P2R PROGRAM

INTEGRATION OF PADDOCK SCALE MODELLING AND SOURCE

FINAL REPORT

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Queensland Department of Environment and Science

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1 EXECUTIVE SUMMARY

The linkage between the Agricultural Production Systems sIMulator (APSIM) model used for paddock scale sugarcane land use constituent load estimation and the Source basin scale model is currently being undertaken by redistributing monthly loads generated from APSIM across the Source model hydrology.

This approach can result in unrealistic constituent concentrations in the basin scale model output if the paddock scale sugar cane is under irrigation. In these cases, paddock scale models tend to estimate higher runoff rates than the basin scale model. The paddock scale loads are then distributed across a smaller than expected runoff volume, resulting in unrealistic modelled constituent concentrations. This is a particular problem for pesticides, where the frequency of high in-stream concentrations, as well as long-term loads, are an important indicator of ecosystem health.

The current model linkage also limits the ability to directly translate some on-farm management practices simulated in APSIM to hydrology in the catchment outlet, such as irrigation management and recycling pits. These practices have the potential to influence both hydrology and constituent loads.

To address these problems, this study has investigated an alternative model linkage by constructing a Source plugin to directly link the sugarcane paddock scale model hydrology and loads to Source by:

- replacing the Source-modelled sugarcane hydrology with APSIM-modelled sugarcane hydrology
- retaining APSIM-modelled sugarcane constituent loads delivered to Source
- incorporating Source-style routing and loss parameters to translate the paddock scale runoff and loads to the stream network.

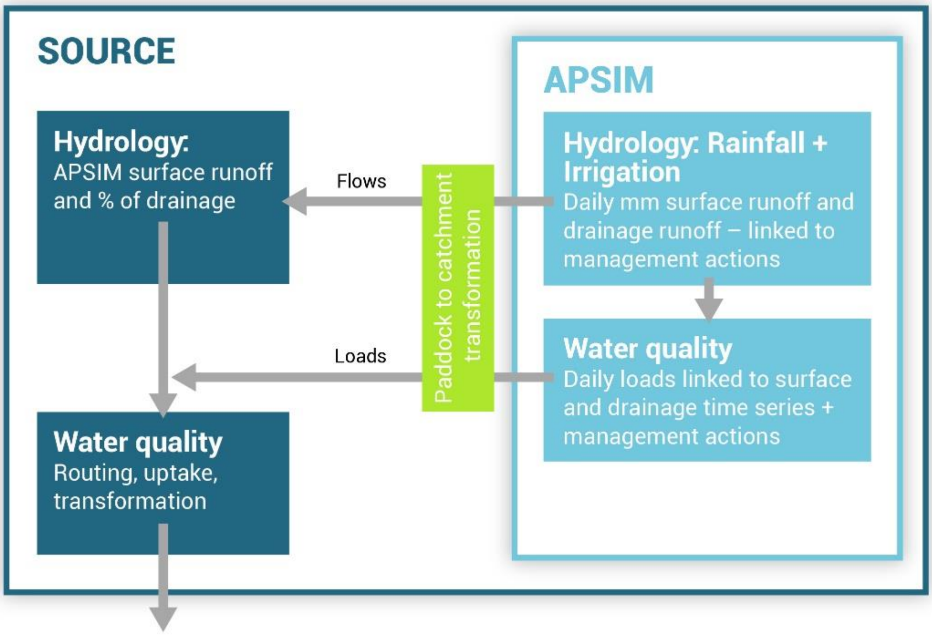


Figure 1-1. Proposed Source and APSIM linkage

Application of the new model linkage to the Pioneer (rain-fed), Barratta (Burdekin—irrigated sugar cane) and Tully–Johnstone (Wet Tropics) models for the water quality constituents dissolved inorganic nitrogen (DIN), atrazine and Diuron demonstrated:

- model hydrologic performance can be maintained or improved through the application of APSIM-generated runoff and drainage
- constituent load correlations with estimated observations (mean annual loads) can be maintained or improved
- modelled constituent concentrations in irrigated sugarcane areas can be improved to better match observations, while in non-irrigated sugarcane areas, concentration profiles can generally be maintained to those modelled previously.

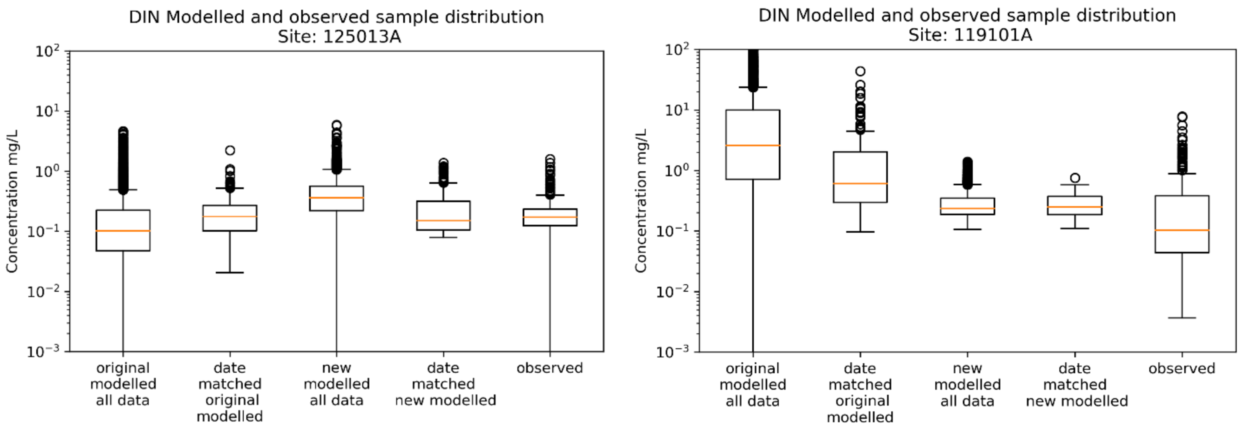


Figure 1-2. Example model old and new modelled concentration results for DIN in a rain-fed catchment (left) and irrigated catchment (right)

The key parameters of the new plugin are the delivery ratio for drainage contribution to the stream, and the surface and drainage constituent delivery ratios. Adjustment of these ratios is available to the modeller as calibration parameters to achieve model fit.

Following from this study, further work has been recommended to:

- expand the number of catchments and locations being tested by the new approach, particularly more testing of irrigated sugarcane areas
- provide guidance for selecting model parameters by investigating the applicability and mechanisms represented by the selected delivery ratios
- reduce reliance on delivery ratio parameters by understanding and adjusting constituent generation timing (application times) and magnitude at the paddock scale
- review the constituent load calculation methodologies to quantify the uncertainty in these estimates that are so important to water quality model calibration.

2 INTRODUCTION

The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (P2R program) is in the process of linking daily paddock scale models (APSIM) to large scale Source catchment models for land uses such as sugar cane. This project aims to review and enhance the current model linkage to overcome identified shortcomings of the current approach.

The current linkage between APSIM for sugarcane land use to the Source catchment models (Sacramento + daily SedNet) is undertaken by redistributing monthly loads generated from APSIM across the Sacramento-generated hydrology of the Source model (*Figure 2-1*). This approach retains both the hydrology of the Source model and the loads generated by paddock scale models, but results in distortions in modelled paddock scale constituent concentrations. This is because, in some areas (e.g. irrigated sugar cane), paddock scale models can simulate more runoff than what is simulated by the Source Sacramento runoff model. The APSIM loads associated with this runoff get distributed across smaller Sacramento runoff volumes, resulting in very high simulated constituent concentrations. The current linkage also limits the ability to directly translate some on-farm management practices simulated in APSIM to the catchment outlet (e.g. irrigation management and recycling pits).

This linkage ensures calibration of both flows and loads at basin scale at the expense of unrealistic constituent concentrations from selected land uses (e.g. pesticides) and limited ability to model the potential impact of some land management practices for sugarcane land use.

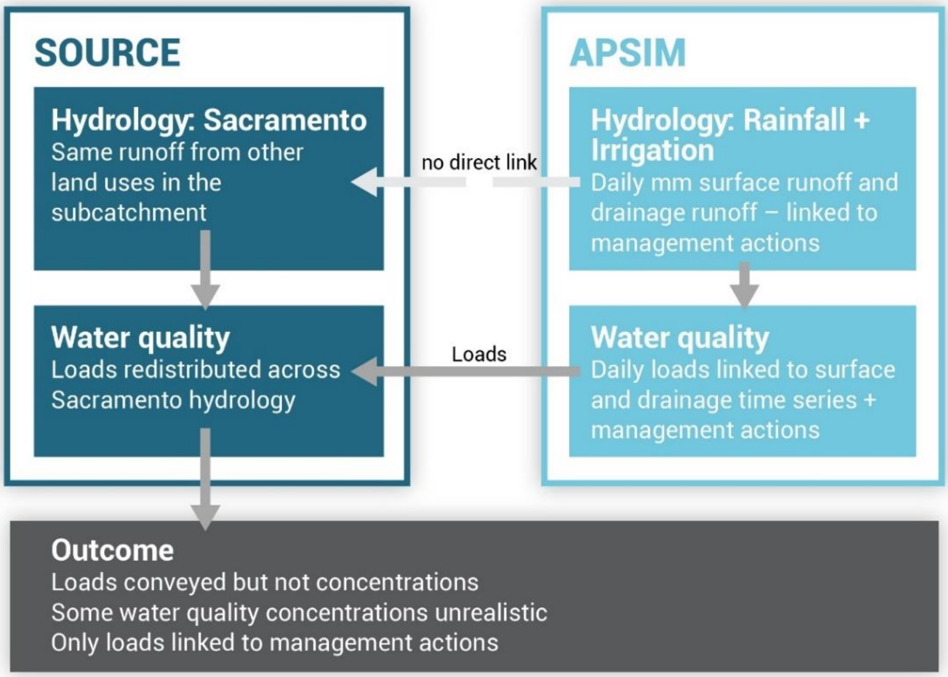


Figure 2-1. Source and APSIM current model linkage

The objective of this project was to investigate alternative methods of paddock and catchment scale model integration that maintain model hydrology and load calibrations, while improving the modelling of constituent concentrations and allowing the translation of on-farm management practices to the basin scale model. The alternative approach has been investigated using the APSIM sugarcane modelling, with particular focus on overall model hydrology, DIN, Diuron and atrazine. This new model integration must therefore account for processes that may occur between runoff and constituent generation at the paddock scale, and flow routing and constituent transport that occur at the catchment scale.

2.1 Methodology and report structure

A trial and error approach was used for this study. Paddock scale APSIM flows and loads for sugarcane land use were implemented directly in Source models via a custom plugin. The intent of this method was to avoid the problems of redistributing paddock scale loads across a different hydrology, thereby retaining paddock scale water quality concentrations, with the aim of achieving model agreement with measured data in three key areas:

- maintaining model hydrology calibrations
- maintaining water quality load estimates
- obtaining agreement in the statistical distribution of predicted and measured water quality concentrations.

The potential impact of importing the paddock scale model outputs into catchment scale models was assessed in two different catchments: Pioneer and Burdekin. The sugarcane land use in the Pioneer catchment is largely rain-fed, with supplemental irrigation, whereas the sugar cane in the Burdekin is fully irrigated.

The initial focus for model evaluation was to investigate the potential impact on model hydrology by integrating APSIM-generated flows into the Source model. Following this evaluation, the water quality constituent loads from paddock scale models were imported to Source and the potential impact on modelled concentrations was evaluated.

To undertake these model assessments and assist with estimating plugin parameters, a series of tools were developed and implemented in a Python notebook. The notebook provided the means to undertake statistical and visual analysis of the model fit for the modified hydrology and water quality approach.

2.1.1 Report structure

Chapter 3 of this report provides a brief overview of the current APSIM to Source linkage methodology and the APSIM and Sacramento model structures, and presents the governing equations for the adopted integration approach used in this study. The second part of the review chapter briefly describes the two test catchments chosen for this project, with particular focus on model hydrology.

Chapter 4 introduces the Python notebook model evaluation tools developed to assist with the proposed model integration approach. The notebook provides a step-by-step implementation and evaluation method so that model integration may be implemented in other models in the Great Barrier Reef (GBR) in a repeatable fashion.

Chapter 5 presents the results of the model integration approach on the two test catchments. Model hydrology is evaluated in addition to three water quality constituents: DIN, Diuron and atrazine.

Chapter 6 presents a discussion of the results, and introduces a framework that would take landscape position into account when considering the potential contribution to the stream. In this chapter, we include selected results from a third model used for testing the integration approach—the Tully–Johnstone model.

Chapter 7 presents a summary and recommendations for further work arising from this project.

3 MODEL OVERVIEW AND PLUGIN DEVELOPMENT

This chapter provides a brief overview of the two key models this project seeks to integrate: APSIM and Sacramento. The review highlights some of the problems associated with the current approach, and then outlines the proposed APSIM to Source linkage methodology to address these problems. The second part of the review chapter describes the two catchments chosen for this project to implement and test the proposed approach.

3.1 APSIM and Sacramento model structures

APSIM (APSIM 2018, Keating et al. 2003) contains a 1-D water balance model that takes into consideration soil water balance and crop growth. APSIM allows particular land uses involving crop growth, such as sugar cane, to be modelled, incorporating modules for nutrient cycling, pesticides and crop harvesting/irrigation management. The key water balance components of APSIM are shown in *Figure 3-1*, and show features consistent with many other basin scale hydrologic water balance models, such as multiple soil horizons and a 'bucket' style approach to soil water balance.

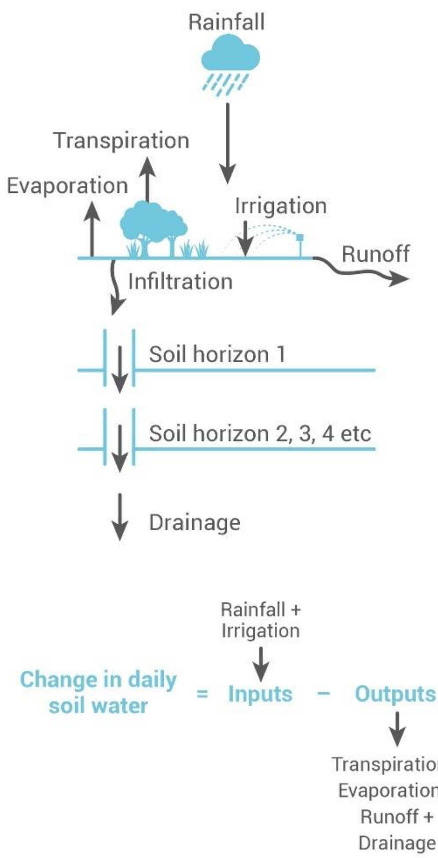


Figure 3-1. SoilWat conceptual model in APSIM (adapted from APSIM 2018)

In APSIM, the 'runoff' and 'drainage' terms are the outputs that could be passed directly to Source or to a plugin. Key features of the SoilWat component include:

- Runoff is calculated via the curve number technique.
- Crops can access water in the different soil horizons depending on root zone depth.

- The 'drainage' term is what is left over after any rainfall and irrigation runoff, crop water use and soil moisture have been calculated.

Further details of the algorithms of APSIM can be found in APSIM (2018) and Keating et al. (2003).

The Sacramento model is one of several available in the eWater Source modelling framework (eWater 2018), and was originally published by Burnash, Ferral and McGuire (1973), with a full description contained in NWS (2018).

