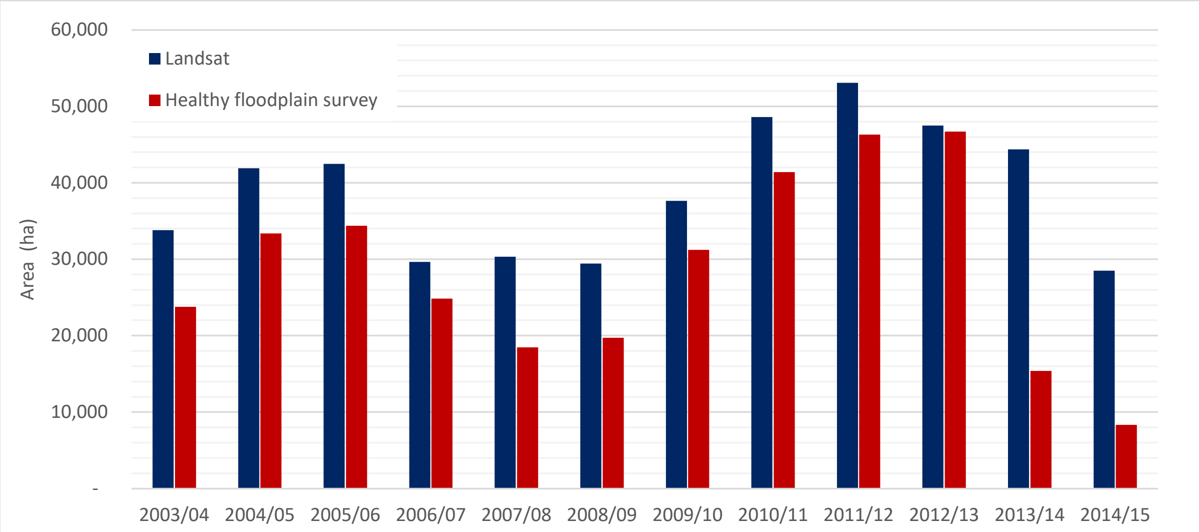
The IBQ farm survey reported summer crop areas were compared against regional scale MODIS and Landsat remote sensed data. Winter crop areas have not been analysed as remote sensing data are less reliable during these periods, and the Namoi Valley is dominated by summer irrigation.

The remote sensing data were obtained from 2004/05 to 2014/15 based on the properties that have been deemed as eligible for a floodplain harvesting licence in the Namoi.

- MODIS analysis uses a time series analysis to look for spectral response which approximates the expected crop behaviour.
- Landsat offers higher spatial resolution; however, Landsat has a slower orbit, hence lower temporal resolution.

Total crop areas for the Landsat dataset were compared to the reported survey data (Figure 51). Remote sensing crop areas are generally larger than those reported via the farm surveys. At a property scale, there were often differences between the remote sensed data and the farm survey results.

Figure 51: Summer crop area comparison for properties completely within the Landsat tile and with farm survey data.



Further checking was undertaken for 30 selected individual properties by deriving irrigated areas from a surface energy balance algorithm-based calculation of actual evapotranspiration using Landsat 7 and Landsat 8 satellite imagery. An index called evapotranspiration reference fraction (ETrF), a ratio of actual to reference evapotranspiration, was used as an indicator for irrigated areas. The index was determined for satellite imagery during summer (January and February) and used to identify irrigated land use based on a set threshold value and an assumption that ETrF values would remain high for irrigated areas. The areas delineated using this approach were further analysed and passed through visual interpretation and noise filtering processes. The results from this check indicated that inter-annual pattern of variability was similar to the other sources of crop area data, although there was variability on an annual basis.

The additional manually supervised remote sensing checks described above for the 30 largest properties were compared to the calibrated crop areas described in Section 6.2.2 and were found to give a closer match than the remote sensing conducted at a regional scale, but were still higher than the calibrated areas.

A further check of crop areas for a larger number of farms was undertaken by visually inspecting remote sensing images available on the IrriSat website, which confirmed that there were significant crop areas that were being under-watered at times, or where a shortened irrigation season had occurred. To the extent that the model does not represent under-watering practices, the calibrated crop areas can be considered to represent an equivalent (smaller) fully watered crop area.

Appendix I River reaches in the river system model

Table 48. Namoi Valley reach division

Reach Name	Upstream gauge	Downstream gauge
Reach 1: Manilla River, Split Rock to Brabri	419043	419020
Reach 2: Manilla River, Brabri to Namoi River @ Manilla	419020 419005 419029	419022
Reach 3: Namoi River, Manilla to d/s Keepit Dam	419022 419028	419007
Reach 4: Namoi River, d/s Keepit Dam to Gunnedah	419007 419006 419084	419001
Reach 5: Namoi River, Gunnedah to Boggabri	419001 419032	419012
Reach 6: Namoi River, Boggabri to Narrabri	419012 419051	419003
Reach 7: Namoi River, Narrabri to Mollee	419003	419039
Reach 8: Namoi River, Mollee to d/s Gunidgera Weir	419039	419059 419061
Reach 9: Namoi River, Gunidgera Weir to d/s Weeta Weir	419059	419068
Reach 10: Namoi River, d/s Weeta Weir to Bullawa	419068	419095
Reach 11: Namoi River, Bullawa to Bugilbone	419095	419021
Reach 12: Namoi River, Bugilbone to Goangra	419021	419026
Reach 13: Namoi River, Goangra to u/s Walgett	419026	419091
Reach 14: Gunidgera Creek, Offtake to d/s Cutting	419061	419079 419063
Reach 15: Gunidgera Creek, d/s Cutting to Namoi River @ Bullawa	419079	419095
Reach 16: Pian Creek, Gunidgera-Pian cutting to Rossmore	419063	419064
Reach 17: Pian Creek, Rossmore to Waminda	419064	419049

Appendix J Flow calibration tables and graphs

Sacramento rainfall-runoff modelling was undertaken for gauged headwater catchments to generate inflow to gap-fill observed flow data and to extend the flow records for long-term simulation. Observed flow data were used to calibrate the rainfall-runoff models at different headwater catchments. The Sacramento modelled flows are compared to observed flows in Table 49. Results are also compared to expected values in the Murray-Darling Basin using the Budyko framework in Figure 52.

For main river gauges, the results are based on a comparison of modelled flows from the Namoi Valley model flow validation scenario (with storage releases and metered diversions forced to observed values) and observed flow data (Table 50). Ungauged inflows from the local catchment along the river between flow gauging stations has also been modelled using a Sacramento model for each river reach. These 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 53.

Table 49. Headwater inflow flow calibration statistics. For each station, mean annual flow, runoff as % of rainfall, daily Nash Sutcliffe, flow bias for full, low, medium and high flow range (%) and reference to graph in this report (Graph reference) are reported

Station No	Mean annual flow (GL)	Runoff as % of rainfall	Daily Nash Sutcliffe	Full flow bias (%)	Low flow bias (%)	Medium flow bias (%)	High flow bias (%)	Graph reference
419005	240.0	11.8	0.71	0.0	11.4	0.5	-0.3	Figure 54
419027	57.1	3.4	0.71	0.0	10.7	6.2	-0.3	Figure 55
419029	17.5	7.2	0.59	0.0	-31.2	1.2	-0.4	Figure 56
419032	83.2	2.5	0.71	0.0	N/A	1.5	0.0	Figure 57
419051	20.8	4.5	0.75	0.0	12.1	3.6	-0.6	Figure 58
419072	13.9	2.3	0.60	0.0	N/A	6.6	-0.4	Figure 59

Figure 52. Headwater Sacramento modelling results compared to aridity index

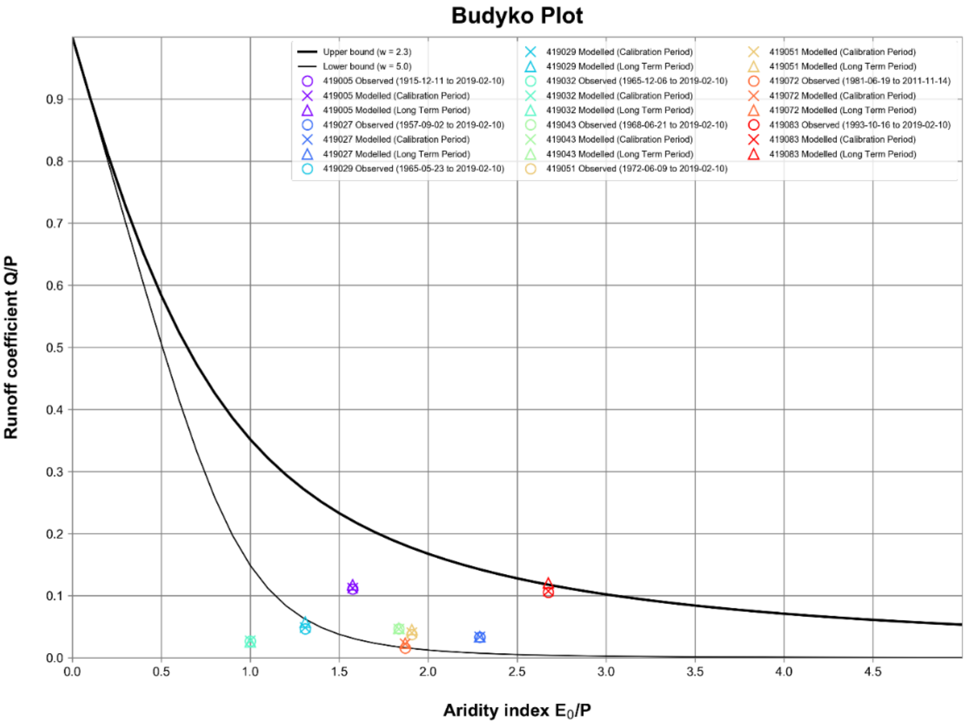


Table 50. Reach flow calibration statistics (2004 – 2015). For each station, mean annual flow, daily Nash Sutcliffe, flow bias for full, low, medium and high flow range (%) and reference to graph in this report (Graph reference) are reported. Final flow bias is from the fully assembled flow calibration model (validation model)

Station No	Mean annual flow (GL)	Daily Nash Sutcliffe	Full flow bias (%)	Low flow bias (%)	Medium flow bias (%)	High flow bias (%)	Graph reference
419020	49	0.98	-0.8	4.7	1.5	-1.4	Figure 60
419022	207	0.98	0	-3.5	0.3	0.1	Figure 61
419007	197	0.83	0.4	-7.1	-4.4	2.8	Figure 62
419012	370	0.90	-4.0	-2.6	-0.8	-4.7	Figure 63
419039	506	0.98	-0.8	8.9	2.1	-1.2	Figure 64
419059 + 419061	389	0.94	-0.7	0.1	-2.0	-0.3	Figure 65
419068	262	0.94	-1.2	-0.5	-2.3	-1.0	Figure 66
419021	308	0.80	-2.5	0.8	2.1	-3.1	Figure 67
419026	337	0.95	-0.2	-1.4	-1.4	-0.1	Figure 68
419064	34	0.83	0.7	-0.1	0.9	0.8	Figure 69
419049	36	0.55	-12.4	6.2	6.2	2.8	Figure 70
419091	604	0.48	-16.7	3.3	8.0	-17.1	Figure 71