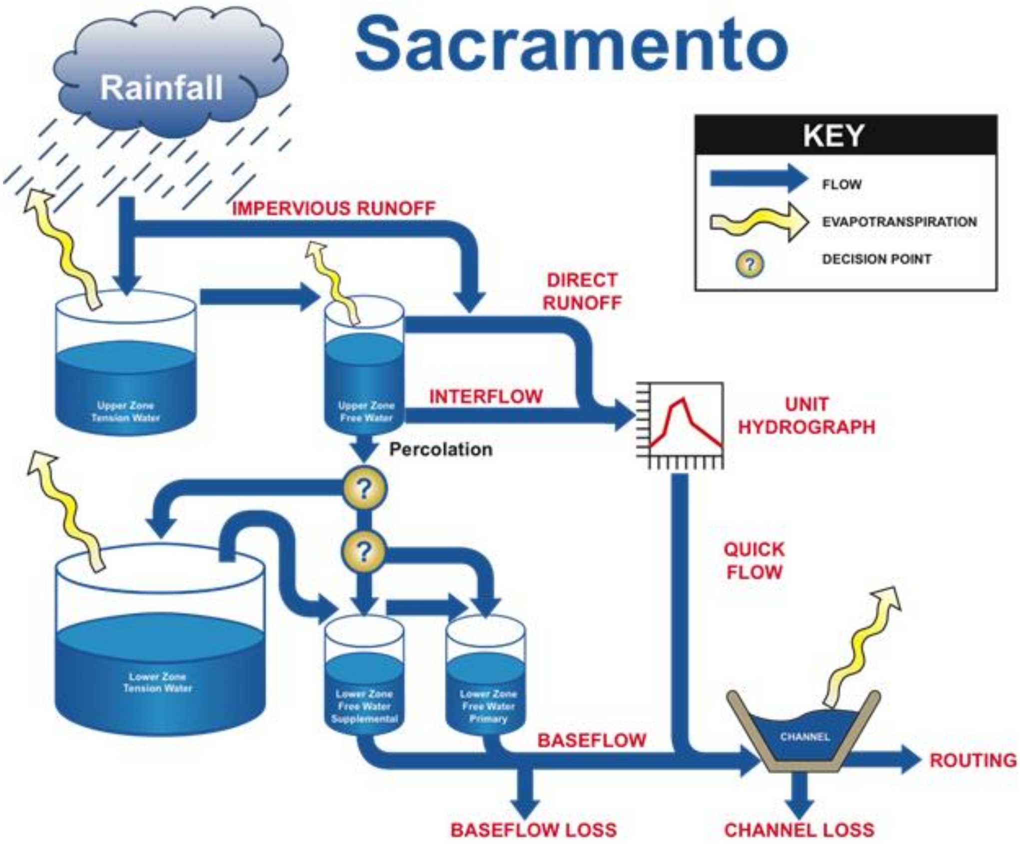


Figure 3-2. Sacramento soil moisture accounting conceptual model (eWater 2018)

In Sacramento:

- The exceedance of soil moisture capacity, infiltration excess or extent of impervious areas determine if runoff will occur.
- Evapotranspiration (ET) from the upper and lower zone soil moisture stores depletes these stores.
- Water can flow from the upper to the lower stores.

The processes captured in the Sacramento model are similar to the mass balance that is undertaken in APSIM, with some conceptual differences:

- APSIM can support more soil horizons and simulate crop growth cycles that can access and deplete the water in these horizons, whereas Sacramento assumes that if ET can happen, it will, regardless of vegetation or crop cycles.

- The curve number technique for runoff calculation in APSIM is arguably less refined than in Sacramento.
- Rainfall and irrigation are applied in APSIM, but only rainfall is currently applied in Sacramento Source models.

Several other elements are included in the Sacramento model to translate flows to the catchment outlet and achieve mass balance at gauge sites:

- Direct runoff and interflow pass through a unit hydrograph model to delay and lag the flows. This output creates the Source model 'quick flow' term.
- The outflow from the lower zone soil moisture stores is determined by a coefficient to delay or lag the outflow from this component of the model.
- Baseflow loss and channel loss allow the Sacramento model to remove some water to groundwater to achieve mass balance at gauge sites. The result of the lower zone lag and baseflow loss components is the 'slow flow' term used in Source.

These three additional elements in the Sacramento model have been considered sufficient in Source to model functional unit (FU) based runoff to the stream network.

In addition to the available lag, unit hydrograph and loss components in Sacramento, streamflow routing and storage operations are also modelled in Source along the river network to further attenuate and translate flows to gauge sites and the catchment outlet. In Source, these processes happen after runoff from individual FUs are aggregated at a subcatchment outlet and delivered to the stream, and are FU model independent.

3.2 Current APSIM to Source linkage

The current APSIM to Source linkage is shown in *Figure 2-1*. The current approach is to take APSIM-generated loads for each month and distribute these across the Sacramento-based, FU-generated daily flow time series for that month (Ellis 2018). The APSIM loads are subject to a delivery ratio and a load conversion factor prior to distribution over the Sacramento runoff time series.

For DIN:

- The drainage and surface runoff are subject to potentially independent delivery ratios, followed by a load conversion factor (applied to the load after delivery ratio is applied) to determine the amount of APSIM load that is passed to Source.
- This load is then distributed across the daily Sacramento hydrology of Source. The APSIM load associated with the runoff is distributed across the quick flow, and the APSIM drainage load is distributed across the Sacramento slow flow.

If the monthly APSIM runoff and drainage do not coincide with monthly Source-generated Sacramento runoff, the loads generated from APSIM, delivered through Source over smaller runoff volumes, result in unusually high model concentrations. This is particularly evident in irrigated sugarcane areas such as the Burdekin, where the estimated discharge to stream from APSIM is considerably larger than that estimated by the Sacramento Source model, as illustrated in *Figure 3-3*.

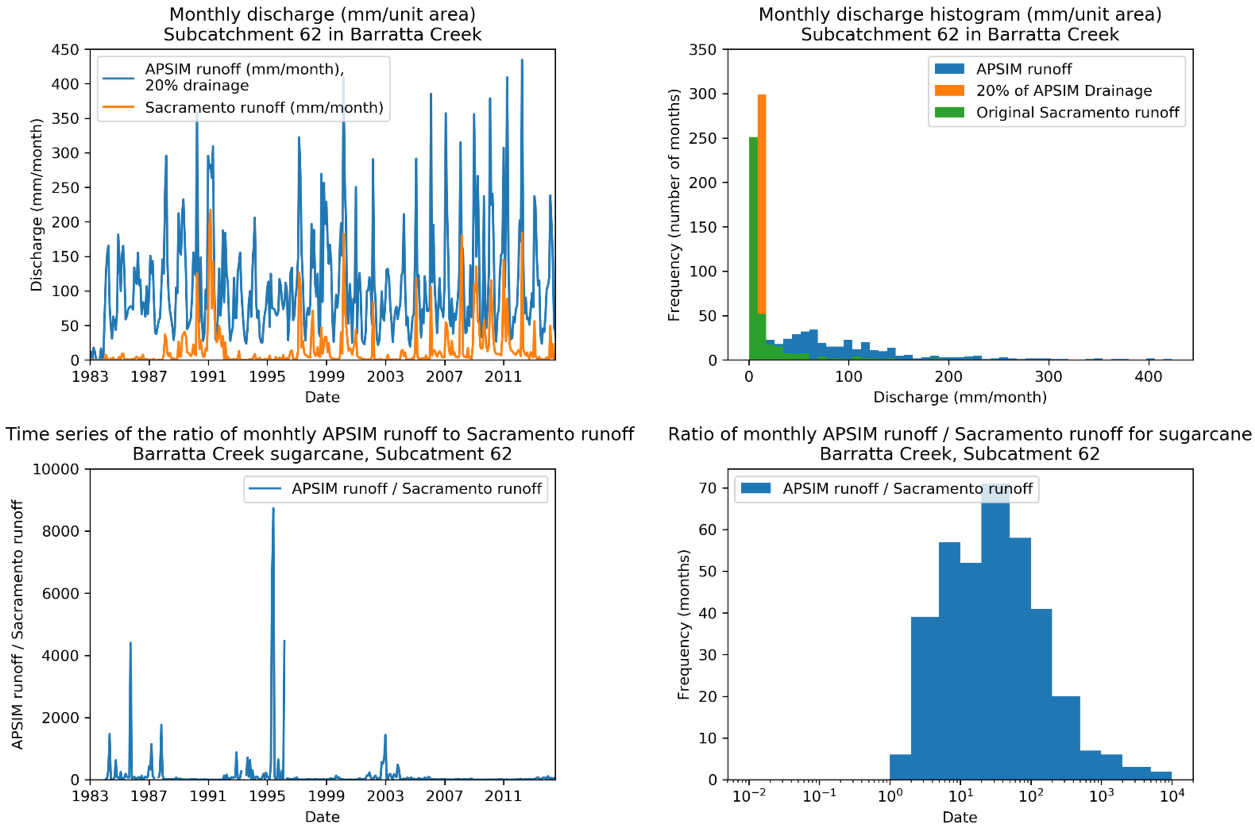


Figure 3-3. Source- and APSIM-generated sugarcane runoff for a selected subcatchment (SC #62) in Barratta Creek showing (a) monthly mm of runoff from sugarcane FU; (b) monthly histogram of runoff for the Sacramento model and the corresponding two APSIM runoff components (surface runoff and drainage); (c) monthly ratio of APSIM runoff to Sacramento runoff; and (d) histogram of monthly ratio of APSIM runoff to Sacramento runoff

For the example subcatchment in Figure 3-3, the difference in model output from the two approaches is considerable, with all monthly flows from APSIM exceeding Source Sacramento monthly runoff. As a result of these differences, the water quality concentration currently modelled by Source is higher than what would be expected, and exceeds the concentrations actually simulated by APSIM.

In the case of the Barratta Creek model with irrigated sugar cane, the current APSIM–Source linkage produces unrealistic constituent concentration ranges when compared to monitoring data. Figure 3-4 shows modelled and measured sample distributions for DIN and Diuron in Barratta Creek. All modelled concentration data is shown alongside date-matched modelled concentration data and measured concentration data. Date-matched median modelled concentrations tend to be almost an order of magnitude higher than recorded values for DIN and Diuron, despite originating from more reasonable concentrations simulated by APSIM, and producing overall mean annual load agreement in the Source model.

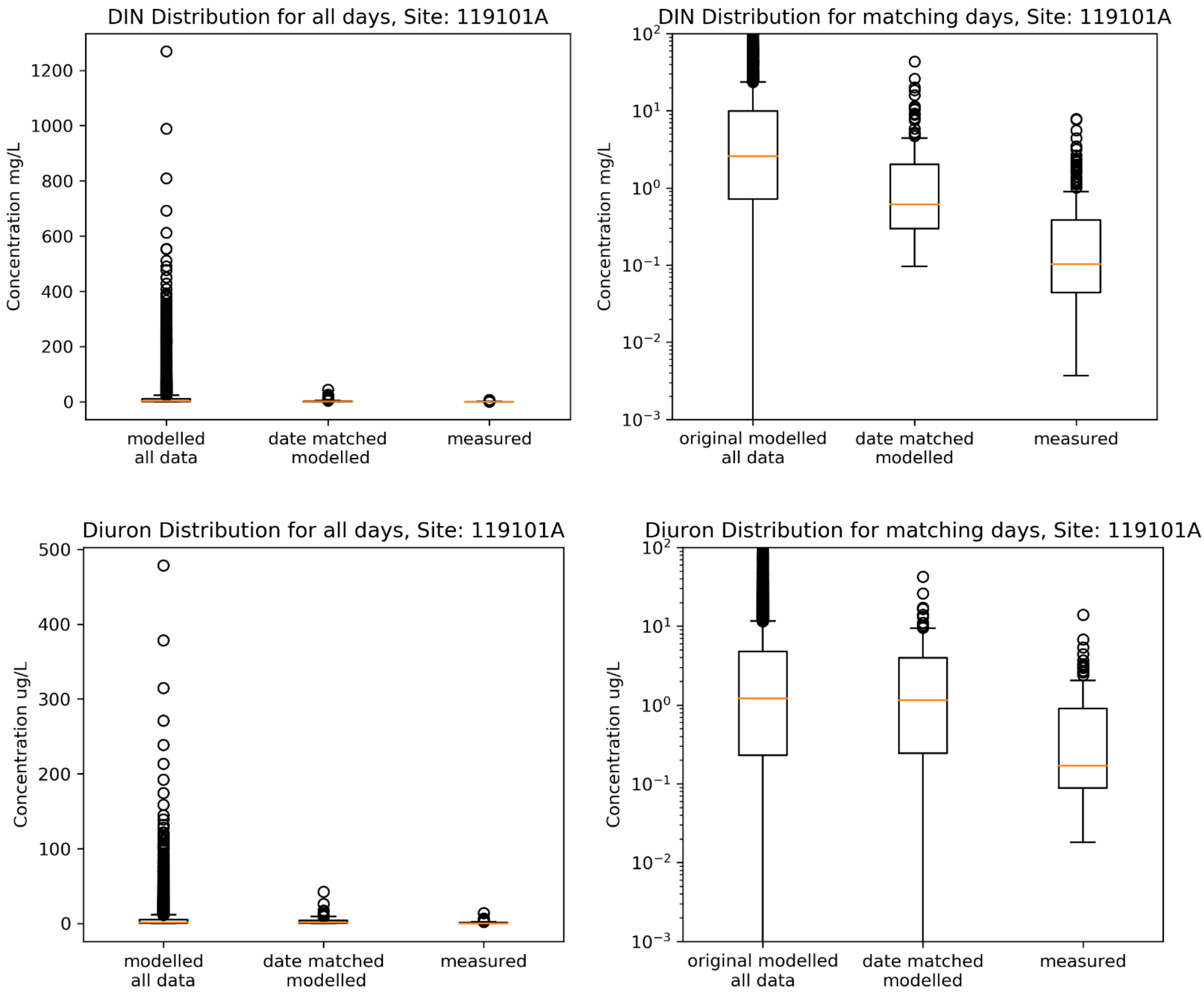


Figure 3-4. Source-generated water quality concentration distributions for DIN and Diuron in Barratta Creek showing all modelled concentration data, date-matched concentration data and measured concentration data

The resolution of this problem could be undertaken in a number of ways. For example, the current model linkage may be further adapted to retain Sacramento hydrology for sugar cane, but include an additional input for irrigation or a more complex method of constituent load transfer.

Further enhancement of the existing linkage may continue to restrict the ability to simulate the impacts of paddock scale management practices that involve runoff management. For this reason, the aim of this project is to investigate and implement alternative options for incorporating the APSIM-generated outputs into the Source models, achieving similar or better agreement in hydrology, catchment loads and constituent concentrations, thereby allowing assessment of the potential catchment scale impacts of paddock scale management practices on flow and water quality.

3.3 Proposed APSIM to Source linkage mechanisms

The proposed model integration approach seeks to directly incorporate both the runoff (surface and drainage) and water quality constituents from the paddock scale models into the existing Source models, effectively replacing both the FU-based hydrology and maintaining a direct link to paddock scale constituent generation.

Integration of the paddock model outputs into the catchment model was achieved through the development of a plugin in Source. The plugin essentially adds a number of additional calculation steps to the previous process of importing paddock scale runoff and constituent loads to convert single paddock scale simulations for a range of management scenarios to aggregated FU scale outputs, the smallest base unit of the Source catchment models.

The proposed model integration approach has three elements to translate APSIM-generated runoff and constituents to subcatchment outlets (from paddock to FU level) (*Figure 3-5*):

- a surface routing store (like the unit hydrograph delay in Sacramento)
- a drainage loss to remove some drainage water to deep drainage not measured at gauge sites and maintain catchment mass balance
- a drainage routing store to attenuate the drainage outflow time series.

These additional model components were selected by comparing the APSIM to Sacramento model structures and determining what processes were currently missing from APSIM, in addition to identifying typical processes incorporated in other studies to apply 1-D models to the basin scale (Appendix B).

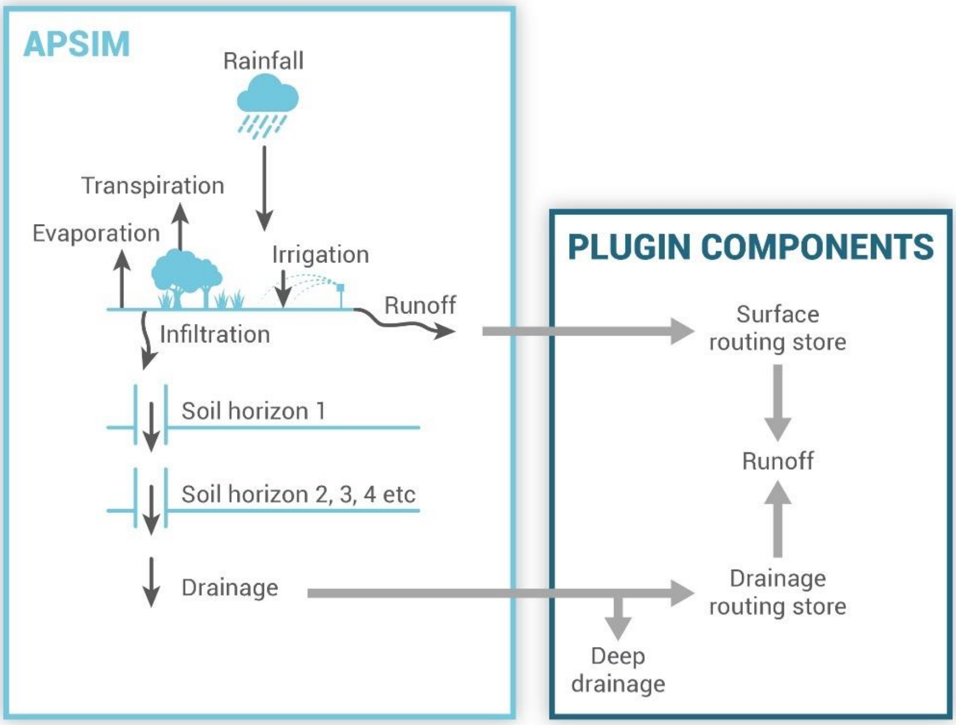


Figure 3-5. Source and APSIM proposed model linkage

3.3.1 Plugin equations

The proposed APSIM to Source plugin (Observed Paddock Hydrology Model with Storage) takes standard APSIM runoff (mm) and drainage (mm), in addition to standard constituent time series (kg/ha/d for DIN and g/ha/d for pesticides), applies losses if appropriate, and passes the time series through the relevant storages before applying the FU-based area and creating the FU-based quick flow, slow flow and constituent time series.

The basic equations of the plugin are as follows:

$$DS = D * (1 - DR) \qquad \text{Equation 1}$$

and

$$DD = D - DS \qquad \text{Equation 2}$$

where:

- D = original APSIM drainage time series (mm/d)
- DD = deep drainage (mm/d) that is not seen at the gauge
- DS = drainage delivered to drainage store
- DR = deep drainage delivery ratio (%)—the ratio of drainage delivered to the drainage store to total drainage calculated by APSIM (value between 0 and 1).

The drainage store and surface stores are calculated using a linear storage:

$$BRt = (DSt + DStore) * DSE \qquad \text{Equation 3}$$

The new drainage store for the next time step becomes:

$$DStore = DSt + DStoret - BRt \qquad \text{Equation 4}$$

The surface store is identical to the drainage store:

$$SRt = (SSt + SStore) * SSE \qquad \text{Equation 5}$$

The new surface store for the next time step becomes:

$$SStore = SSt + SStoret - SRt \qquad \text{Equation 6}$$

where:

- BR = baseflow store runoff (mm/d)
- SR = surface store runoff (mm/d)
- DS = drainage delivered to drainage store (mm/d)
- SS = surface runoff delivered to the surface store (mm/d) = the time series provided by APSIM
- DSE = drainage store emptying ratio—the percentage of drainage store delivered to the stream in a time step—typically between 0.03 and 0.1, and similar to the LZFK and LZPK values in the Sacramento model
- SSE = surface store emptying ratio—the percentage of the surface store delivered to the stream in a time step—typically close to 1 and similar in value to the UH1 parameter in the Sacramento model.

Water quality constituents (mass) delivered from APSIM to Source are treated the same way as the flow time series:

- Constituents associated with the surface runoff (i.e. pesticides in sediment phase and water phase) are passed to the surface store via a delivery ratio (%) and emptied from the surface store via the linear storage.
- Constituents associated with the drainage runoff (i.e. a component of the DIN) are partially removed via the deep drainage delivery ratio to conserve the water and mass balance to this point, before being subject to a second delivery ratio (%), before being passed to and emptied from the drainage store via linear storage.
- With all water quality constituents, the modeller has an option to apply monthly constituent delivery ratios to try and match the typical monthly concentration profiles observed at particular sites.

3.3.2 Plugin data requirements, parameters and interface

The plugin requires APSIM time series data for sugarcane runoff and drainage. The typically processed APSIM data can be loaded individually or accumulated into a single time series data file for import to Source.

The parameters for drainage delivery ratio, surface store emptying ratio and drainage store emptying ratio can be applied on a subcatchment-by-subcatchment basis, but the recommended approach is to apply regional parameters consistent with the existing Sacramento hydrology calibration regions. Calculations undertaken by the Python notebook tools (chapter 4) can assist in determining these parameters on a regional basis. Care should be taken to understand the calibration period used in the APSIM model, and how this relates to the longer time periods and climatic conditions typically simulated by the catchment model. It should be noted that the management practices simulated using the APSIM models represent a single year, and are not matched to the longer time periods typically simulated by the catchment model.

Delivery ratios for water quality constituents are typically determined to match loads estimated at the closest downstream gauge with loads estimated from monitoring data. The recommended approach is to apply global delivery ratio parameters initially while investigating the process; however, modellers have the option to apply monthly global parameters or subcatchment-based parameters if it can be justified with existing data.

Instructions on plugin use are included in Appendix C.

3.4 Trial application catchments

Two existing Source models used to estimate load reductions for the GBR annual report card form the basis for this review and subsequent testing of proposed paddock to reef linkages. These models are the Pioneer River (part of the Whitsunday Coast model domain) and the Barratta Creek (part of the Burdekin model domain).

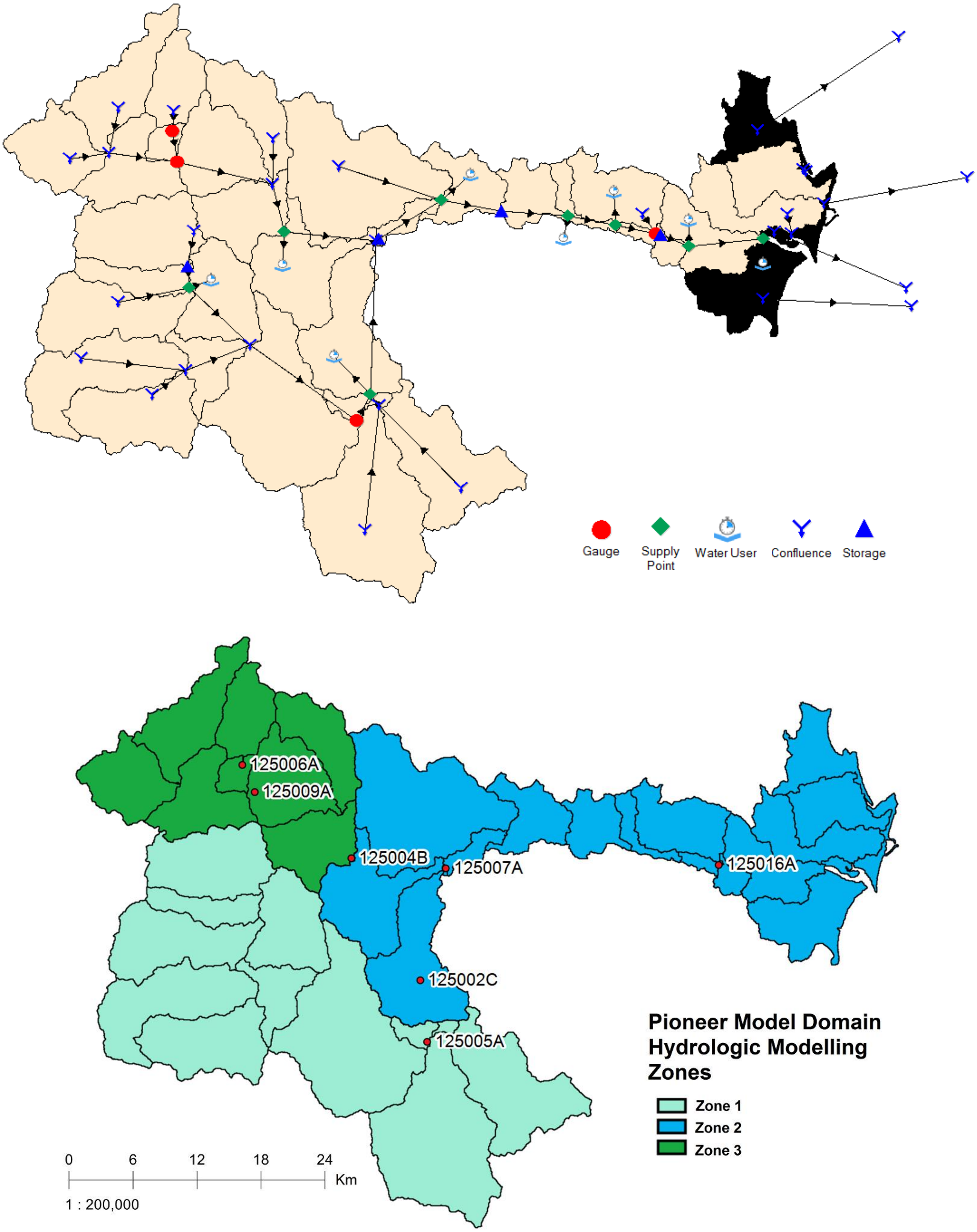


Figure 3-6. Pioneer Source model structure, hydrologic zones and gauge locations

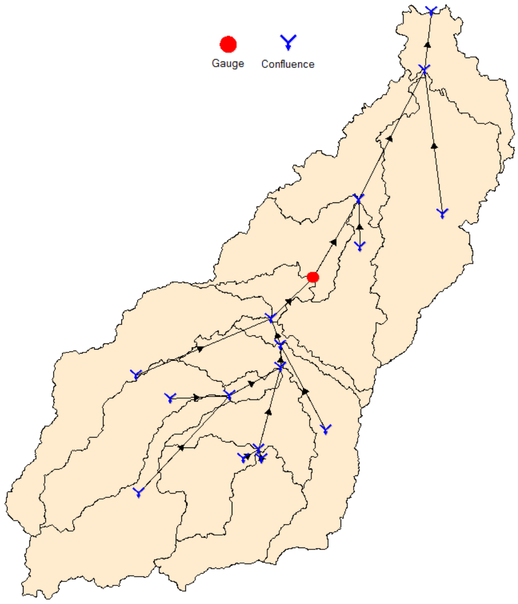


Figure 3-7. Barratta Creek Source model structure and datasets

The Pioneer model was chosen for this study because of the large proportion of sugarcane land use FU that is predominantly rain-fed. This sugarcane system should therefore exhibit runoff behaviour that is consistent with the runoff (and water quality) response to rainfall similar to other land uses within the catchment.

The Barratta Creek model contains the sugarcane FU that is predominantly irrigated. This sugarcane system could be expected to exhibit the runoff and water quality load export response to rainfall plus irrigation. This system may exhibit occasions where runoff (and associated loads) are generated from irrigation events or small rainfall events that would otherwise have not ordinarily have triggered runoff. In these systems, if the runoff from the sugar cane is modelled using the Sacramento rainfall runoff model, using loads are modelled using APSIM, there may be occasions when the load and runoff are out of synchronisation. This could potentially result in unusual model behaviour such as extreme water quality concentrations.

The different sugarcane FU systems provide this study with an opportunity to build and test new model linkages between the APSIM paddock scale models and Source basin scale models that are consistent in terms of treatment of hydrology and water quality data transfer.

The core features of the Pioneer and Barratta Creek models are summarised in *Table 3-1*. Hydrologic performance for the Pioneer and Barratta Creek models, prior to any sugarcane runoff amendments or plugins, is summarised in *Table 3-2*. *Table 3-3* provides model evaluation criteria for bias and Nash Sutcliffe Efficiency (NSE) statistics.

Table 3-1. Source model features

Model feature	Pioneer model	Barratta Creek model
Area (km²)	1664.3 km²	1219.2 km²
Sugarcane area (km², % of model domain)	362.7 km² 22%	401 km² 33%
Run time period	1/1/1986 - 30/6/2014 34.5 years	1/12/1983 - 30/6/2014 30.5 years
Water storages (number, volume)	4 166,825 ML total	0 0 ML total
Water supply points (number, mean annual extraction ML)	8 203,260 ML/yr	0 0 ML/yr
Model gauges (open) (number, catchment area, mean annual flow ML/yr, data time span)	**125005A**: 509 km², 234,075 ML/yr 12/12/1973 14/09/2016 **125006A**: 35 km2, 53,547ML/yr 28/01/1976 13/12/2016 **125009A**:198 km² , 240,728 ML/yr 19/06/2002 20/07/2016 **125013A**: 1485 km², 1,120,011 ML/yr 14/1/2008 25/08/2016	-
Additional gauges (open) not represented in the model (number, catchment area, mean annual flow ML/yr, time span)	**125002C:**757 km² 337,921 ML/yr 17/02/1958 07/07/2016 **125004B**:326 km² 346,576 ML/yr 03/07/1986 20/07/2016 **125007A**:1211 km² 734,731 ML/yr 09/11/1977 09/08/2016 **125016A**:1488 km², 1,064,711 ML/yr 22/12/2005 25/08/2016	**119101A**: 753 km² 202,028 ML/yr 09/10/1974 04/10/2016
Proportion of model ungauged (%)	10.6%	38.2%
Mean annual modelled flow (ML/yr)	795,048 ML/yr	283,219 ML/yr
Number of base hydrologic parameter sets(hydrologic zones)	3	1
Modelled sugarcane contribution to mean annual flow (baseline model %, ML/yr)	26.8%, 242,297 ML/yr	35.8%, 101,455ML/yr

Table 3-2. Summary hydrologic performance

Gauge	Gauge name	Area (km2)	Years of record	Gauge period coverage (%)	Daily NSE	Monthly NSE	Bias (%) compared to gauged
	Pioneer model domain						
125006A	Finch Hatton Creek	35	34.3	99%	0.594	0.870	-24.0
125009A	Cattle Creek at Highmans Bridge	198	12.0	35%	0.747	0.917	-20.5
125004B	Cattle Creek at Gargett	326	27.5	80%	0.703	0.951	-3.7
125005A	Blacks Creek at Whitefords	509	33.9	98%	0.712	0.929	17.7
125002C*	Pioneer River at Sarichs	757	33.1	96%	0.800	0.964	-3.3
125007A	Pioneer River at Mirani Weir Tailwater	1211	32.9	95%	0.661	0.932	19.8
125013A	Pioneer River at Dumbleton Weir Headwater	1485	6.4	18%	0.515	0.532	-13.3
125016A	Pioneer River at Dumbleton Weir Tailwater	1488	8.5	25%	0.708	0.978	-1.1
	Barratta Creek model domain						
119101A	Barratta Creek at Northcote	753	27.4	90%	0.759	0.864	-16.2

** Gauge 125002C does not appear to have a subcatchment outlet coinciding directly with the gauge – statistics are an estimate only.*

Table 3-3. Typical evaluation criteria for model hydrology

MODEL PERFORMANCE	DAILY NSE	Volume Bias (%)	Monthly NSE
Excellent	> 0.95	< 1%	> 0.95
Good	0.9-0.95	1% - 5%	0.9-0.95
Average	0.8-0.9	5% - 10%	0.8-0.9
Fair	0.5 - 0.8	10% - 20%	0.5 - 0.8
Poor	< 0.5	> 20%	< 0.5

Table 3-2 shows that the Nash Sutcliffe coefficient of efficiency for monthly (and daily) modelled time series indicates fair to excellent model performance, demonstrating good overall model fit.

The mean annual runoff rates for individual subcatchments in the Pioneer are highly variable (*Figure 3-8*). In the northern catchments, mean annual runoff is over 1200 mm/yr from 2200 mm/yr rainfall. In the south, the runoff is 330 mm/yr from mean annual rainfall of 1140 mm/yr. The mean annual runoff rates for individual subcatchments in the Barratta Creek model range from 165 mm/yr from 800 mm/yr rainfall in the south-west to 330 mm/yr from 1050 mm/yr rainfall in the north-east.