Figure 53. Main river reach Sacramento modelling results compared to aridity index

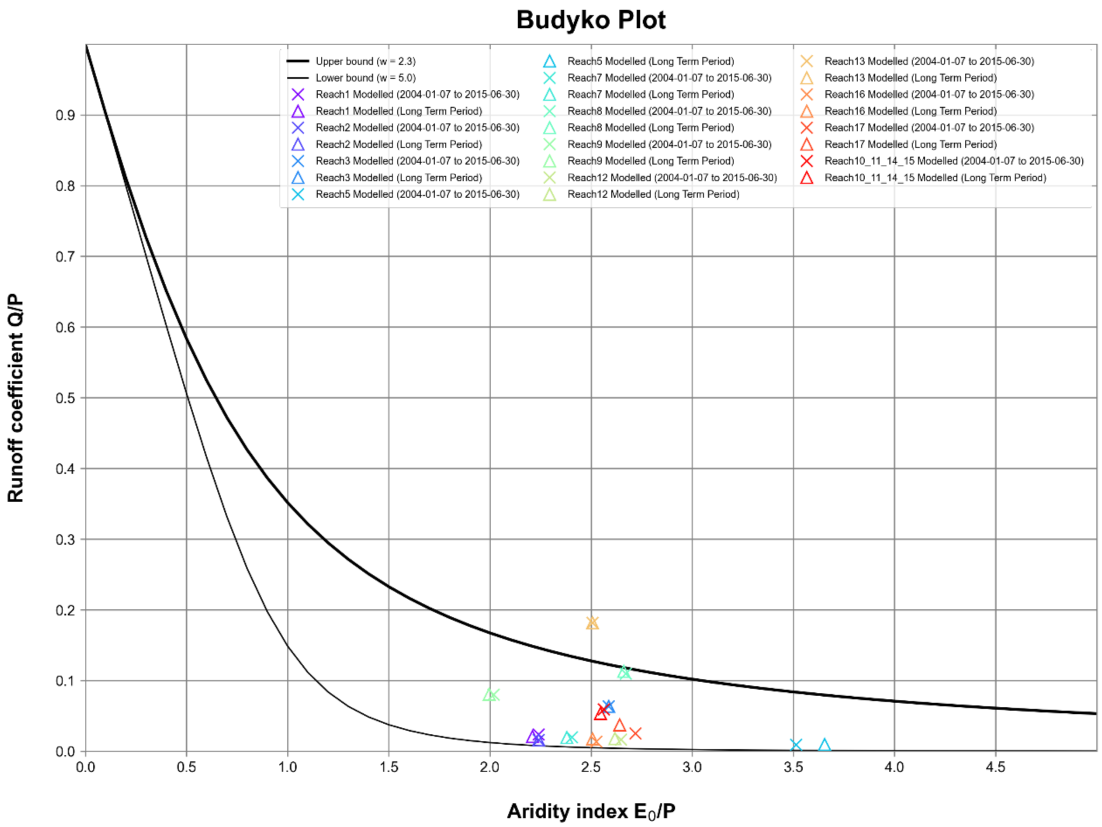
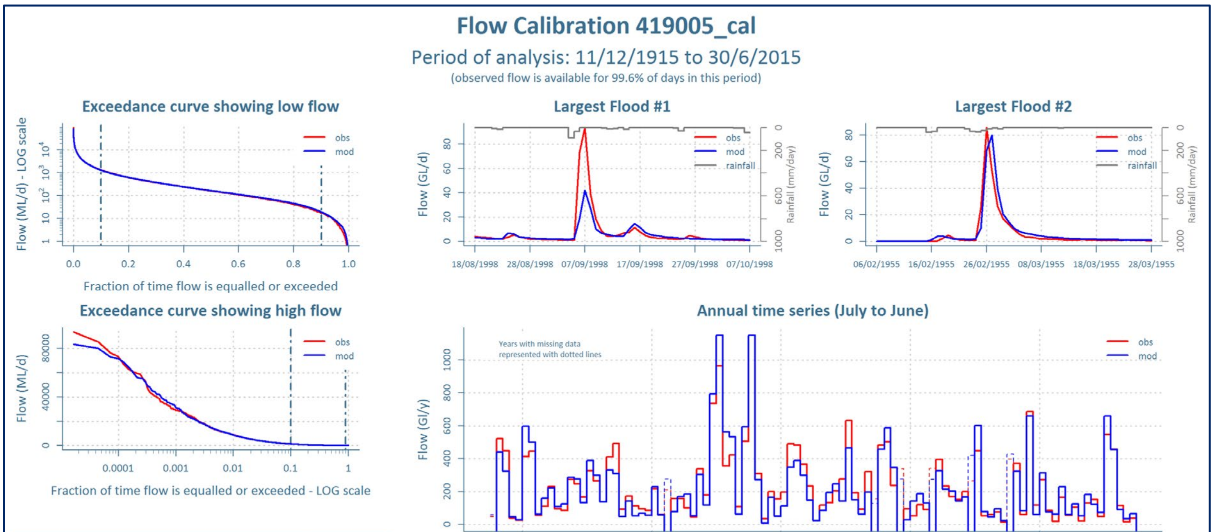


Figure 54. Flow calibration graphs for gauging station 419005 Namoi River @ North Cuerindi

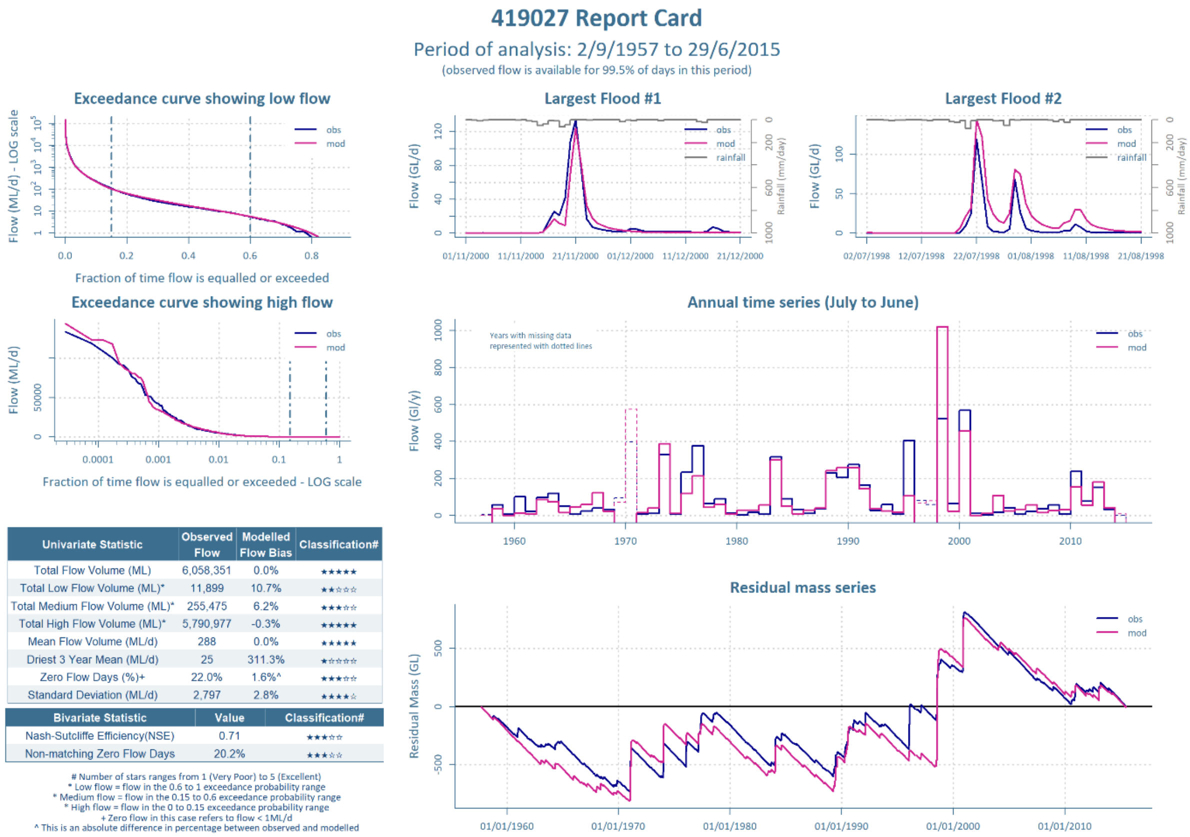


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	23,832,076	0.0%	★★★★★
Total Low Flow Volume (ML)*	29,249	11.4%	★★☆☆☆
Total Medium Flow Volume (ML)*	7,889,086	0.5%	★★★★★
Total High Flow Volume (ML)*	15,913,741	-0.3%	★★★★★
Mean Flow Volume (ML/d)	658	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	434	40.8%	★☆☆☆☆
Zero Flow Days (%)+	0.9%	0.3%^	★★★★☆
Standard Deviation (ML/d)	2,280	0.0%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.71	★★★☆☆
Non-matching Zero Flow Days	0.6%	★★★★★

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 55. Flow calibration graphs for gauging station 419027 Mooki River @ Breeza