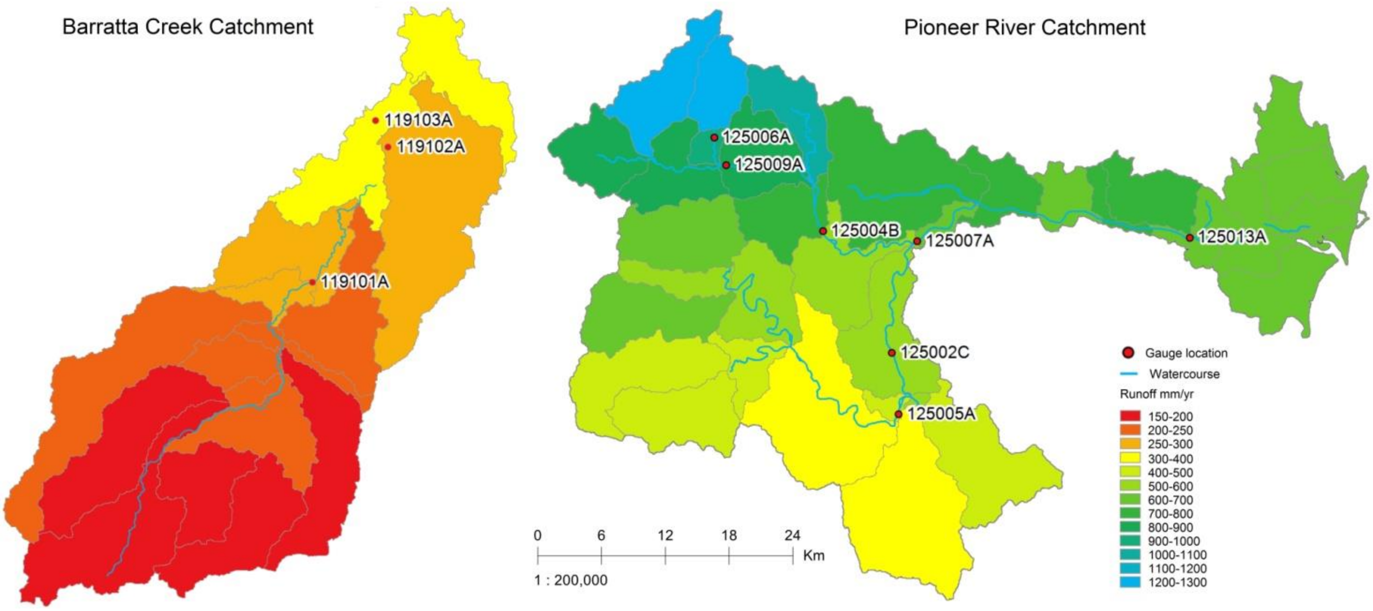


Figure 3-8. Mean annual modelled runoff (mm/yr) January 1983 – June 2014 for Barratta, 1986–2014 for Pioneer

4 PYTHON NOTEBOOK MODEL EVALUATION TOOLS

The Python notebook is designed to provide some calculation and visualisation tools to assist modellers derive plugin parameters and assess model performance with plugins operational.

The notebook has been prepared in a Jupyter notebook loaded from Anaconda using standard packages (http://jupyter.org/). The Python version is version 3.

The notebook contains some basic instructions for use, and has been designed to follow a typical workflow to collate data, create the tools used to evaluate hydrology, undertake initial model performance evaluation, derive APSIM plugin parameters and then re-evaluate the model performance. The notebook is broken into a series of parts as follows.

Part 1 of the notebook contains a preamble with some explanatory text about what to expect from the notebook.

Part 2 of the notebook undertakes some basic flow data processing to import stream gauge data, APSIM drainage and runoff data, and model-generated flow data. This section of the notebook also introduces some routines to plot the data for individual sites in both normal and log space, and compare flow duration curves and calculate statistics (NSE, bias) for daily and monthly correlation. This section forms the baseline for assessing the hydrology performance of the model when APSIM flows are introduced. Typical outputs from the notebook for a typical site are shown graphically below, and also include calculation of basic correlation statistics for individual gauge sites such as:

- 112101B discharge (ML/day)
- percent bias = -1.34
- RMSE daily flows = 1793.0
- daily NSE = 0.785
- RMSE monthly flows = 468.0
- monthly NSE = 0.961

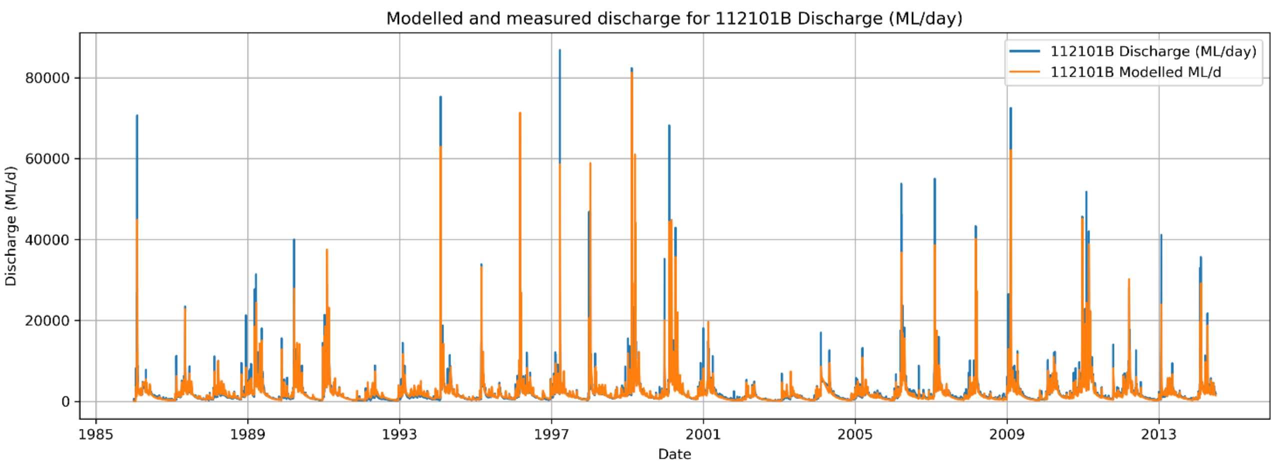


Figure 4-1. Observed and modelled daily discharge time series

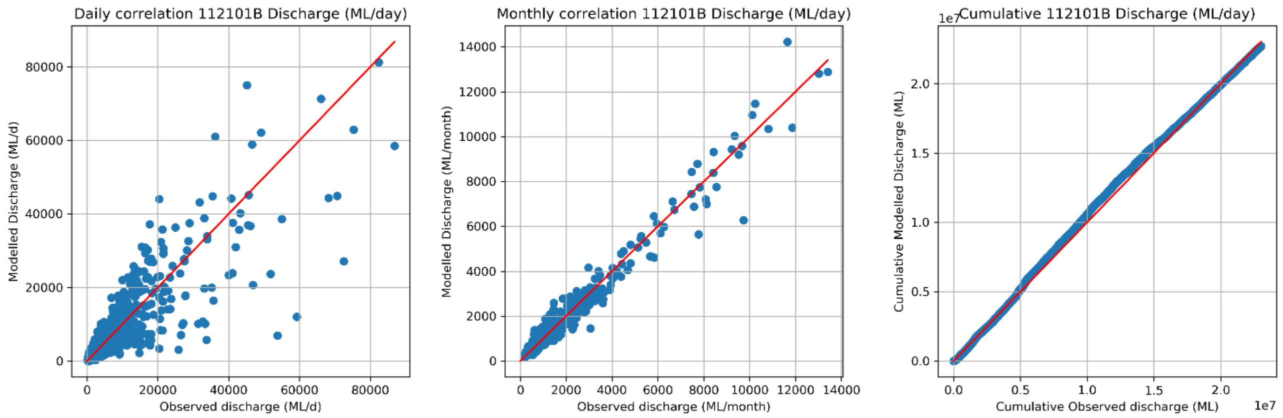


Figure 4-2. Observed vs modelled daily, monthly and cumulative discharge

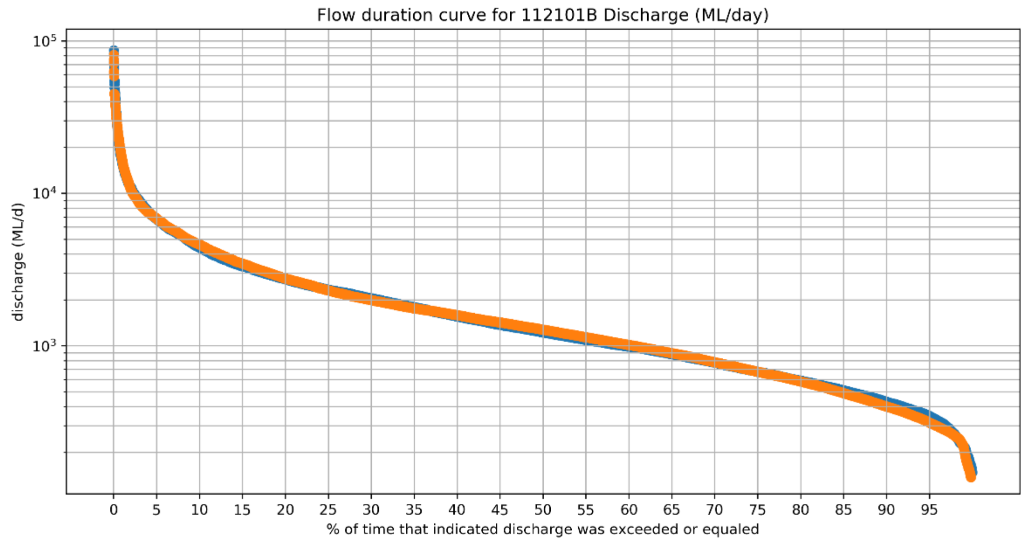


Figure 4-3. Observed and modelled flow duration curve

Part 3 of the notebook facilitates the import of the more specific sugarcane runoff from the model to calculate how much APSIM runoff and drainage to apply in the plugin. Specifically:

- runoff (total) and baseflow time series data from all subcatchments in the model are imported
- total modelled surface and baseflow runoff by region is calculated
- corresponding APSIM runoff and baseflow are calculated
- APSIM drainage delivery ratio is calculated, in addition to recommended surface and drainage store emptying ratios.

The typical output from this module leads to recommended regional percentage drainage to apply in the plugin, noting that, typically, 100% of surface runoff will usually be applied.

```
In [22]: Sac_surface_runoff(Sac_cane_baseflow,Sac_cane_total,DrainageTimeseries,RunoffTimeseries,areas_ha)

         Region =  1.0
         Total modelled surface runoff =  648611626.0
         Total modelled baseflow =  719364194.0
         Modelled baseflow proportion =  0.53
         APSIM surface runoff =  502650171.0
         APSIM drainage =  839798983.0
         APSIM baseflow proportion =  0.63

         Percentage APSIM drainage to apply =  1.03
         Suggested surface store emptying ratio =  1.0  - UH1 from the Sacramento parameters
         Suggested baseflow store emptying ratio =  0.0318  to  0.0042

         Region =  2.0
         Total modelled surface runoff =  384990100.0
         Total modelled baseflow =  394608986.0
         Modelled baseflow proportion =  0.51
         APSIM surface runoff =  202011323.0
         APSIM drainage =  636751299.0
         APSIM baseflow proportion =  0.74

In [23]: # Now create the input file necessary to import the required amount of surface and drainage
         # bit complicated to implement in the notebook now, so lets just do it outside and get the data comparisions done
```

Figure 4-4. Example notebook outputs showing estimate

After data processing, for every region, the amount of drainage to apply is calculated and parameters are suggested for the surface store and drainage store emptying ratios. At this stage, the notebook does not then go and put these values into an input file and run the Source model. It is up to the modeller to undertake this step.

Modellers have a choice at this stage to either apply the runoff and drainage parameters on a regional basis (as per Sacramento hydrology parameters), or accumulate the outputs from all gauges and find the best global proportion of drainage to apply. The **recommended** approach is to apply drainage parameters on a regional basis. If the suggested drainage proportion is greater than 1, then an upper limit of 1 should be applied. These recommended parameters can then be loaded into the model to undertake Part 4: APSIM hydrology assessment.

Part 4 of the notebook revisits the routines of **Part 2** to assess the new model output after the APSIM runoff and drainage have been applied, using the recommended parameters estimated from **Part 3**.

Part 5 of the notebook begins the water quality assessment and calibration by importing observed load and concentration data in addition to modelled data (typically under the 100% delivery ratio assumption). The module then calculates recommended parameters for water quality constituents that agree with observed mean annual concentrations. Example output includes:

- gauge = 113006A
- mean annual estimated observed DIN concentration = 0.218 mg/L
- mean annual modelled DIN concentration = 0.271 mg/L
- total modelled load = 6721.0 t
- percentage APSIM DIN to apply = 0.805.

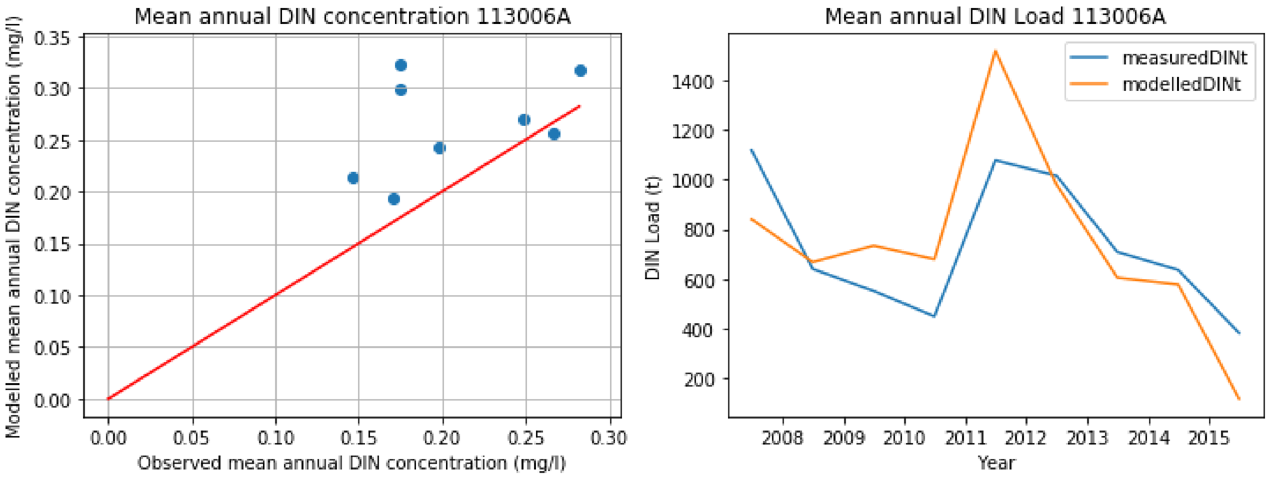


Figure 4-5. Mean annual modelled DIN concentrations and loads for site Pioneer: 113006A

The intention of this section of the notebook is to facilitate modification of the **DIN delivery ratio**, allowing the Source model to be rerun with the new delivery ratio in place in the subsequent modules.

In the current case, the derived percentage APSIM DIN to apply is determined by the mean annual modelled and measured concentrations. Concentrations are used in this new approach rather than loads used previously, as this accounts for potential differences in model hydrology. Care should be taken in this step to account for any other model sources of DIN, such as other land uses, storage transfers, in applying the APSIM DIN delivery ratio.

Unlike hydrology, the current approach here with multiple APSIM DIN delivery ratios is to take these out of the notebook and calculate the average DIN delivery ratio that will give the best fit across all gauges on a flow-weighted basis. Work is currently underway in this area to explore the validity of other approaches to account for the landscape position and the relative contribution to the stream.

There is, of course, an option in the plugin to include a delivery ratio for surface and drainage proportions. The hydrology parameters of 100% surface delivery, proportion drainage delivery, drainage store emptying ratio and surface store emptying ratio should also be retained for constituent parameterisation. Care should be taken here to ensure these values are consistent across the model.

Part 5a of this notebook does what Part 5 does, but for atrazine and Diuron, and can easily be adapted for other pesticides.

Part 6 provides additional tools (charts and data) for further model performance evaluation after model parameterisation. The intent of these tools is to provide visual assessments (and potential data outputs) for model fit of daily concentrations. In previous sections of this notebook, APSIM flows and loads were adjusted to agree with typical flow statistics and mean annual concentrations. This section goes further to look at monthly concentration correlations and flow-based concentration profiles. The APSIM to Source plugin has the ability to include monthly delivery ratios and separate constituent storage parameters. The tools in this section may provide the modeller with the data required to adjust these parameters in the search for a better statistical model fit.

Typically these additional tools include:

- water quality data distribution comparison

- monthly box plots of modelled and measured water quality data on a site-by-site basis and overall
- flow threshold-based box plots of modelled and observed data.

Examples of these data outputs are shown below.

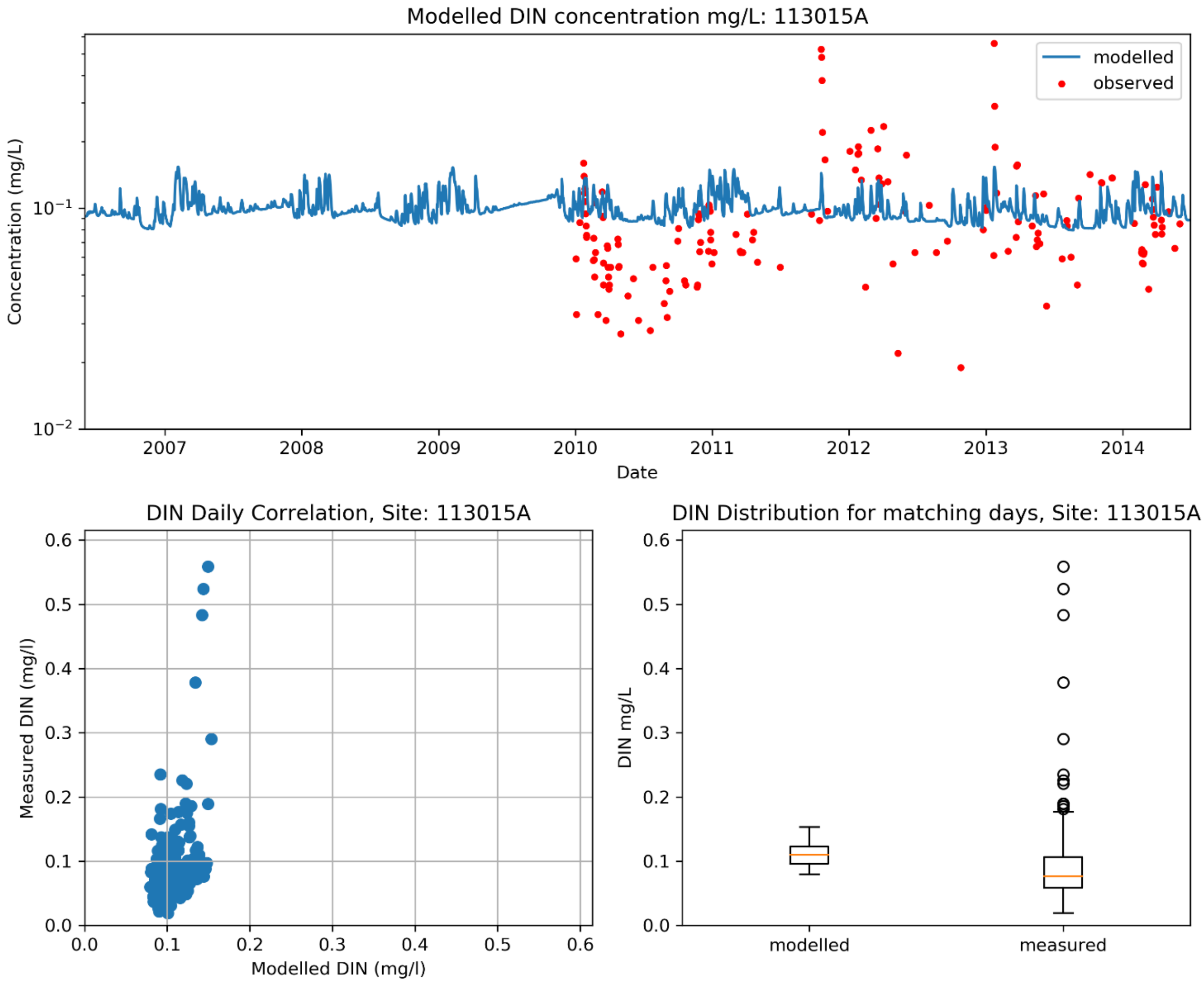


Figure 4-6. Examples of Python developed tools to assess modelled and measured concentrations, showing time series of modelled and observed data, scatter plot of observed and date-matched modelled data, and box plots of date-matched modelled and measured data

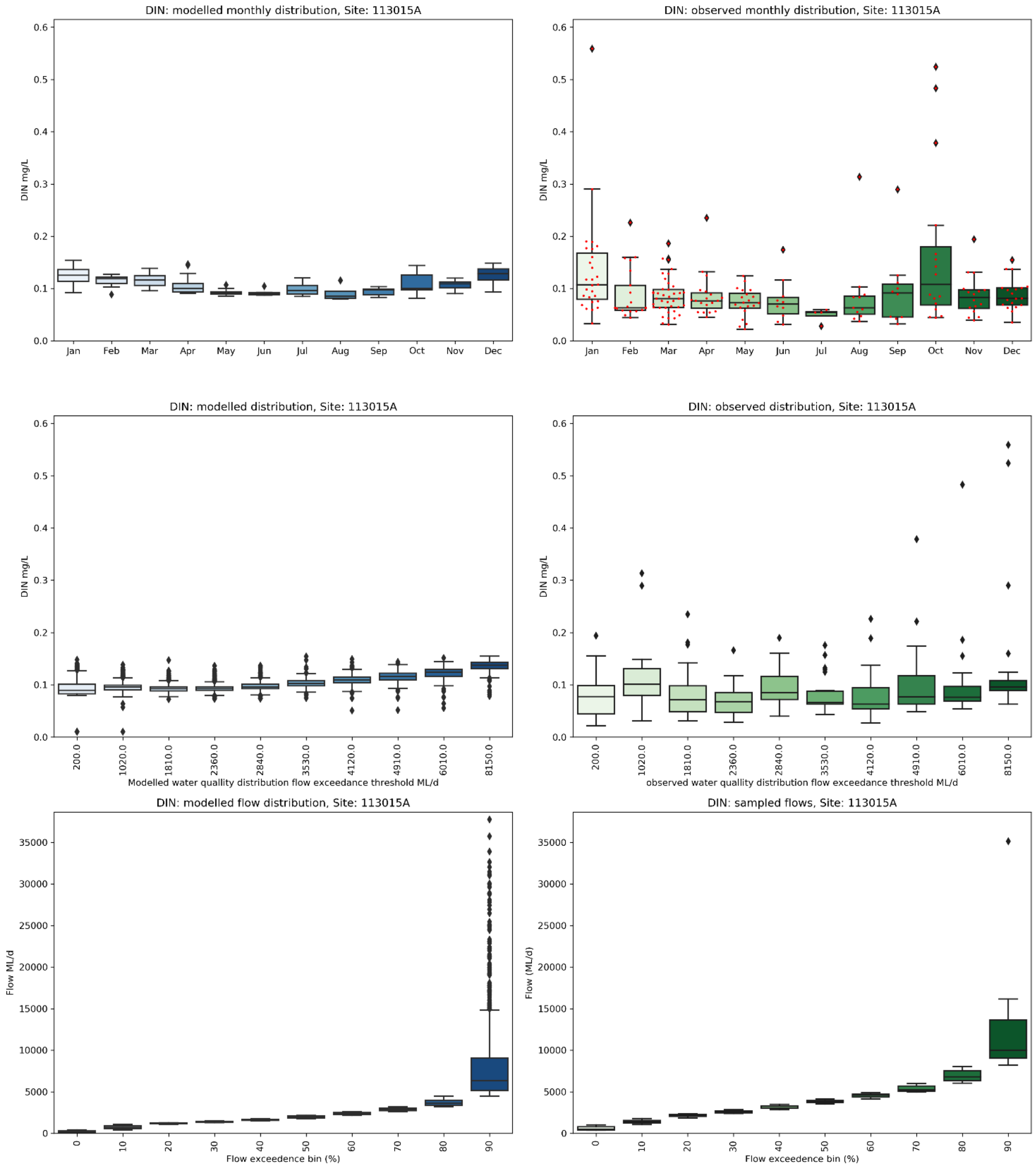


Figure 4-7. Examples of Python developed tools to assess modelled and measured concentrations, showing monthly modelled and measured water quality data, distributions of modelled data stratified into flow bands, and flow representation of available samples

5 APSIM AND SOURCE INTEGRATION EVALUATION

5.1 Pioneer hydrology (rain-fed)

The Pioneer catchment is considered to be operating with supplementary irrigation on sugar cane (i.e. the sugar cane is predominantly rain-fed). The hydrology derived for that model via Source is likely to reflect the typical runoff response to rainfall and is considered calibrated. In this case, the Source-modelled runoff is replaced with APSIM-derived surface runoff, and then a proportion of APSIM drainage runoff is added to match overall sugarcane runoff rates already estimated by the calibrated model.

Following the replacement of Sacramento-derived runoff with APSIM-derived runoff for sugarcane areas, model statistics describing model fit for the Pioneer catchment are recalculated to estimate the potential impact on model hydrology through the adoption of APSIM-derived runoff.

The approach of adding APSIM-derived drainage time series to make up the shortfall in sugarcane-derived runoff is applied consistently across each hydrologic zone:

- The total shortfall in sugarcane runoff for each of the three hydrologic zones is calculated.
- A single estimate of percentage drainage water required to meet the total zone shortfall is calculated.
- The zone-based percentage of drainage water is applied from APSIM to the Source model in addition to 100% of the surface runoff for each subcatchment.

For the Pioneer, the percentage of APSIM drainage time series required to meet the zone-based shortfall in sugarcane runoff is 97% for high rainfall Zone 3, 81% for Zone 2 and 58% for Zone 1.

The impact on hydrologic performance for the Pioneer model through the replacement of flows associated with 22% of the model domain are provided in *Table 5-1*. The table shows that the original model performance baseline is largely maintained, and in some cases, marginally improved. No attempt was undertaken to address the model bias in some of the upstream catchment areas through adjustment of the drainage proportion. This may be considered in the future.

Table 5-1. Summary hydrologic performance for the Pioneer model

		Original model performance			Model performance with APSIM		
Gauge	Gauge Name	Daily NSE	Monthly NSE	Bias (%)	Daily NSE	Monthly NSE	Bias (%)
125006A	Finch Hatton Creek	0.594	0.870	-24.0	0.61	0.86	-25.7
125009A	Cattle Creek at Highmans Bridge	0.747	0.917	-20.5	0.75	0.92	-20.7
125004B	Cattle Creek at Gargett	0.703	0.951	-3.7	0.72	0.953	-5.3
125005A	Blacks Creek at Whitefords	0.712	0.929	17.7	0.74	0.936	17.85
125002C	Pioneer River at Sarichs	0.800	0.964	-3.3	0.81	0.969	-3.7
125007A	Pioneer River at Mirani Weir Tailwater	0.661	0.932	19.8	0.77	0.948	16.27
125013A	Pioneer River at Dumbleton Weir Headwater	0.515	0.532	-13.3	0.529	0.561	-9.7
125016A	Pioneer River at Dumbleton Weir Tailwater	0.708	0.978	-1.1	0.714	0.979	1.08

Time series, flow duration and cumulative volume plots showing modelled data vs recorded stream gauge data for all gauges in the Pioneer are provided in Appendix E. Python notebook files associated with these calculations accompany this report. Example output from the notebook for the most downstream site (125016A) is provided below. This site is downstream of Dumbleton Weir, and shows a distinct drop-off in the modelled flow duration curve for flows less than 100 ML/d. The likely cause of this drop-off is insufficient resolution in the outlet rating curve used in the model, with the first point of the rating curve coinciding with flows equivalent to 100,000 ML/d.

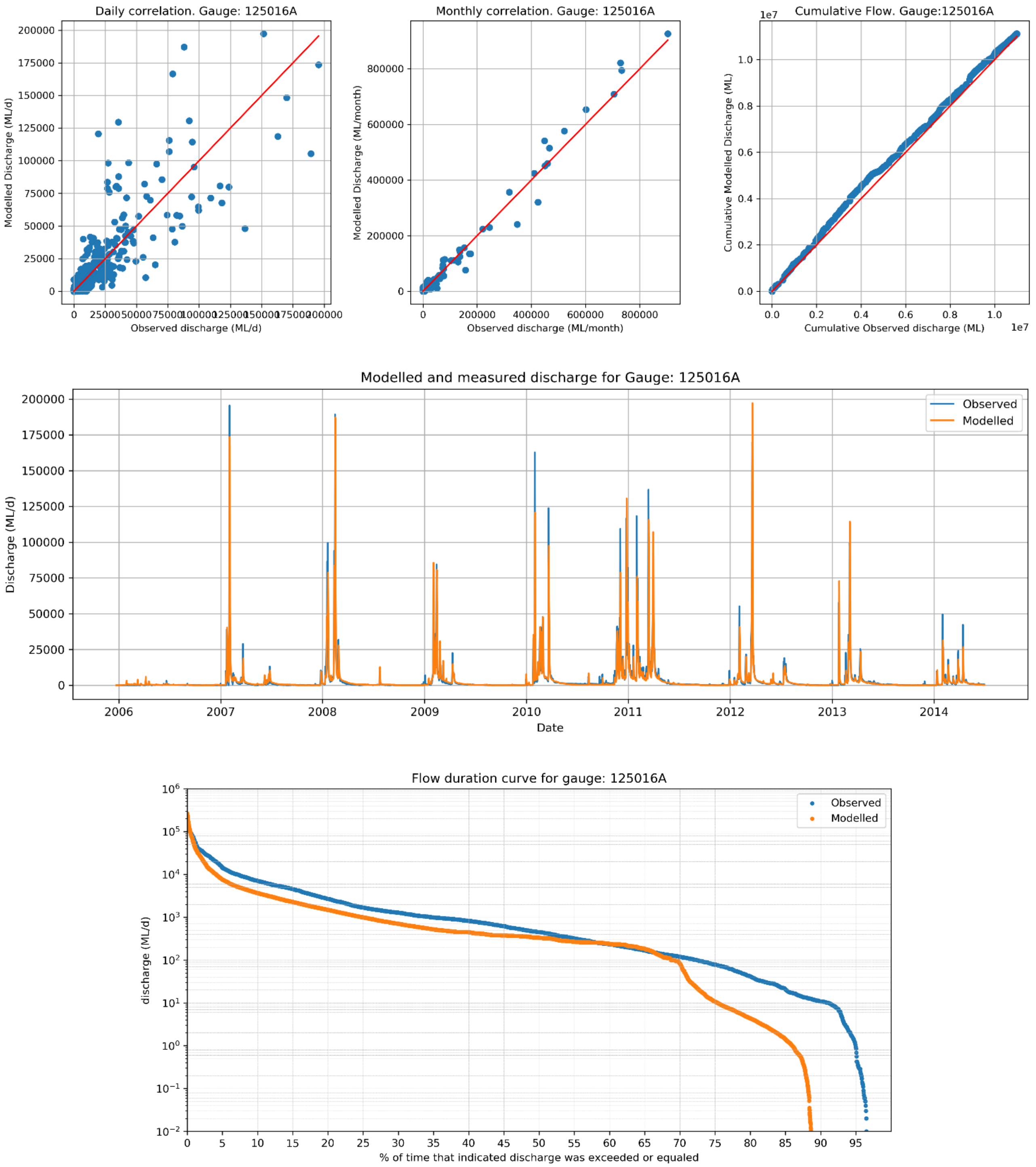


Figure 5-1. Notebook-generated correlations of APSIM-modelled vs observed (gauged) series for site 125016A

5.2 Barratta Creek hydrology (irrigated cane)

The Barratta catchment is considered to be operating under full irrigation on sugar cane. The hydrology derived for sugar cane in that model via Source is not likely to reflect the typical runoff response to rainfall because the additional water applied through irrigation has not been taken into account. Two potential outcomes from this are:

- the current sugarcane hydrology may not be appropriate for estimating the proportion of surface and baseflow APSIM runoff
- catchment runoff may be over-predicted to compensate for the lack of irrigation waters applied to the sugarcane FUs in the model.

For these reasons, the replacement of Source-modelled runoff with a combination of APSIM-derived surface runoff and a proportion of APSIM drainage runoff is unlikely to match overall sugarcane runoff rates already estimated by the model. In this case, the application of APSIM sugarcane runoff and drainage should be in proportion to gauge records, rather than past model results.

In the current case, the Source-derived hydrology has also been adjusted to take the pre- and post-cane irrigation into account. This process is described below.

5.2.1 Land use change and the introduction of irrigated sugarcane

The development of irrigated sugarcane areas in eastern parts of the Barratta Creek catchment upstream of the only gauge (119101A) was largely undertaken between the late 1980s and mid 1990s. By 2001, the majority of sugarcane development had occurred (*Figure 5-3*). The runoff response to rainfall may be expected to be different pre- and post-sugarcane development. The cumulative flow plot of modelled and measured flows for Barratta Creek (*Figure 5-2*) supports this expectation. With the exception of one very large streamflow event, prior to 1994, modelled streamflow follows the gauged record; however, after the mid 1990s, the cumulative modelled flows diverge from the cumulative gauge flows, possibly as a result of drought conditions.