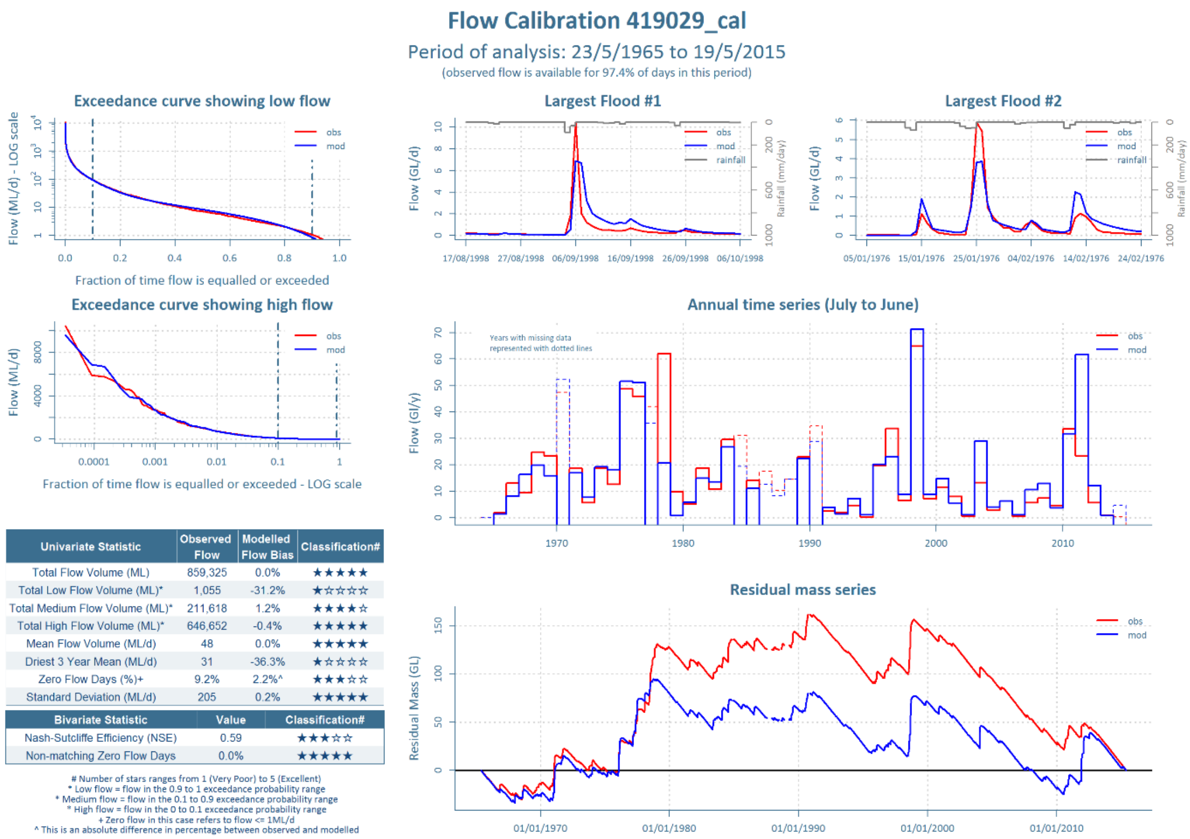


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	6,058,351	0.0%	★★★★★
Total Low Flow Volume (ML)*	11,899	10.7%	★★☆☆☆
Total Medium Flow Volume (ML)*	255,475	6.2%	★★★☆☆
Total High Flow Volume (ML)*	5,790,977	-0.3%	★★★★★
Mean Flow Volume (ML/d)	288	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	25	311.3%	★☆☆☆☆
Zero Flow Days (%)+	22.0%	1.6%^	★★★☆☆
Standard Deviation (ML/d)	2,797	2.8%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.71	★★★☆☆
Non-matching Zero Flow Days	20.2%	★★★☆☆

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 0.15 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.15 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 419029 Halls Creek @ Ukolan

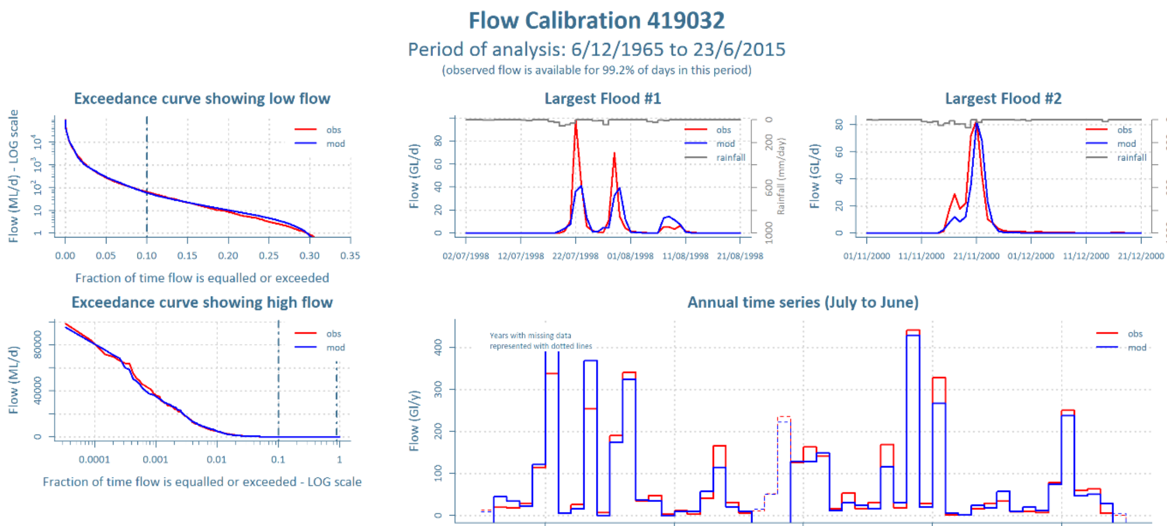


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	859,325	0.0%	★★★★★
Total Low Flow Volume (ML)*	1,055	-31.2%	★☆☆☆☆
Total Medium Flow Volume (ML)*	211,618	1.2%	★★★★☆
Total High Flow Volume (ML)*	646,652	-0.4%	★★★★★
Mean Flow Volume (ML/d)	48	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	31	-36.3%	★☆☆☆☆
Zero Flow Days (%)+	9.2%	2.2%^	★★★☆☆
Standard Deviation (ML/d)	205	0.2%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.59	★★★☆☆
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 57. Flow calibration graphs for gauging station 419032 Coxs Creek at Boggabri

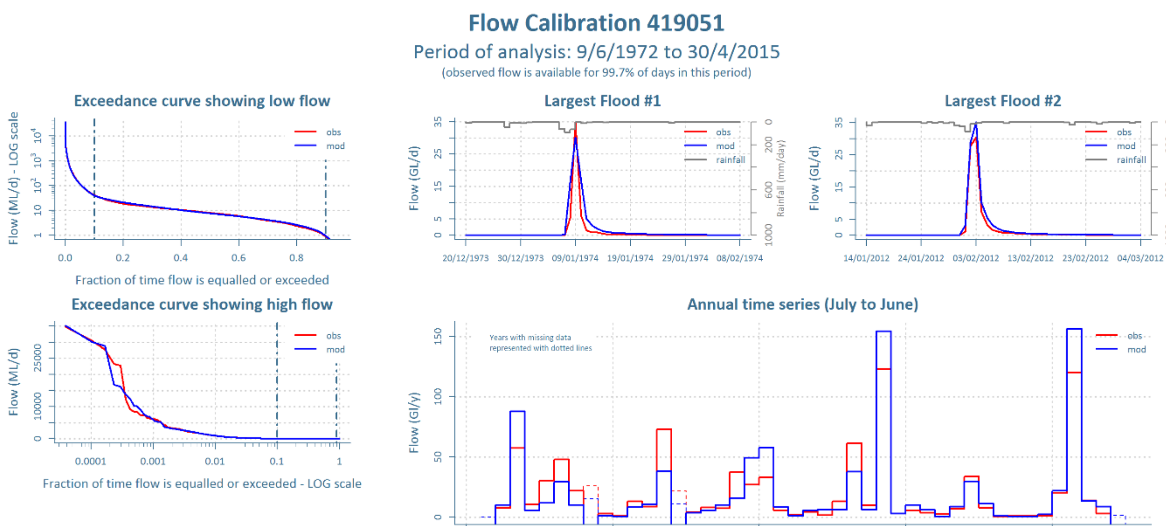


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	4,088,393	0.0%	★★★★★
Total Low Flow Volume (ML)*	0	-1099.9%	★☆☆☆☆
Total Medium Flow Volume (ML)*	54,972	1.5%	★★★★☆
Total High Flow Volume (ML)*	4,033,420	0.0%	★★★★★
Mean Flow Volume (ML/d)	228	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	17	71.0%	★☆☆☆☆
Zero Flow Days (%)+	70.3%	0.0%^	★★★★★
Standard Deviation (ML/d)	2,337	-1.2%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.71	★★★☆☆
Non-matching Zero Flow Days	20.9%	★★★☆☆

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 58. Flow calibration graphs for gauging station 419051 Maules Creek @ Avoca East



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	884,706	0.0%	★★★★★
Total Low Flow Volume (ML)*	335	12.1%	★★☆☆☆
Total Medium Flow Volume (ML)*	124,837	3.6%	★★★★☆
Total High Flow Volume (ML)*	759,534	-0.6%	★★★★★
Mean Flow Volume (ML/d)	57	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	28	-43.6%	★☆☆☆☆
Zero Flow Days (%)+	10.6%	0.4%^	★★★★☆
Standard Deviation (ML/d)	591	-2.3%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.75	★★★★☆
Non-matching Zero Flow Days	8.0%	★★★★☆

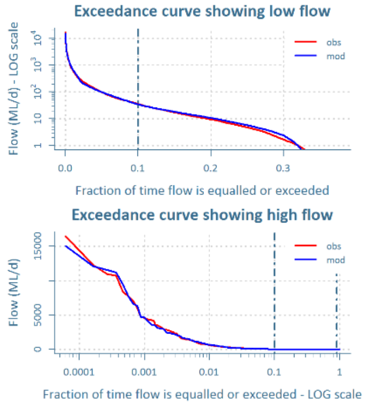
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.9 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.9 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

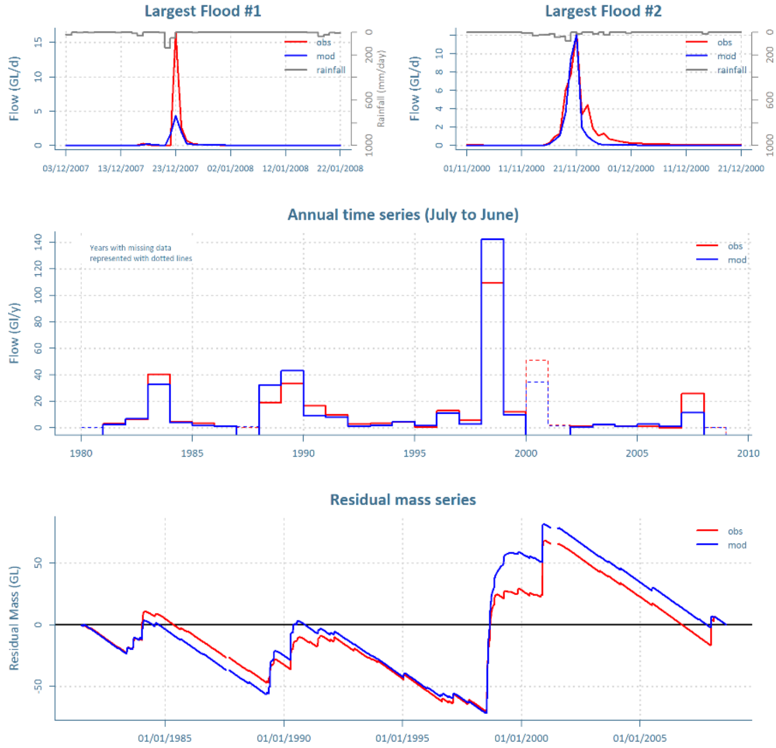
Figure 59. Flow calibration graphs for gauging station 419072 Baradine Creek @ Kienbri