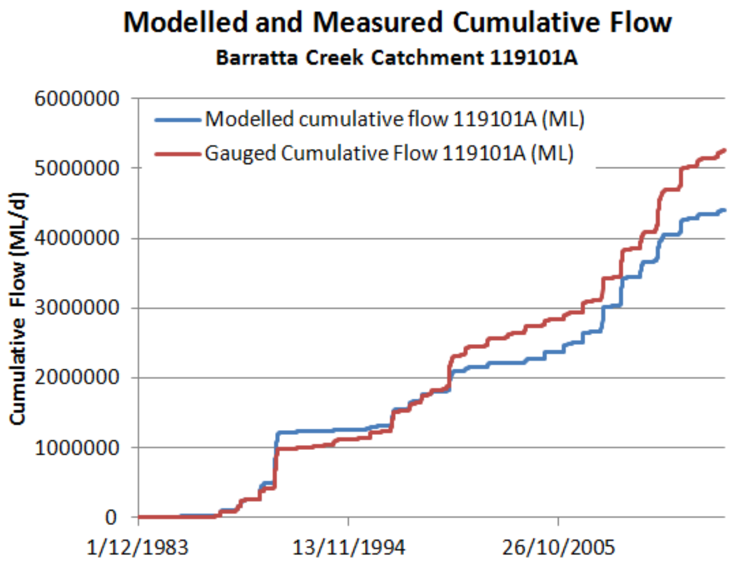


Figure 5-2. Barratta Creek (119101A) modelled and measured cumulative stream flow

The gap between modelled and gauged flows post-cane development suggests that the rainfall runoff calibration may have some bias toward trying to match flows under the influence of irrigated sugarcane or drought conditions, potentially requiring some adjustment.

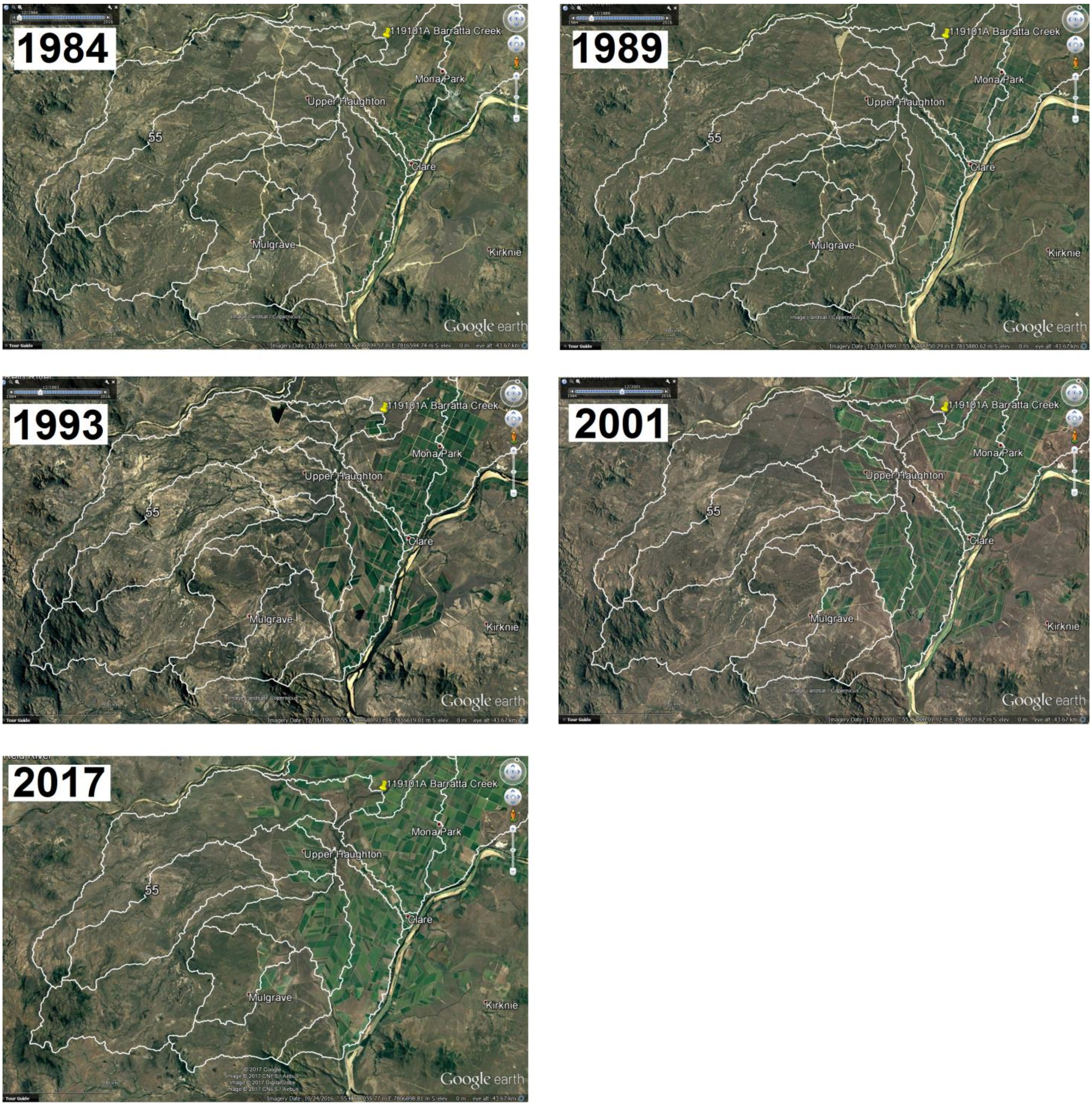


Figure 5-3. Barratta Creek sugarcane land use change upstream of gauge 119101A (Google Earth)

5.2.2 Modifying the Sacramento rainfall runoff parameters

The current set of rainfall runoff parameters (derived using PEST) for the Barratta Creek model are provided in *Table 5-2*, and show that four of the Sacramento parameters are outside of typical minimum or maximum bounds.

Table 5-2. Typical Sacramento model parameters and Barratta Creek parameters (Source: eWater 2018)

Param.	Description	Units	Default	Typical min	Typical max	Barratta Creek
LZPK	The ratio of water in *LZFPM*, which drains as baseflow each day.	fraction	0.01	0.001	0.015	0.0010
LZSK	The ratio of water in *LZFSM*, which drains as baseflow each day.	fraction	0.05	0.03	0.2	0.1336
UZK	The fraction of water in *UZFWM*, which drains as interflow each day.	fraction	0.3	0.2	0.5	**0.5376**
UZTWM	Upper zone tension water maximum—the maximum volume of water held by the upper zone between field capacity and the wilting point which can be lost by direct evaporation and evapotranspiration from soil surface. This storage is filled before any water in the upper zone is transferred to other storages.	mm	50	25	125	**135.03**
UZFWM	Upper zone free water maximum—this storage is the source of water for interflow and the driving force for transferring water to deeper depths.	mm	40	10	75	**109.80**
LZTWM	Lower zone tension water maximum—the maximum capacity of lower zone tension water. Water from this store can only be removed through evapotranspiration.	mm	130	75	300	**10.000**
LZFSM	Lower zone free water supplemental maximum—the maximum volume from which supplemental baseflow can be drawn.	mm	25	15	300	36.219
LZFPM	Lower zone free water primary maximum—the maximum capacity from which primary baseflow can be drawn.	mm	60	40	600	299.69
PFREE	The minimum proportion of percolation from the upper zone to the lower zone directly available for recharging the lower zone free water stores.	%	0.06	0	0.5	0.2835
REXP	An exponent determining the rate of change of the percolation rate with changing lower zone water storage.	none	1	0	3	1.0002
ZPERC	The proportional increase in Pbase that defines the maximum percolation rate.	none	40	0	80	18.821
SIDE	The ratio of non-channel baseflow (deep recharge) to channel (visible) baseflow.	ratio	0	0	0.8	0.0900
SSOUT	The volume of the flow which can be conveyed by porous material in the bed of stream.	mm	0	0	0.1	2.27888 E-05
PCTIM	The permanently impervious fraction of the basin contiguous with stream channels, which contributes to direct runoff.	%	0.01	0	0.05	0.0361
ADIMP	The additional fraction of the catchment which develops impervious characteristics under soil saturation conditions.	%	0	0	0.2	1.37507 E-05
SARVA	A decimal fraction representing that portion of the basin normally covered by streams, lakes and vegetation that can deplete stream flow by evapotranspiration.	%	0	0	0.1	0.0410
RSERV	Fraction of lower zone free water unavailable for transpiration.	%	0.3	0	0.4	0.3
UH1	The first component of the unit hydrograph, i.e. the proportion of instantaneous runoff not lagged.	%	1	0	1	0.9993
UH2	The second component of the unit hydrograph, i.e. the proportion of instantaneous runoff runoff lagged by one time-step.	%	0	0	1	0.0006
UH3	The third component of the unit hydrograph.	%	0	0	1	0
UH4	The fourth component of the unit hydrograph.	%	0	0	1	0
UH5	The fifth component of the unit hydrograph.	%	0	0	1	0

At 10 mm, the LZTWM parameter is furthest from typical bounds, and represents the amount of water that is drawn from the soil lower zone via ET. Model sensitivity to the parameters found outside their regular bounds has not yet been undertaken for this project, however the following observations have been made:

- The small LZTWM may be compensating for the larger than typical UZTWM to remove water via ET.
- The larger than typical UZFWM and UZK parameters possibly combine to remove more water quickly from the upper soil store to the stream, increasing the runoff from rainfall.
- The combination of small LZTWM and high UZTWM, UZFWM and UZK parameters are possibly working to maximise surface runoff and limit the amount of water passing to baseflow, and are possibly a response to a model that is trying to compensate for additional runoff from irrigated sugar cane.

Sacramento parameter adjustment for the highlighted parameters has been undertaken for the Barratta Creek model using some manual adjustment and the Source calibration tool (*Table 5-3*). Only the period prior to the full development of irrigated sugar cane has been considered (1986–1995) for this adjustment.

Table 5-3. Adjusted Sacramento model parameters for Barratta Creek

Param.	Description	Units	Default	Typical Min	Typical Max	Barratta Creek	Adjusted
UZK	The fraction of water in *UZFWM*, which drains as interflow each day.	fraction	0.3	0.2	0.5	0.53765	**0.5**
UZTWM	Upper Zone Tension Water Maximum. The maximum volume of water held by the upper zone between field capacity and the wilting point which can be lost by direct evaporation and evapotranspiration from soil surface. This storage is filled before any water in the upper zone is transferred to other storages.	mm	50	25	125	135.032	**52.2**
UZFWM	Upper Zone Free Water Maximum, this storage is the source of water for interflow and the driving force for transferring water to deeper depths.	mm	40	10	75	109.804	**75**
LZTWM	Lower Zone Tension Water Maximum, the maximum capacity of lower zone tension water. Water from this store can only be removed through evapotranspiration.	mm	130	75	300	10.0002	**75**

Model calibration for the pre-cane era (1986–1995) is shown below.

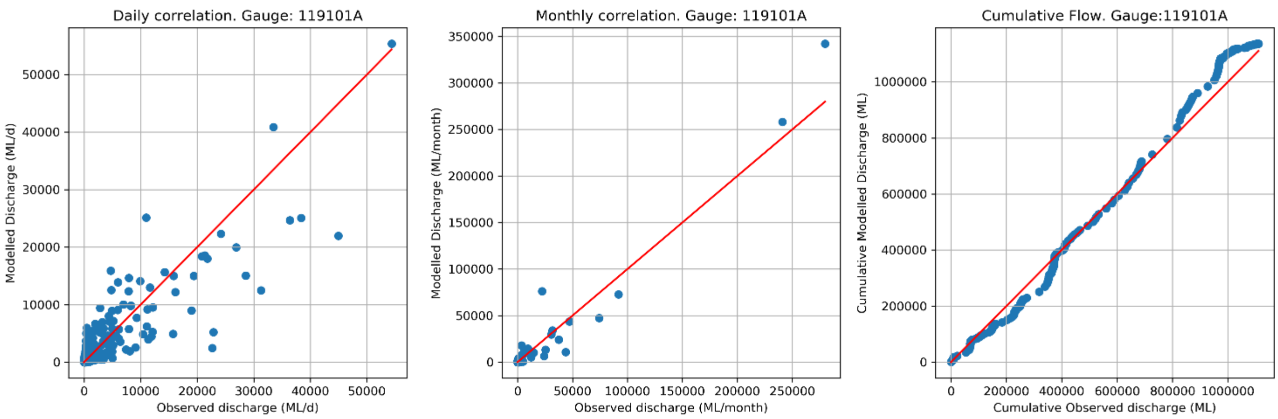


Figure 5-4. Pre-cane Barratta Creek (119101A) calibration

Using the pre-cane model calibration as a starting point, APSIM time series were substituted for the sugarcane-based FU Sacramento runoff. Notebook calculations suggest that, with the application of

100% surface runoff, approximately 20% to 30% drainage runoff can also be applied. In the current case, 20% APSIM drainage runoff was selected as contributing to the stream. Example output and model calibration statistics are provided in *Table 5-4* and *Figure 5-5*.

Table 5-4. Summary hydrologic performance

		Original model performance			Model performance with APSIM		
Gauge	Gauge Name	Daily NSE	Monthly NSE	Bias (%) compared to gauged	Daily NSE	Monthly NSE	Bias (%) compared to gauged
119101A	Barratta Creek at Northcote	0.759	0.864	-16.2			
119101A	Pre-cane Barratta Creek at Northcote, Adjusted hydrology				0.78	0.93	1.2
119101A	Post Cane with APSIM* Barratta Creek at Northcote				0.72	0.83	-9.8

* 100% surface flow and 20% drainage flow for the APSIM sugarcane land use

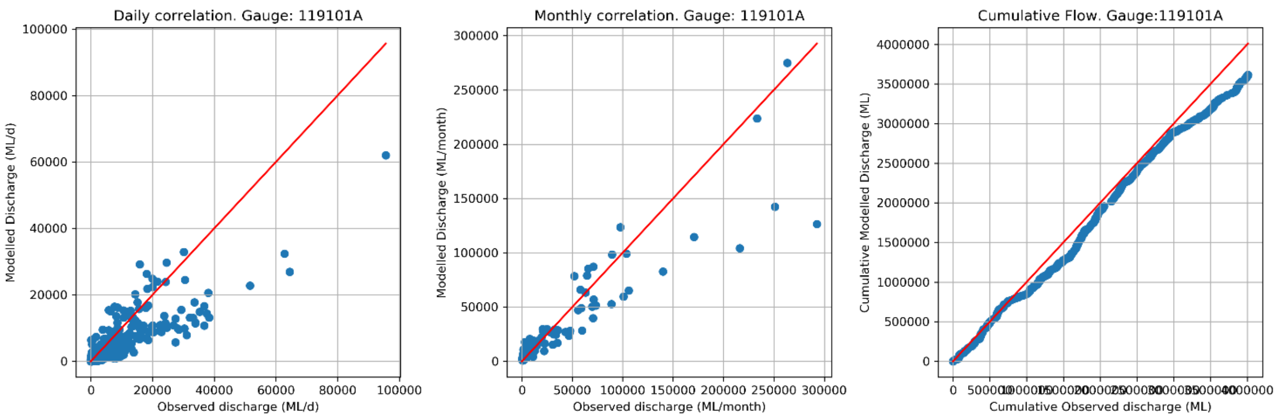


Figure 5-5. 1996–2014 Barratta Creek (119101A) correlation with 20% APSIM drainage