Flow Calibration 419072

Period of analysis: 19/6/1981 to 13/8/2008

(observed flow is available for 98.4% of days in this period)





Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	371,372	0.0%	★★★★★
Total Low Flow Volume (ML)*	0	-1099.9%	★☆☆☆☆
Total Medium Flow Volume (ML)*	23,723	6.6%	★★★☆☆
Total High Flow Volume (ML)*	347,650	-0.4%	★★★★★
Mean Flow Volume (ML/d)	38	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	5	-19.4%	★★☆☆☆
Zero Flow Days (%)+	67.9%	0.1%^	★★★★★
Standard Deviation (ML/d)	357	-1.3%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.60	★★★☆☆
Non-matching Zero Flow Days	17.4%	★★★☆☆

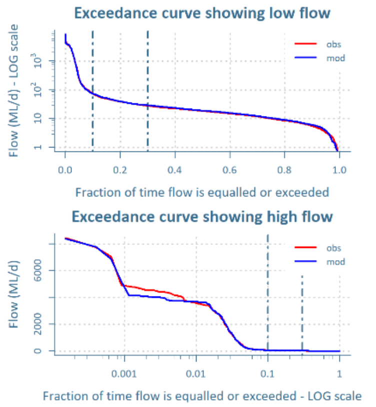
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.9 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.9 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

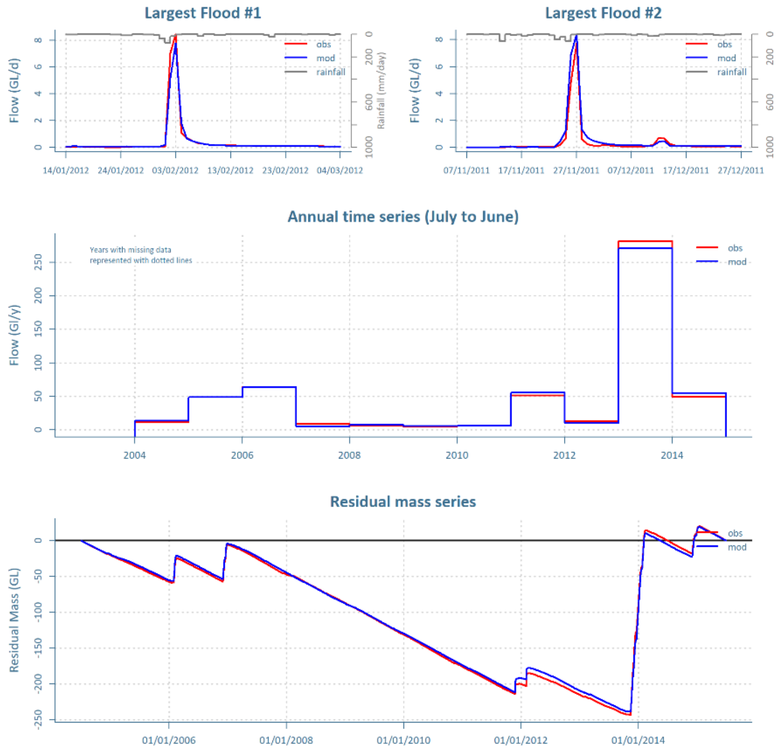
Figure 60. Flow calibration graphs for gauging station 419020 Manilla River @ Brabri

Calibration Reach 419020

Period of analysis: 1/7/2004 to 30/6/2015

(observed flow is available for 100% of days in this period)



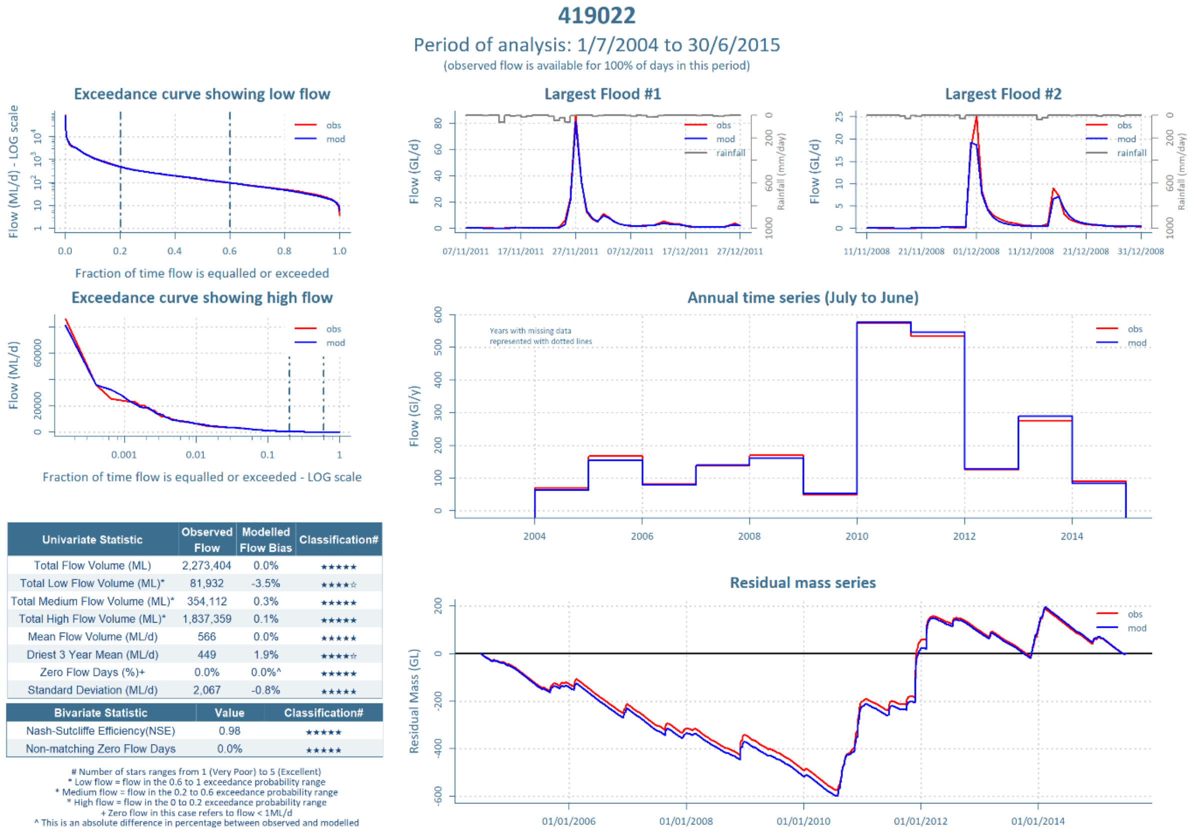


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	542,943	-0.7%	★★★★☆
Total Low Flow Volume (ML)*	38,460	4.5%	★★★★☆
Total Medium Flow Volume (ML)*	33,597	2.5%	★★★★☆
Total High Flow Volume (ML)*	470,886	-1.3%	★★★★☆
Mean Flow Volume (ML/d)	135	-0.7%	★★★★☆
Driest 3 Year Mean (ML/d)	314	-2.4%	★★★★☆
Zero Flow Days (%)+	1.0%	0.4%^	★★★★☆
Standard Deviation (ML/d)	592	-1.9%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.98	★★★★★
Non-matching Zero Flow Days	0.0%	★★★★★

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 0.1 to 0.3 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 419022 Manilla River @ Manilla

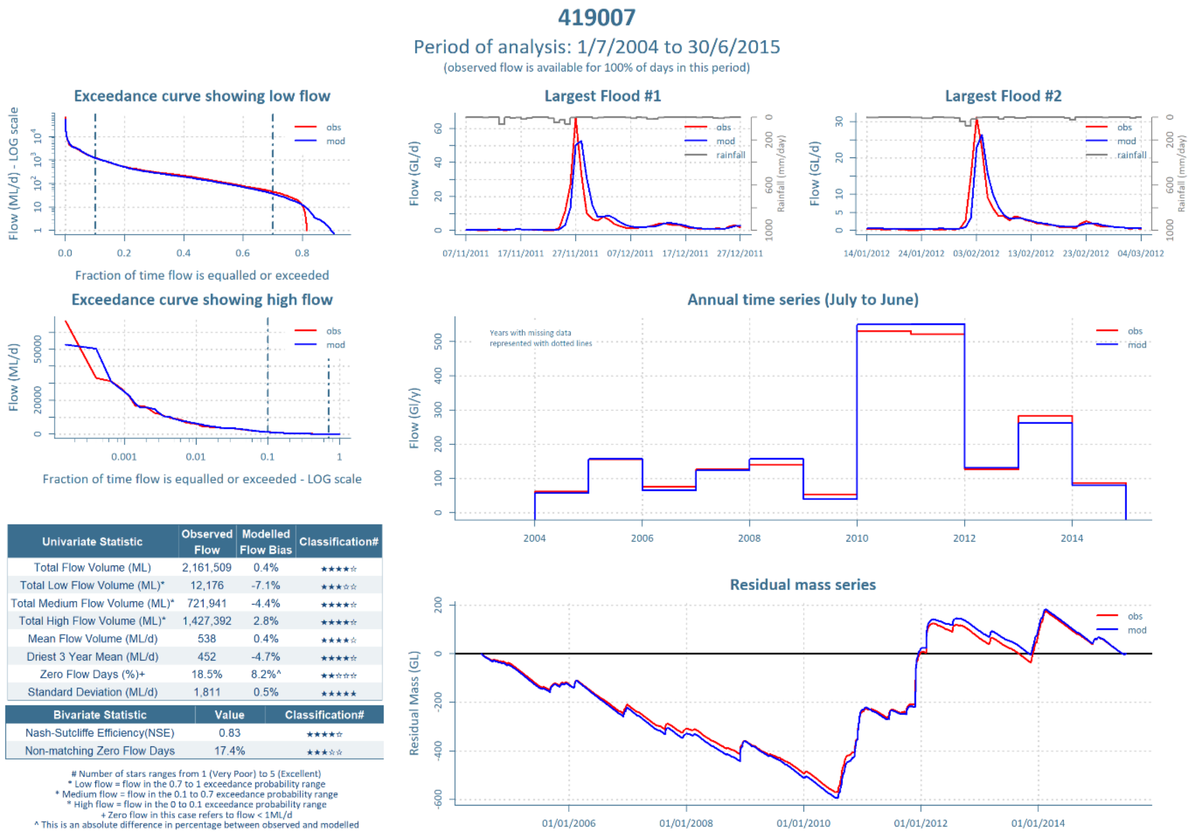


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	2,273,404	0.0%	★★★★★
Total Low Flow Volume (ML)*	81,932	-3.5%	★★★★☆
Total Medium Flow Volume (ML)*	354,112	0.3%	★★★★★
Total High Flow Volume (ML)*	1,837,359	0.1%	★★★★★
Mean Flow Volume (ML/d)	566	0.0%	★★★★★
Driest 3 Year Mean (ML/d)	449	1.9%	★★★★☆
Zero Flow Days (%)+	0.0%	0.0%^	★★★★★
Standard Deviation (ML/d)	2,067	-0.8%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.98	★★★★★
Non-matching Zero Flow Days	0.0%	★★★★★

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 62. Flow calibration graphs for gauging station 419007 Namoi River @ Manilla

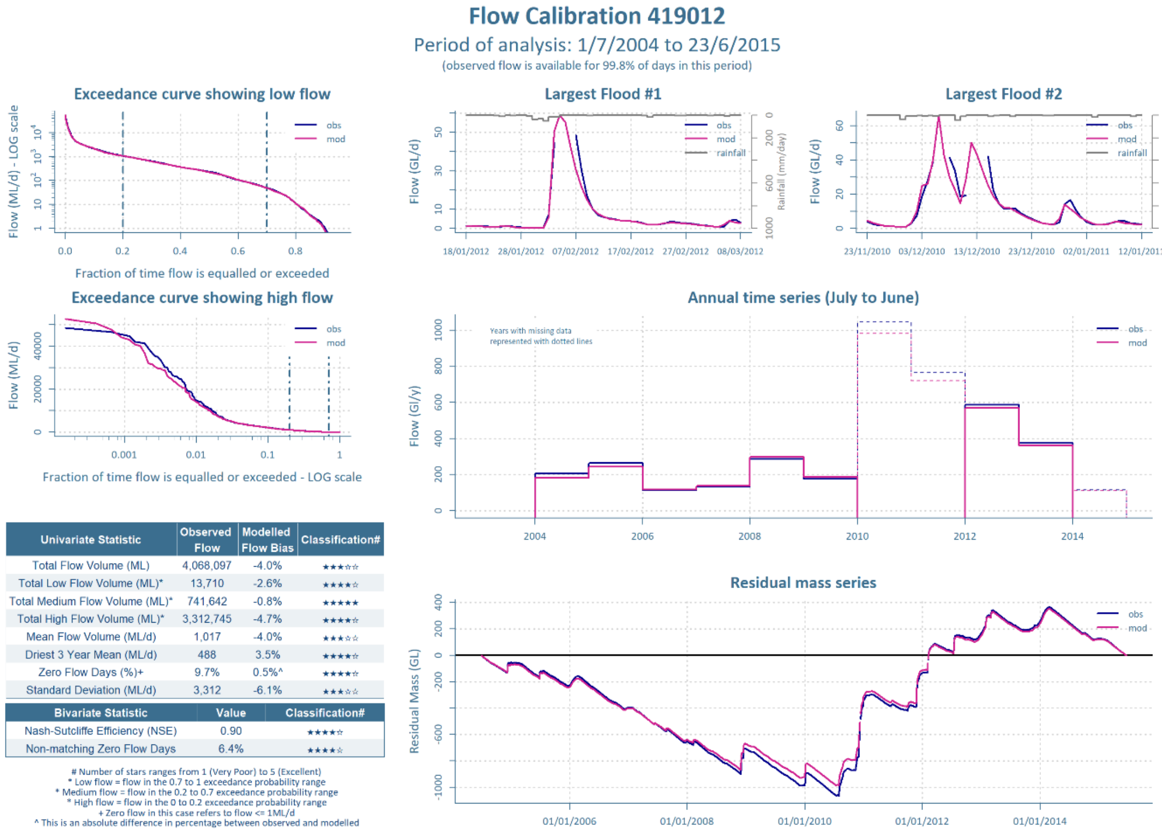


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	2,161,509	0.4%	★★★★☆
Total Low Flow Volume (ML)*	12,176	-7.1%	★★★☆☆
Total Medium Flow Volume (ML)*	721,941	-4.4%	★★★★☆
Total High Flow Volume (ML)*	1,427,392	2.8%	★★★★☆
Mean Flow Volume (ML/d)	538	0.4%	★★★★☆
Driest 3 Year Mean (ML/d)	452	-4.7%	★★★★☆
Zero Flow Days (%)+	18.5%	8.2%^	★★☆☆☆
Standard Deviation (ML/d)	1,811	0.5%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.83	★★★★☆
Non-matching Zero Flow Days	17.4%	★★★☆☆

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 63. Flow calibration graphs for gauging station 419012 Namoi River @ Boggabri

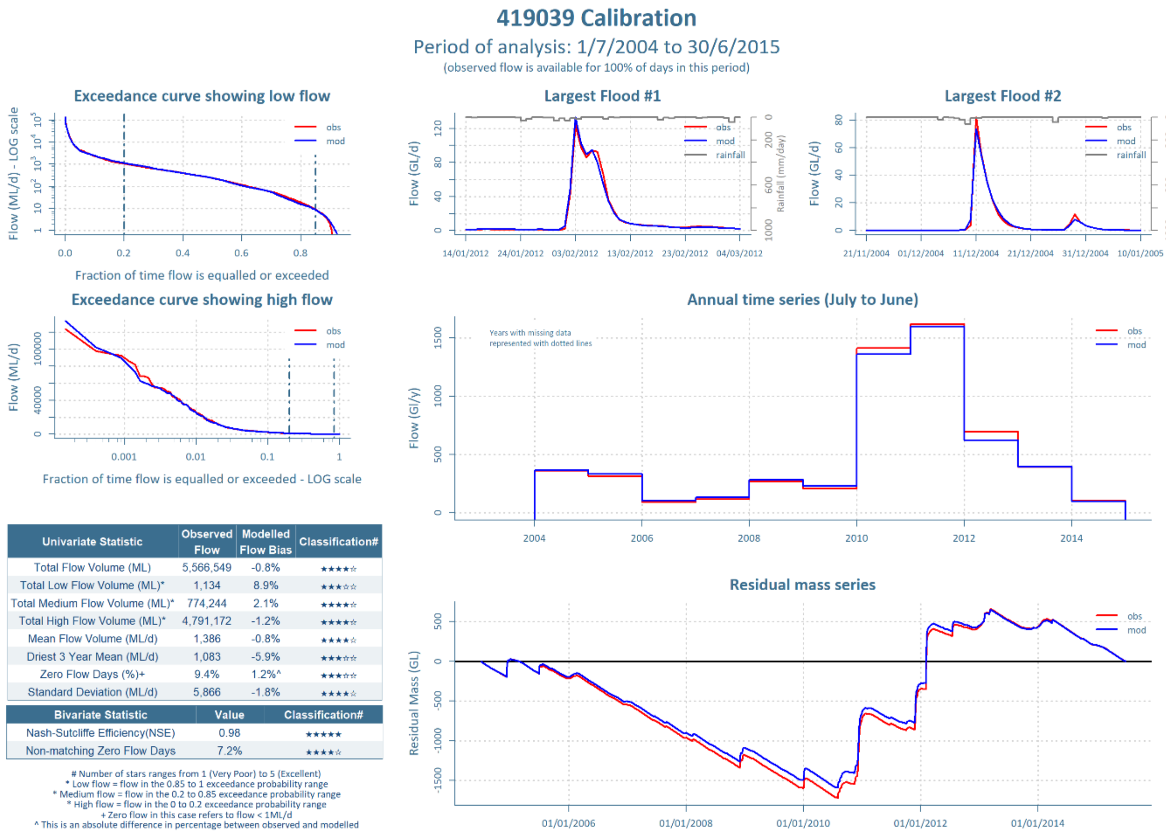


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	4,068,097	-4.0%	★★★☆☆
Total Low Flow Volume (ML)*	13,710	-2.6%	★★★★☆
Total Medium Flow Volume (ML)*	741,642	-0.8%	★★★★★
Total High Flow Volume (ML)*	3,312,745	-4.7%	★★★★☆
Mean Flow Volume (ML/d)	1,017	-4.0%	★★★☆☆
Driest 3 Year Mean (ML/d)	488	3.5%	★★★★☆
Zero Flow Days (%)+	9.7%	0.5%^	★★★★☆
Standard Deviation (ML/d)	3,312	-6.1%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.90	★★★★☆
Non-matching Zero Flow Days	6.4%	★★★★☆

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 0.2 to 0.7 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 64. Flow calibration graphs for gauging station 419039 Namoi River @ Mollee