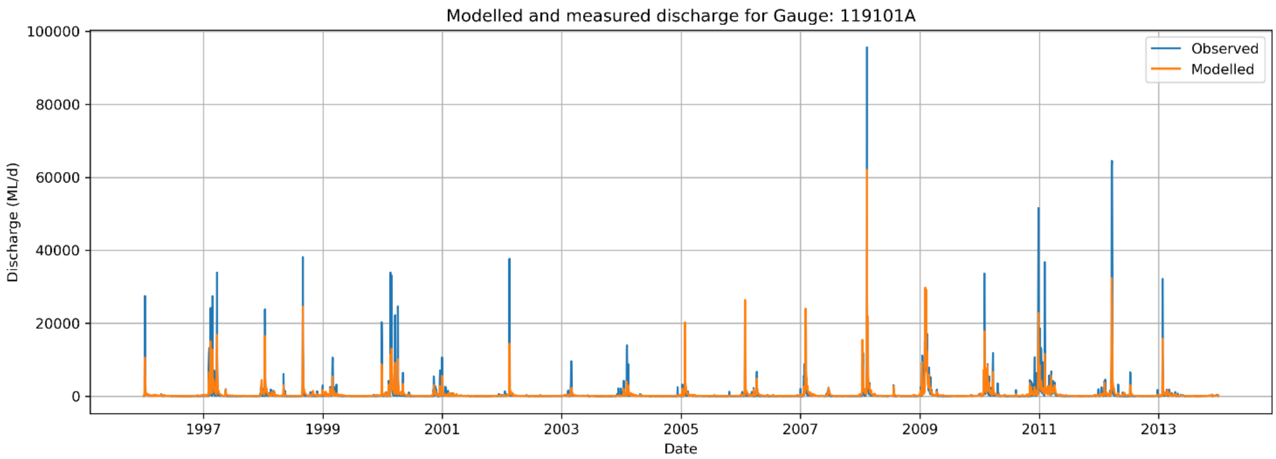
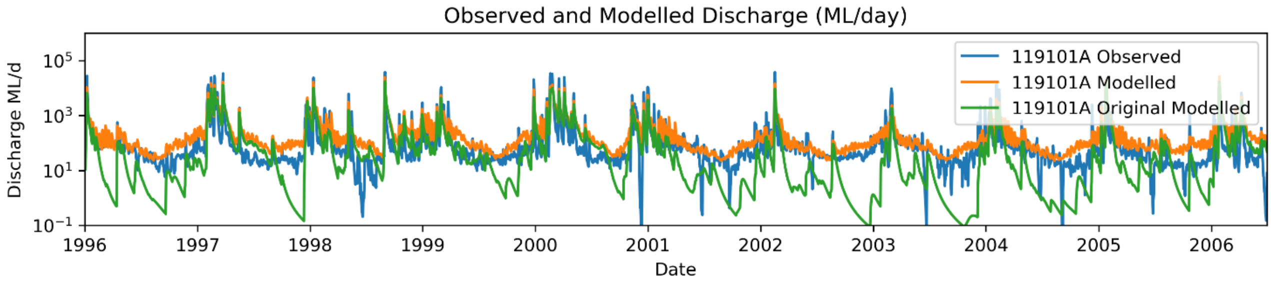


Figure 5-6. 1996–2014 Barratta Creek (119101A) modelled and gauged (observed) time series



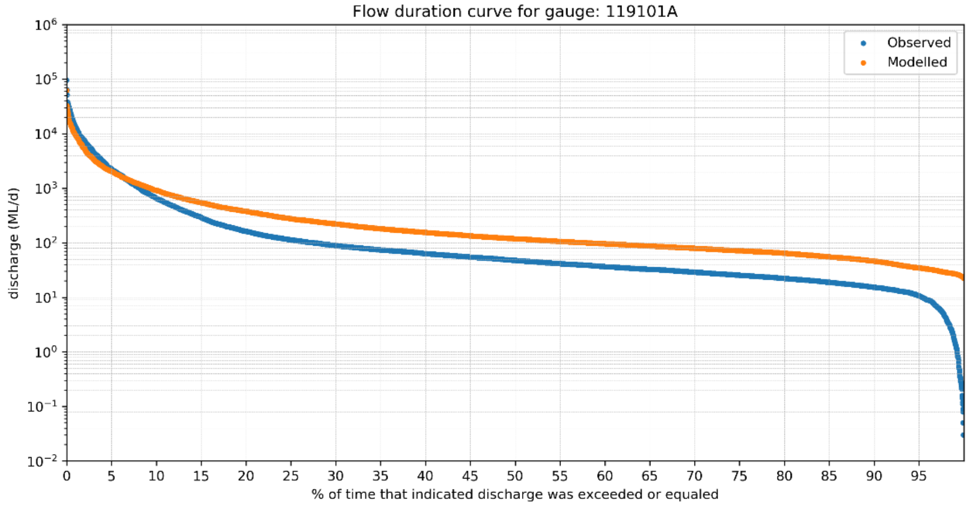


Figure 5-7. 1996-2014 Barratta Creek (119101A) modelled and measured time series and flow duration curve

- The adjusted hydrology produces less runoff in the pre-cane period.
- The adjusted hydrology + APSIM inputs in the post-cane period generally follows the cumulative measured discharge.
- Including a higher percentage of cane drainage further rectifies the model bias, but increases the baseflow, which is already exceeding the observed record as shown in time series plots and flow duration curve.
- Despite the overestimation of baseflows, the model hydrology with APSIM is more able to replicate the dry season baseflows and inter-event baseflows than the pre-cane model hydrology. The model structure is not yet capable of adjusting the extent of sugarcane FU throughout the simulation period, and thereby incrementally changing the model hydrology through time. This feature may be incorporated in the future if required.

5.3 APSIM and Source-generated water quality loads and concentrations

5.3.1 Pioneer water quality

In the Pioneer catchment, three gauge sites have accompanying water quality load measurements overlapping model simulations for DIN of between 1 and 8 years (125013A = 8 years, 125004A = 2 years and 125005A = 1 year), and one site (125013A—just upstream of 125016A) for Diuron and atrazine of approximately 4 years.

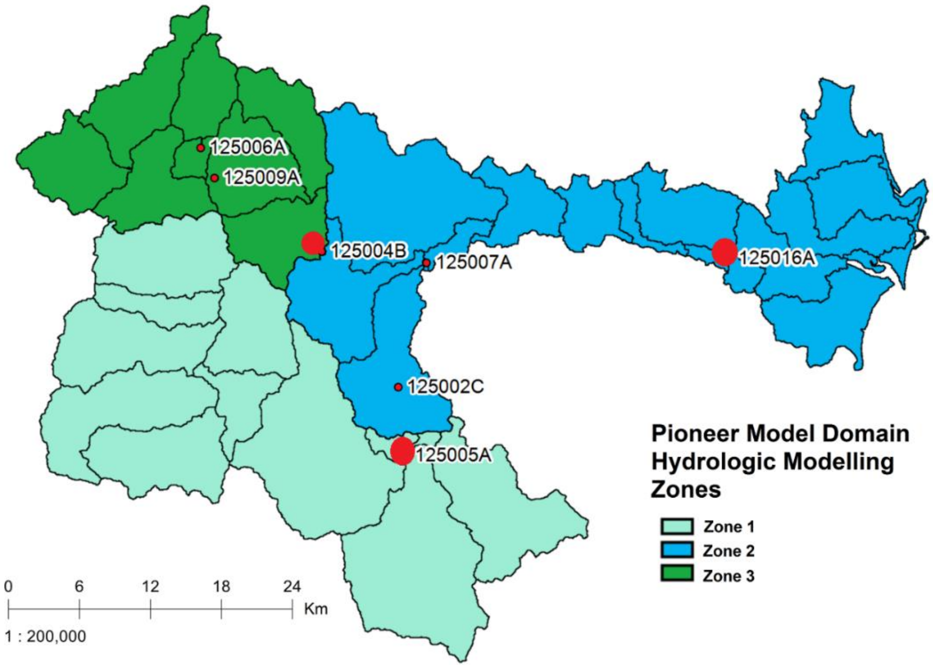


Figure 5-8. 1996–2014 Barratta Creek (119101A) modelled and measured time series and flow duration curve

Using the proportions of surface and drainage discharge from APSIM to generate sugarcane-based loads, and then applying 100% DIN, atrazine and Diuron contribution from surface, drainage, sediment and water phases, results in estimates of the delivery ratio parameters for the plugin. For DIN:

- The estimated mean annual observed DIN concentration at site 125004B is 0.161 mg/L, and at 100% modelled DIN, the mean annual concentration for matching years is 1.04 mg/L, associated with a total modelled load of 1278 t.
- The estimated mean annual observed DIN concentration at site 125013A is 0.215 mg/L, and at 100% modelled DIN, the mean annual concentration for matching years is 0.656 mg/L, associated with a total modelled load of 7225 t.
- The estimated mean annual observed DIN concentration at site 125002A is 0.166 mg/L, and at 100% modelled DIN, the mean annual concentration for matching years is 0.072 mg/L, associated with a total modelled load of 22 t.
- Through application of the Python notebook calculations, the delivery ratio of DIN to apply in both surface and drainage is 0.154, 0.328 and 1.617 for gauges 125004B, 125013A and 125002A respectively. A global DIN proportion has been derived by weighting the gauge

specific proportions according to total modelled load. This results in a global DIN proportion of 0.3, or, allowing for other catchment sources, of DIN: **0.27**. The discussion section provides comment on the appropriateness of the selected delivery ratios.

For Diuron:

- The estimated mean annual observed Diuron concentration at site 125013A is 0.212 ug/L, and at 100% modelled Diuron, the mean annual concentration for matching years is 0.664 ug/L, associated with a total modelled load of 4002 kg.
- Through application of the Python notebook calculations, the delivery ratio of Diuron to apply in both surface and drainage is **0.319**.

For atrazine:

- The estimated mean annual observed atrazine concentration at site 125013A is 0.224 ug/L, and at 100% modelled atrazine, the mean annual concentration for matching years is 0.074 ug/L, associated with a total modelled load of 447 kg.
- Through application of the Python notebook calculations, the delivery ratio of atrazine to apply in both surface and drainage is **2.85** (i.e. there is not enough atrazine in the APSIM-modelled time series).

The constituent delivery ratios applied in conjunction with the hydrology parameters are designed to match mean annual concentrations rather than mean annual loads. This approach accounts for potential differences in model hydrology at gauging sites. Using this method, if the hydrology matches, then the mean annual load will match as well. The mean annual measured and modelled water quality data for the Pioneer model is provided in *Table 5-5*.

Table 5-5. Summary DIN performance for the Pioneer model

Year end	Measured DIN (t)	Modelled DIN (t)	Measured mg/L	Modelled mg/L	Measured ML	Modelled ML
			125013A			
30/06/2007	205.8	484.8	0.23	0.48	884963	1004430
30/06/2008	174.3	329.5	0.13	0.22	1364326	1513534
30/06/2009	114.9	230.8	0.12	0.22	927461	1033237
30/06/2010	477	279.7	0.36	0.19	1326065	1438026
30/06/2011	643	552.2	0.19	0.18	3372934	3130941
30/06/2012	226.1	240.3	0.19	0.18	1216712	1316726
30/06/2013	253.5	209.9	0.20	0.19	1247976	1078031
30/06/2014	257.6	92.6	0.44	0.18	581628	503122
			125004A			
30/06/2007	147.8	191.8	0.30	0.47	495496	406892
30/06/2009	83.2	86.2	0.20	0.24	424007	358768
			125005A			
30/06/2009	27.4	22.1	0.12	0.07	235953	308616
total all sites	2611	2720	0.22	0.22	12077521	12092325

Table 5-6. Summary atrazine and Diuron performance for the Pioneer model

Year end	Meas. atrazine (kg)	Mod. atrazine (kg)	Meas. diuron (kg)	Mod. diuron (kg)	Meas. atrazine (ug/L)	Mod. atrazine (ug/L)	Meas. diuron (ug/L)	Mod. diuron (ug/L)	Meas. Flow ML	Mod flow ML
30/06/2011	530	346	520	755	0.157	0.110	0.154	0.241	3372934	3130941
30/06/2012	220	407	140	229	0.181	0.309	0.115	0.174	1216712	1316726
30/06/2013	460	494	440	201	0.369	0.459	0.353	0.186	1247976	1078031
30/06/2014	230	95	260	92	0.395	0.189	0.447	0.182	581628	503123
total	1440	1342	1360	1277	0.224	0.223	0.212	0.212	6419250	6028821

Graphical outputs associated with the application of these delivery ratios are time series plots of modelled and measured concentrations, and scatter and box plots of water quality constituent concentrations as shown below.

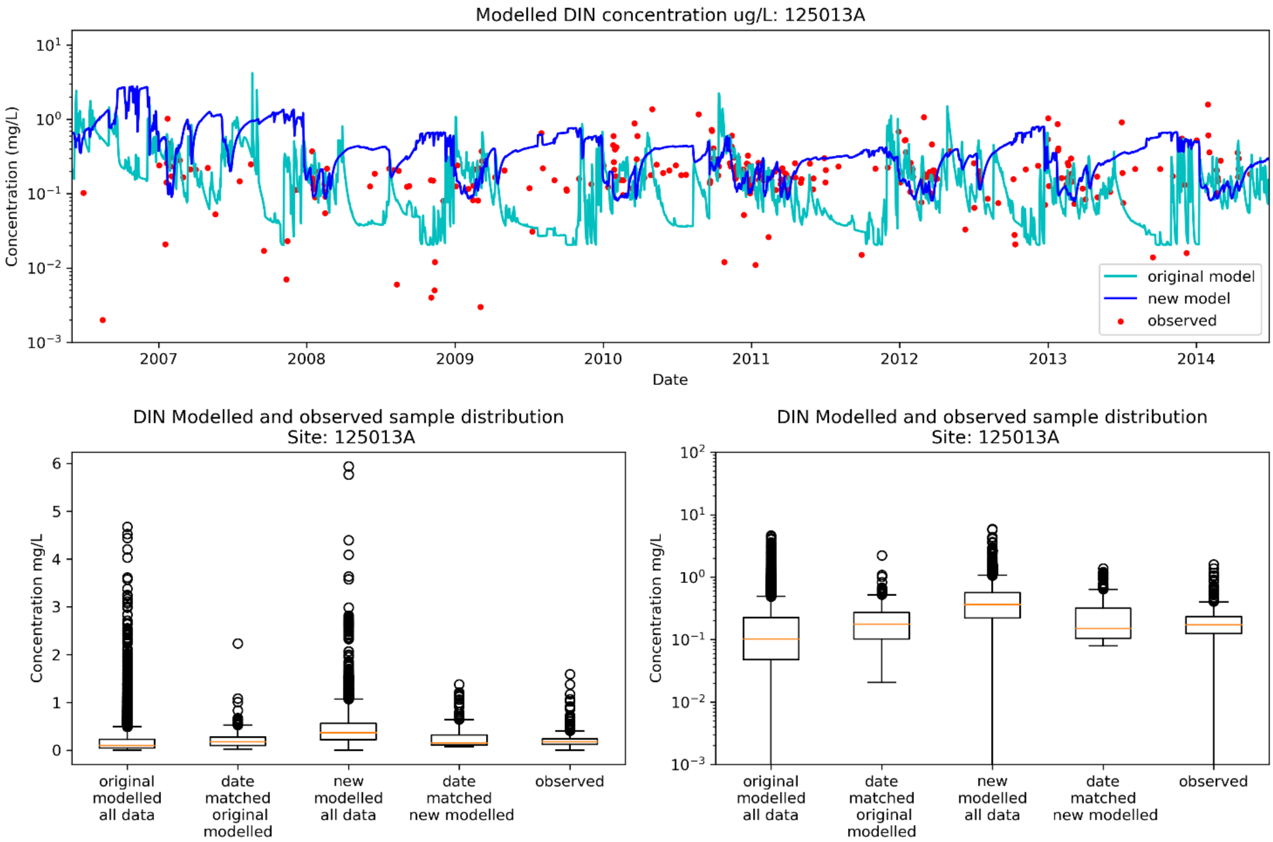


Figure 5-9. Pioneer modelled and measured daily DIN concentration time series and box plots for matching days including original and new model outputs

Daily time series and scatter plots for DIN in the Pioneer show:

- The modelled range of DIN tends to not fall below 0.1 mg/L, largely due to averaging of constituents from mixing in storages and background DIN concentrations.
- The new model behaviour typically delivers higher DIN concentrations in baseflows and recession flows—almost the opposite of previous model behaviour.

- The day-matched box plots of DIN show similar ranges to observed and previous model distributions. The median modelled and measured DIN are similar, as is the range.

Overall, the modelled mean annual DIN concentration is 0.22 mg/L and estimated mean annual DIN concentration is 0.215 mg/L at the most downstream water quality measurement site 125013A.