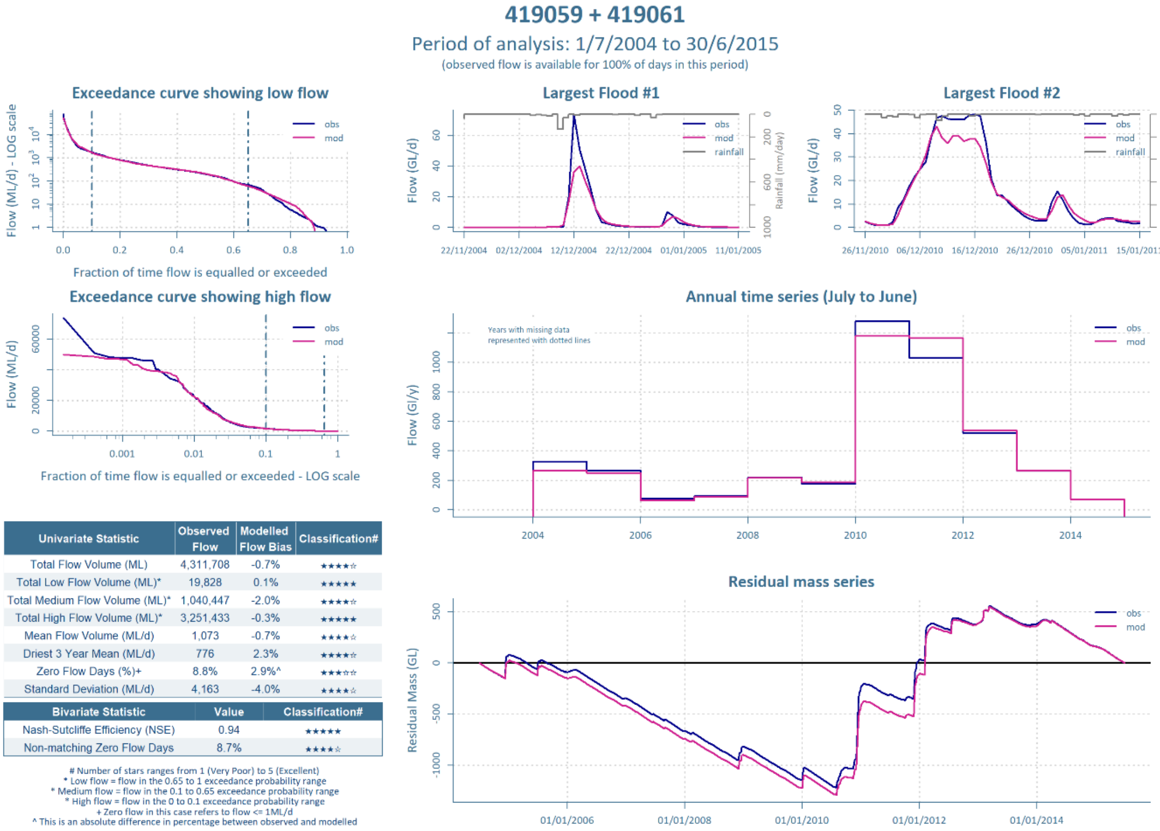


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	5,566,549	-0.8%	★★★★☆
Total Low Flow Volume (ML)*	1,134	8.9%	★★★☆☆
Total Medium Flow Volume (ML)*	774,244	2.1%	★★★★☆
Total High Flow Volume (ML)*	4,791,172	-1.2%	★★★★☆
Mean Flow Volume (ML/d)	1,386	-0.8%	★★★★☆
Driest 3 Year Mean (ML/d)	1,083	-5.9%	★★★☆☆
Zero Flow Days (%)+	9.4%	1.2%^	★★★☆☆
Standard Deviation (ML/d)	5,866	-1.8%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.98	★★★★★
Non-matching Zero Flow Days	7.2%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.85 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.85 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 65. Flow calibration graphs for gauging station 419059 Namoi River @ d/s Gunidgera Weir + 419061 Gunidgera Creek d/s offtake

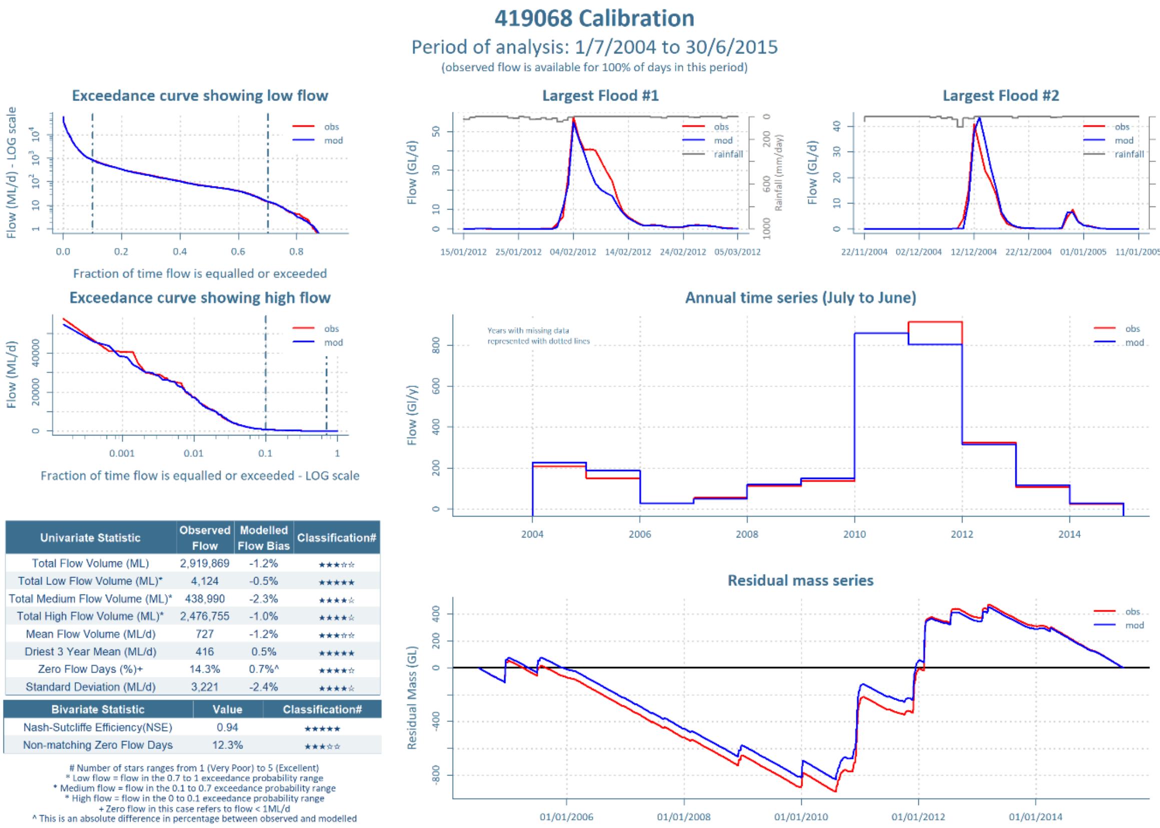


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	4,311,708	-0.7%	★★★★☆
Total Low Flow Volume (ML)*	19,828	0.1%	★★★★★
Total Medium Flow Volume (ML)*	1,040,447	-2.0%	★★★★☆
Total High Flow Volume (ML)*	3,251,433	-0.3%	★★★★★
Mean Flow Volume (ML/d)	1,073	-0.7%	★★★★☆
Driest 3 Year Mean (ML/d)	776	2.3%	★★★★☆
Zero Flow Days (%)+	8.8%	2.9%^	★★★☆☆
Standard Deviation (ML/d)	4,163	-4.0%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.94	★★★★★
Non-matching Zero Flow Days	8.7%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.65 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.65 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 66. Flow calibration graphs for gauging station 419068 Namoi River @ d/s Weeta Weir

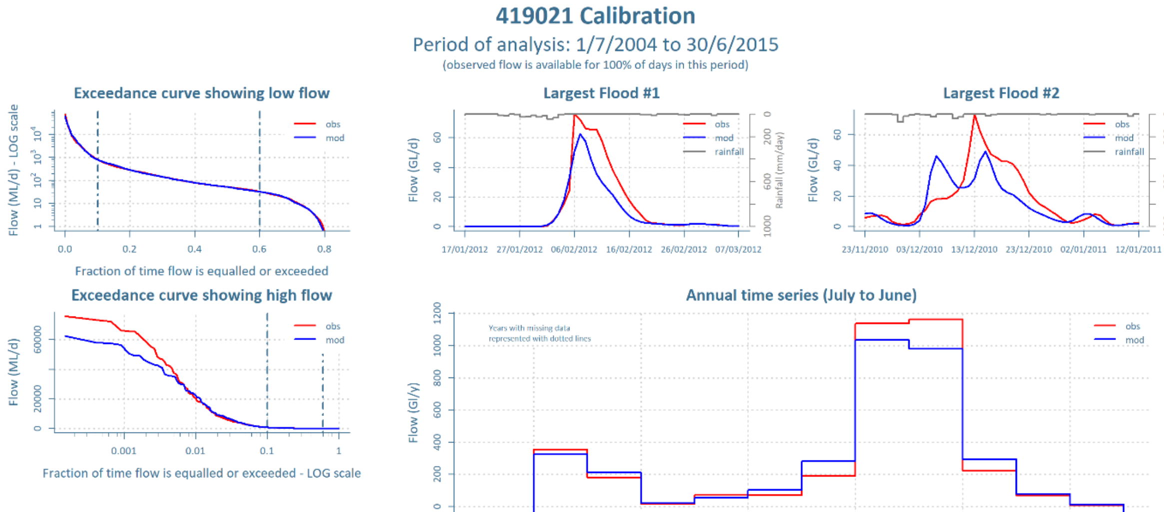


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	2,919,869	-1.2%	★★★☆☆
Total Low Flow Volume (ML)*	4,124	-0.5%	★★★★★
Total Medium Flow Volume (ML)*	438,990	-2.3%	★★★★☆
Total High Flow Volume (ML)*	2,476,755	-1.0%	★★★★☆
Mean Flow Volume (ML/d)	727	-1.2%	★★★☆☆
Driest 3 Year Mean (ML/d)	416	0.5%	★★★★★
Zero Flow Days (%)+	14.3%	0.7%^	★★★★☆
Standard Deviation (ML/d)	3,221	-2.4%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.94	★★★★★
Non-matching Zero Flow Days	12.3%	★★★☆☆

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 67. Flow calibration graphs for gauging station 419021 Namoi River @ Bugilbone

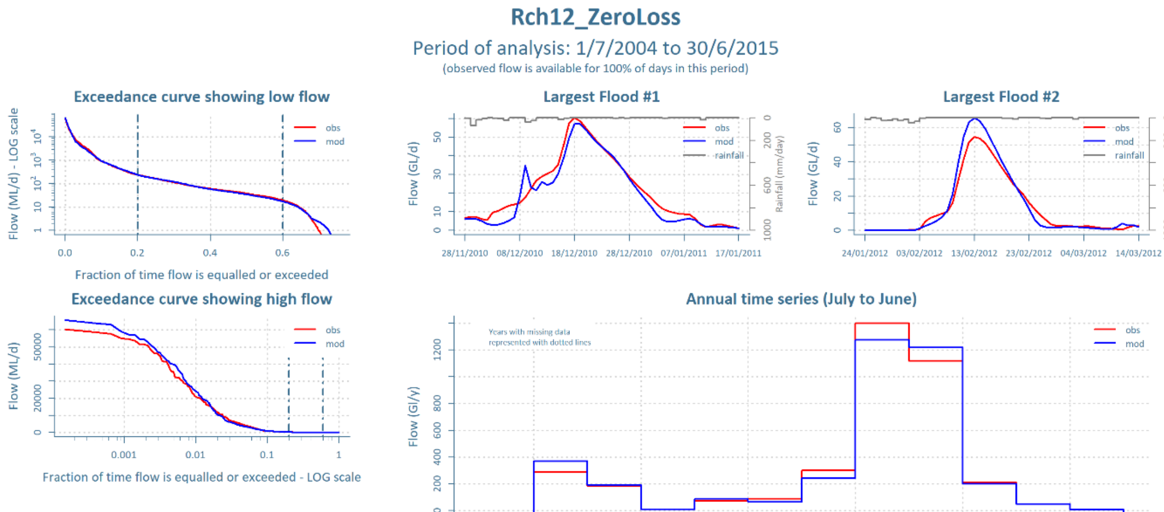


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	3,479,435	-2.5%	★★★☆☆
Total Low Flow Volume (ML)*	11,815	0.8%	★★★★★
Total Medium Flow Volume (ML)*	355,373	2.1%	★★★★☆
Total High Flow Volume (ML)*	3,112,247	-3.1%	★★★★☆
Mean Flow Volume (ML/d)	866	-2.5%	★★★☆☆
Driest 3 Year Mean (ML/d)	270	30.1%	★☆☆☆☆
Zero Flow Days (%)+	20.5%	0.5%^	★★★★☆
Standard Deviation (ML/d)	4,678	-11.7%	★★☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.80	★★★★☆
Non-matching Zero Flow Days	11.5%	★★★☆☆

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 0.1 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 68. Flow calibration graphs for gauging station 419026 Namoi River @ Goangra

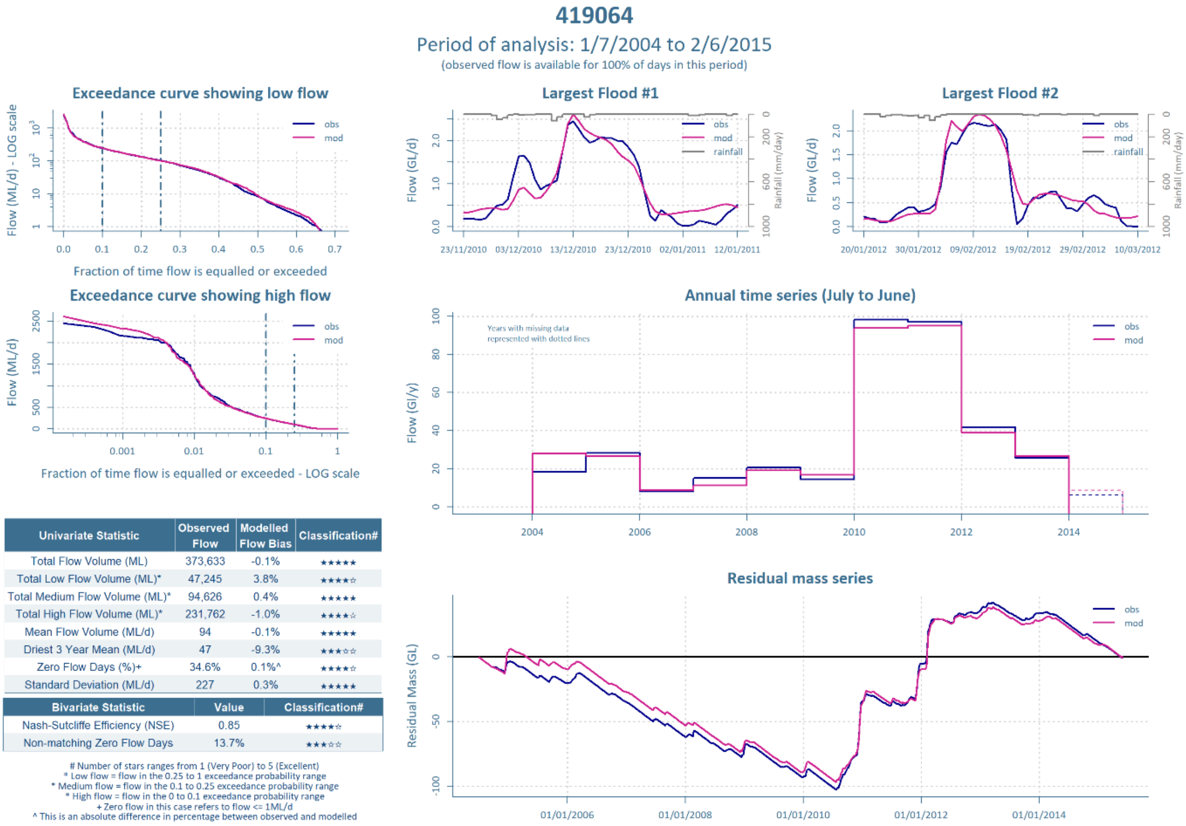


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	3,719,112	-0.2%	★★★★☆
Total Low Flow Volume (ML)*	3,733	-1.4%	★★★★☆
Total Medium Flow Volume (ML)*	130,873	-1.4%	★★★★☆
Total High Flow Volume (ML)*	3,584,506	-0.1%	★★★★★
Mean Flow Volume (ML/d)	926	-0.2%	★★★★☆
Driest 3 Year Mean (ML/d)	239	-3.3%	★★★★☆
Zero Flow Days (%)+	30.2%	2.8%^	★★★☆☆
Standard Deviation (ML/d)	4,357	6.2%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.95	★★★★★
Non-matching Zero Flow Days	10.7%	★★★☆☆

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 0.2 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 69. Flow calibration graphs for gauging station 419064 Pian Creek @ Rossmore

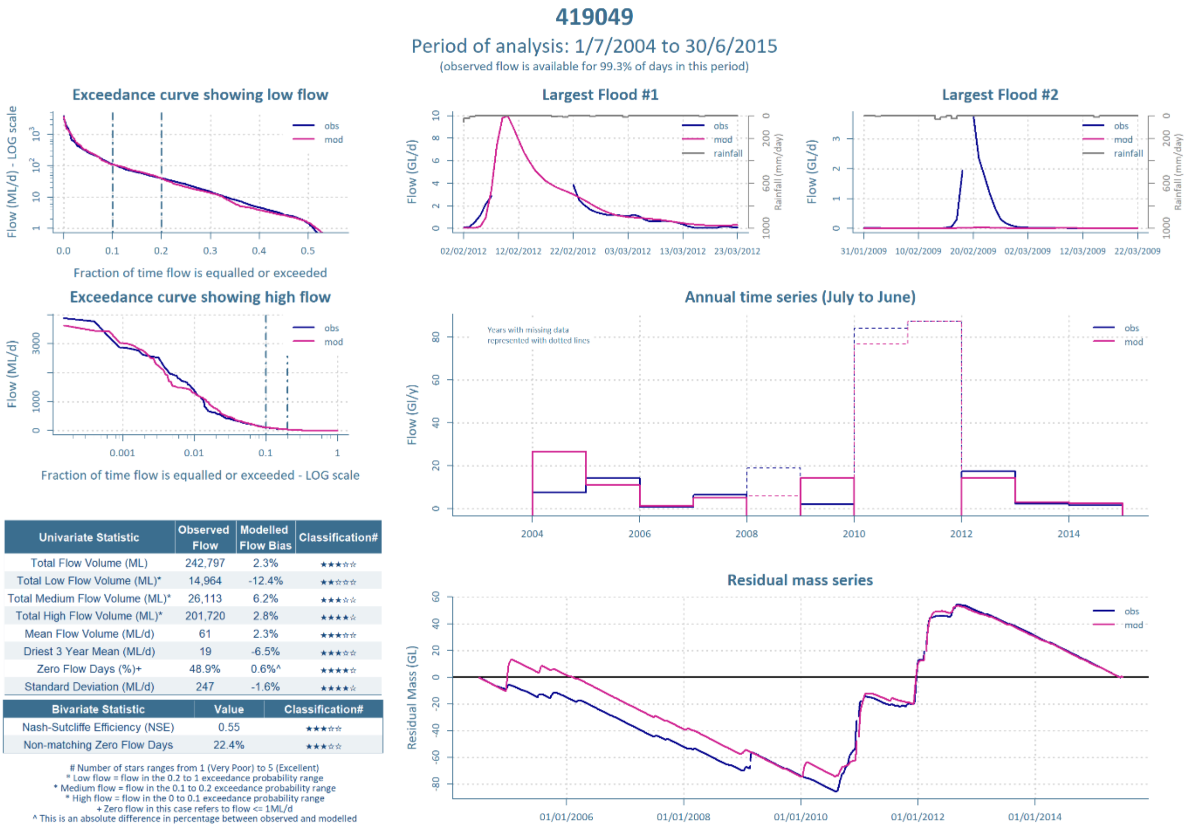


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	373,633	-0.1%	★★★★★
Total Low Flow Volume (ML)*	47,245	3.8%	★★★★☆
Total Medium Flow Volume (ML)*	94,626	0.4%	★★★★★
Total High Flow Volume (ML)*	231,762	-1.0%	★★★★☆
Mean Flow Volume (ML/d)	94	-0.1%	★★★★★
Driest 3 Year Mean (ML/d)	47	-9.3%	★★★☆☆
Zero Flow Days (%)+	34.6%	0.1%^	★★★★☆
Standard Deviation (ML/d)	227	0.3%	★★★★★

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.85	★★★★☆
Non-matching Zero Flow Days	13.7%	★★★☆☆

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 0.1 to 0.25 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 419049 Pian Creek @ Waminda



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	242,797	2.3%	★★★☆☆
Total Low Flow Volume (ML)*	14,964	-12.4%	★★☆☆☆
Total Medium Flow Volume (ML)*	26,113	6.2%	★★★☆☆
Total High Flow Volume (ML)*	201,720	2.8%	★★★★☆
Mean Flow Volume (ML/d)	61	2.3%	★★★☆☆
Driest 3 Year Mean (ML/d)	19	-6.5%	★★★☆☆
Zero Flow Days (%)+	48.9%	0.6%^	★★★★☆
Standard Deviation (ML/d)	247	-1.6%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.55	★★★☆☆
Non-matching Zero Flow Days	22.4%	★★★☆☆

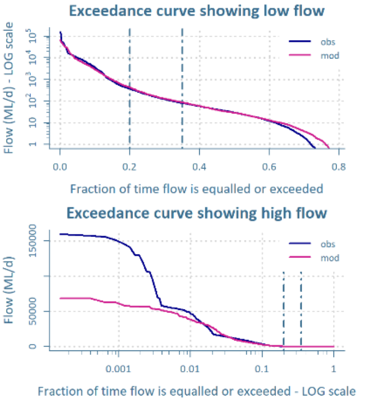
Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.2 to 1 exceedance probability range
* Medium flow = flow in the 0.1 to 0.2 exceedance probability range
* High flow = flow in the 0 to 0.1 exceedance probability range
+ Zero flow in this case refers to flow <= 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 71. Flow calibration graphs for gauging station 419091 Namoi River @ u/s Walgett

419091

Period of analysis: 1/7/2004 to 28/4/2015

(observed flow is available for 100% of days in this period)



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	7,937,507	-16.7%	★☆☆☆☆
Total Low Flow Volume (ML)*	40,993	3.3%	★★★★☆
Total Medium Flow Volume (ML)*	104,608	8.0%	★★★☆☆
Total High Flow Volume (ML)*	7,791,905	-17.1%	★★☆☆☆
Mean Flow Volume (ML/d)	2,007	-16.7%	★☆☆☆☆
Driest 3 Year Mean (ML/d)	566	102.3%	★☆☆☆☆
Zero Flow Days (%)+	28.0%	4.1%^	★★★☆☆
Standard Deviation (ML/d)	9,615	-32.4%	★☆☆☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency (NSE)	0.48	★★☆☆☆
Non-matching Zero Flow Days	22.4%	★★★☆☆

\# Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.35 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.35 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

Appendix K Supplementary access periods

The observed and modelled supplementary access periods, cumulated over the validation period are compared for three selected river reaches in Figure 72 to Figure 74. The upstream reach overestimates the periods of supplementary access as the model simulates numerous periods with small volumes of access that are often not announced in practice. However, the volumes of supplementary licences and use in this river reach are relatively small. A better match is achieved in the reaches further downstream where most of the supplementary access occurs.

Figure 72. Observed and simulated cumulative supplementary access from Boggabri to Narrabri (Reach 6)

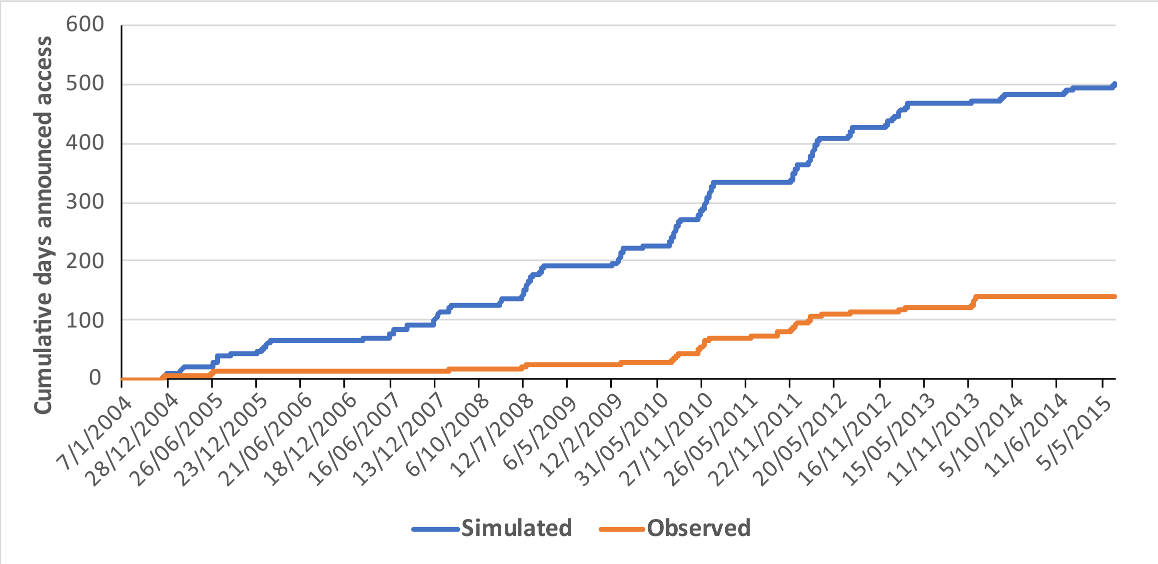


Figure 73. Observed and simulated supplementary access periods from d/s Weeta Weir to Bullawa (Reach 10)

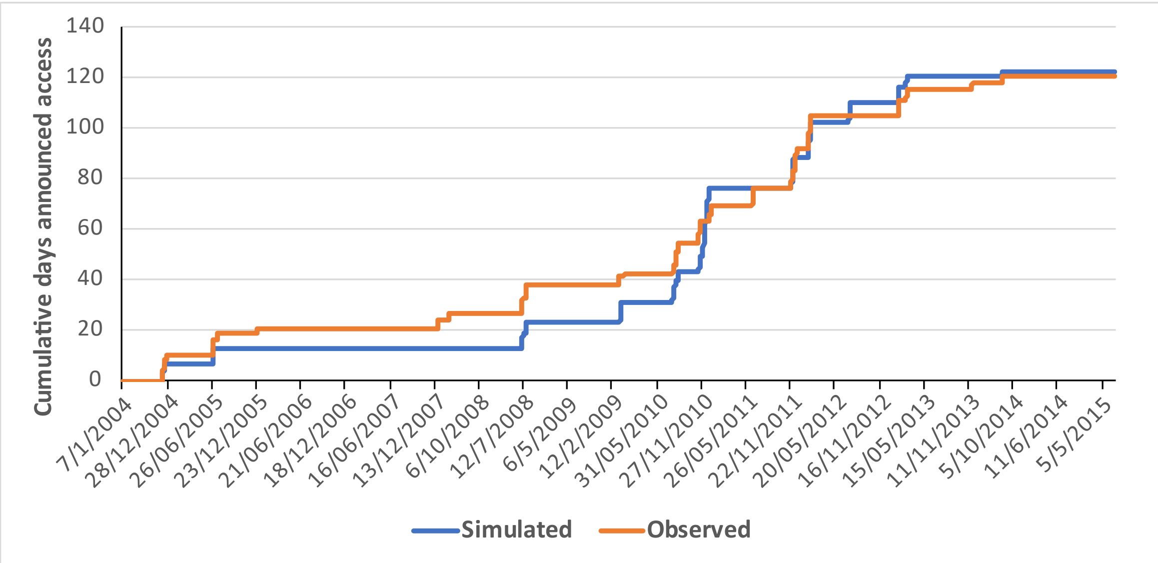
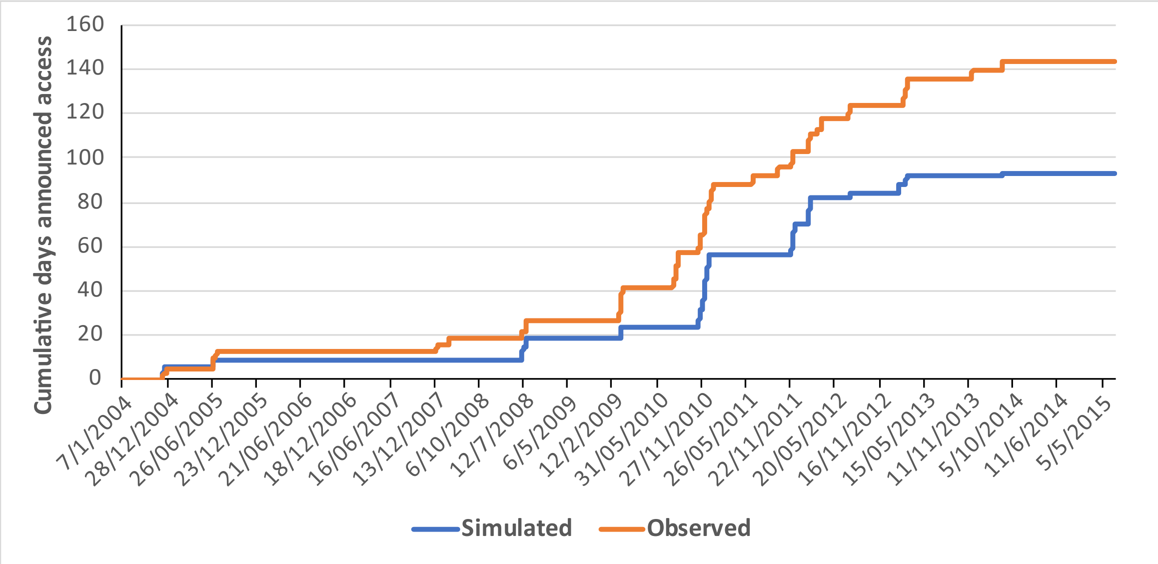


Figure 74. Observed and simulated cumulative supplementary access from Gunidgera offtake to d/s cutting (Reach 14)



Appendix L Model versions

Over the period of development several upgrades of Source were adopted. The final versions of the model and software used for reporting results are listed in Table 51.

Table 51. Model version details: Source rsproj file name, relevant scenario input set and Source version

Source file name	Scenario input set	Source version
Used in this report: NAMO_CAL_264_5.17.0_report_results.nightlybuild.rsproj	LongTerm_Scenarios>EligibleWorks_08_09_built_GW_TSR_Flux>Upper_Namoi_Fixes>AutoCal_RiskFuncs	5.16.0.12332 with continuous accounting fixes LT run
Used in sections 8.4.1 in this report: NAMO_CAL_264_5.17.0_report_results.nightlybuild.rsproj	LongTerm_Scenarios>EligibleWorks_08_09_built_GW_TSR_Flux>Upper_Namoi_Fixes>AutoCal_RiskFuncs>2004_Hotstart	5.16.0.12332 with continuous accounting fixes LT run

Sensitivity tests were completed in a slightly earlier version of the software/model, but this is not expected to make an appreciable difference to the outcomes presented in the report.

Appendix M Glossary

In addition to the information provided in this appendix, the reader is directed to excellent online resources, such as that provided by Water NSW[28].

Table 52. Abbreviations/acronyms

Abbreviation	Description
ABARE	Australian Bureau of Agricultural Research
ABS	Australian Bureau of Statistics
AWD	Available Water Determination
BDL	Baseline Diversion Limit
CEWH	Commonwealth Environmental Water Holder
ESID	Extraction Site IDentification number
FAO	Food and Agriculture Organisation (within the United Nations)
HEW	Held Environmental Water
Hydstra	Product brand name
IBQ	Irrigator Behaviour Questionnaire (used interchangeably with 'farm survey')
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)
MODIS	Moderate Resolution Imaging Spectroradiometer (a remote sensing instrument)
NRAR	Natural Resources Access Regulator
NSE	Nash-Sutcliffe Efficiency (a goodness-of-fit calibration measure)
SBM	Storage bathymetry model
SDL	Sustainable Diversion Limit
SILO	Scientific Information for Land Owners (always called SILO)
TOL	Transmission and Operational Loss
WAS	Water Accounting System (database)
WLS	Water Licensing System
WSP	Water Sharing Plan

[28] 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

Table 53. Terms

Term	Description
2008/2009 Scenario	Model baseline scenario representing floodplain harvesting works in place in 2008/09. The derivation of this baseline scenario is described in companion Model Build report
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 Plan Limit Scenario
Cap Scenario	Generally based on 1993/94 conditions however an allowance was made for enlargement of Pindari Dam which means some development levels are based on November 1999
Current Conditions Scenario	Model scenario that uses the best available information on most recent known levels of irrigation infrastructure and entitlements
Namoi WSP	Shortened term for the Water *Sharing Plan for the NSW Namoi Regulated River Water Source 2016*
Plan limit	The authorised long-term average annual extraction limit as defined in the Water Sharing Plan
Plan Limit Scenario	Model scenario that includes cap on diversions – uses development levels as at 2001/02 and management arrangements and share components as at 1 July 2009
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*