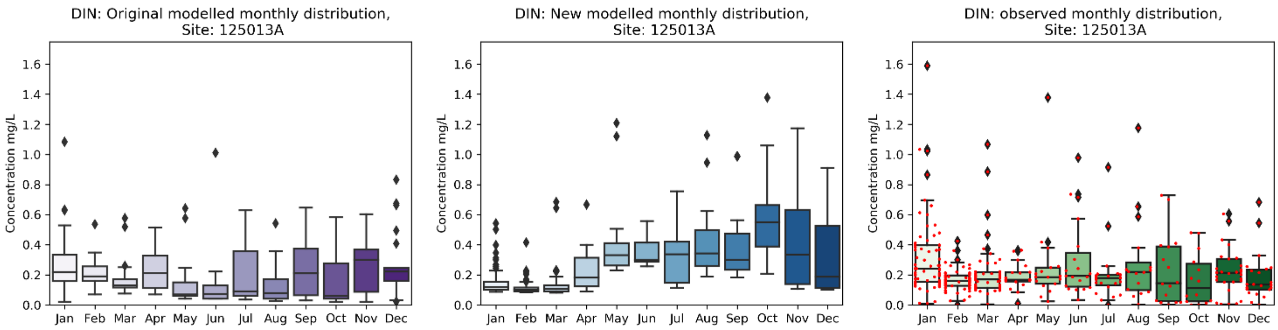


Figure 5-10. Pioneer modelled and measured DIN concentration for months for original, new models and observed data

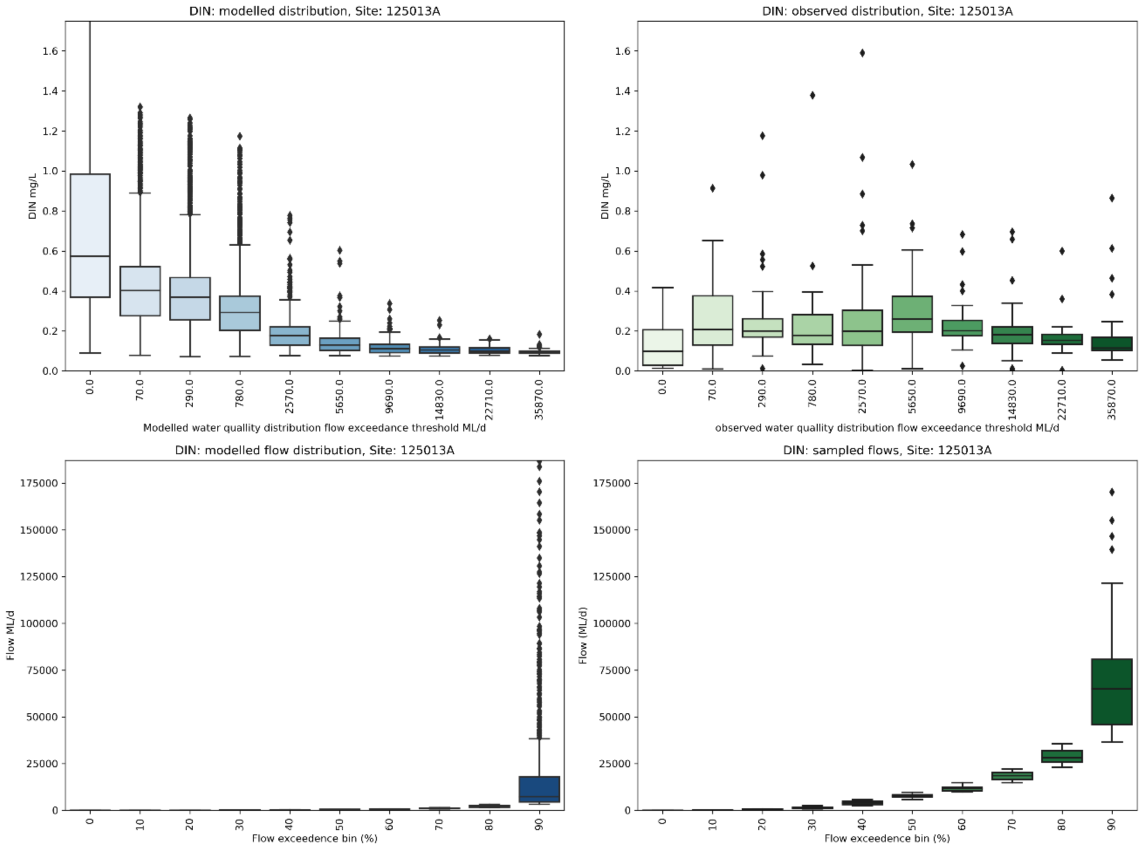


Figure 5-11. Pioneer modelled and measured DIN concentration for flow bands and associated sampling regime distribution

The monthly DIN box plots (*Figure 5-10* upper plot) show elevated concentrations in April through to December. This pattern is not evident in the monitoring data, which indicated January, June and September are more likely to be associated with some elevated concentrations of DIN, although median concentrations throughout the whole year are very similar.

When paired with flow data (*Figure 5-11*), the measured DIN concentrations tend to be highest with low to medium flows. This is captured by the model, but in a much more pronounced way, and the lowest flows have some of the highest concentrations. This may indicate that additional processes may be at work removing more DIN in the drainage during the lowest flows.

Lastly, the lower plots of *Figure 5-11* show the flow ranges associated with 10th percentile flow bins of DIN samples compared to 10th percentile bins for all modelled flows. These plots show the propensity of sampling for higher flows (for better loads estimates) compared to low flow (routine) measurements.

Similar plots for atrazine and Diuron are shown below.

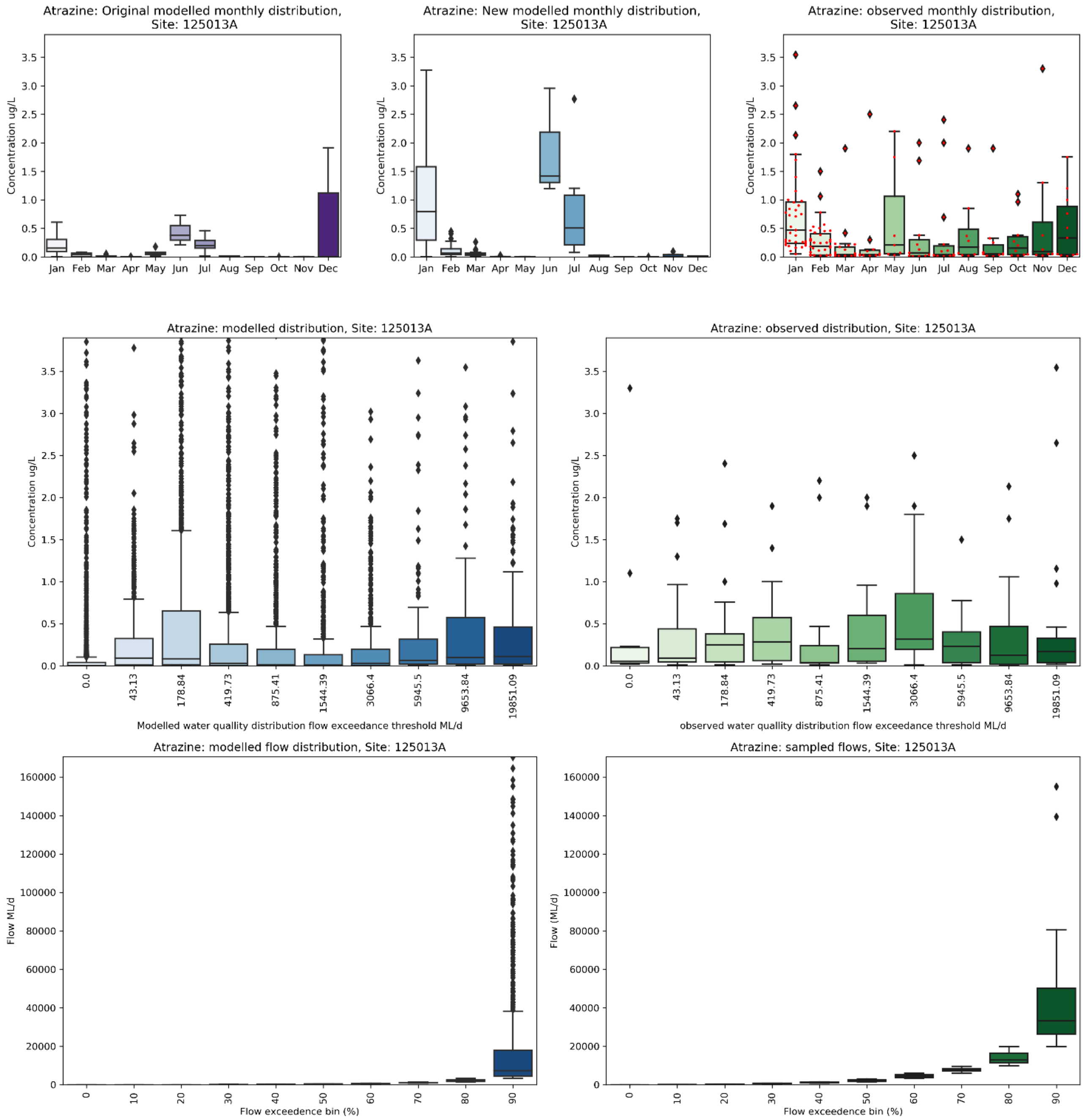


Figure 5-12. Pioneer modelled and measured atrazine concentration for months for original, new models and observed data (top) and for flow bands and flow sampling regime

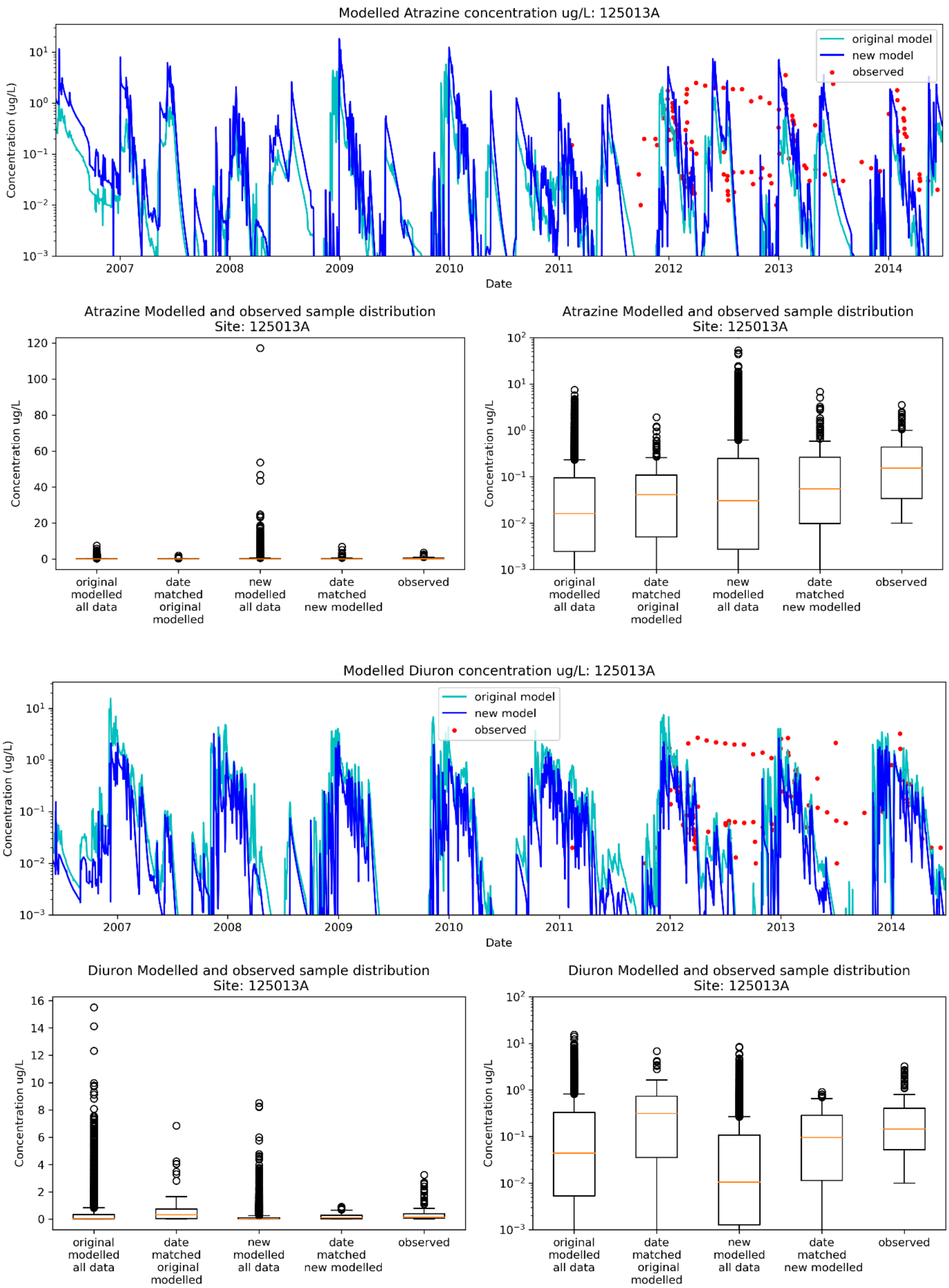


Figure 5-13. Pioneer modelled and measured daily atrazine and Diuron concentration time series and box plots for matching days, including original and new model outputs

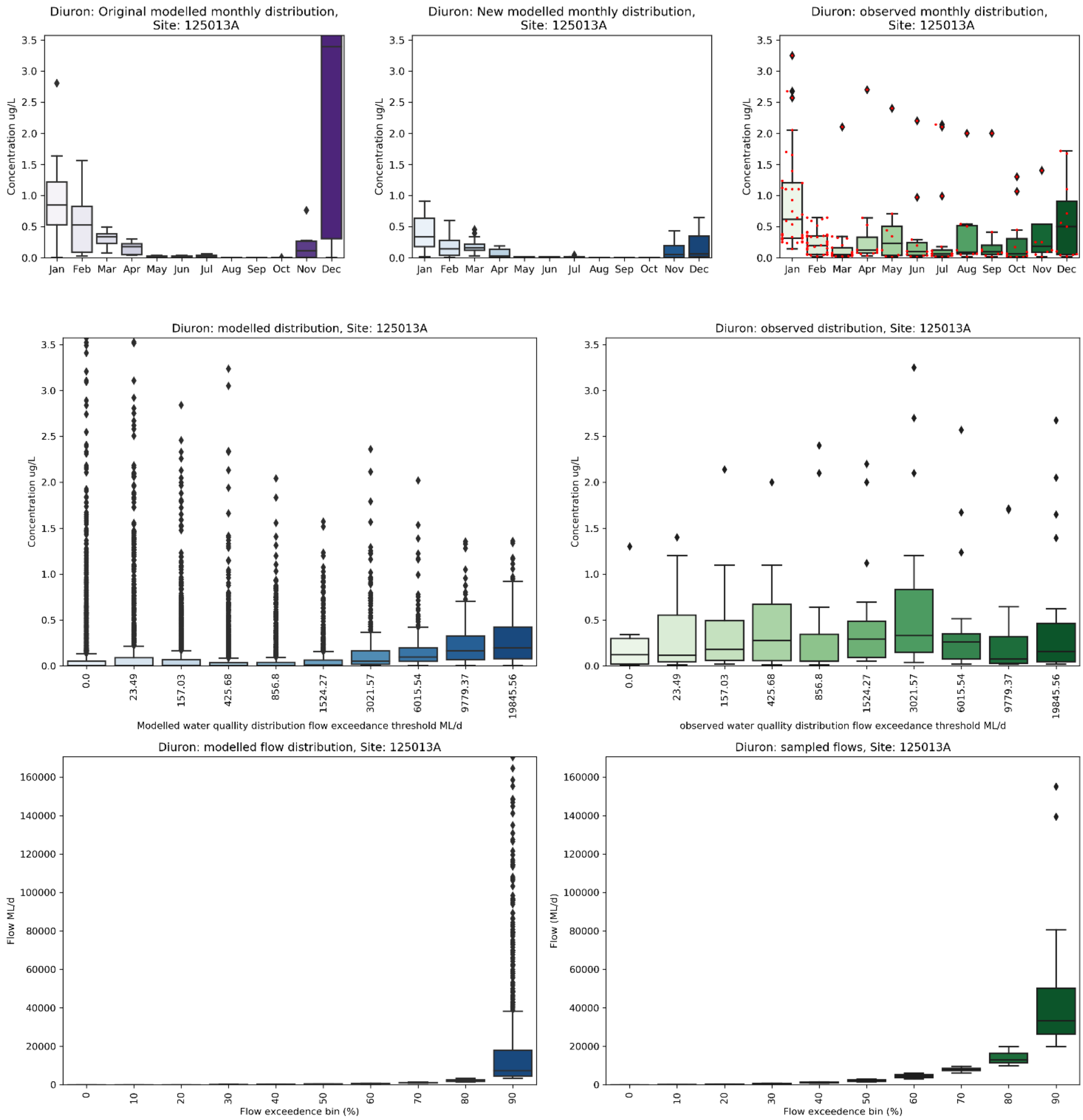


Figure 5-14. Pioneer modelled and measured Diuron concentration

Box plots for atrazine and Diuron generally show that the use of these chemicals is more widespread across months compared to the modelled monthly distribution. The matching days box plot distributions are in general agreement, although the modelled atrazine showed higher concentrations than observed, predominantly due to having to scale-up the atrazine delivery ratio to achieve mean annual concentration figures. As the monthly atrazine box plot shows, this constituent needs to be more distributed across the year in APSIM, rather than scaled in Source.

5.3.2 Barratta Creek water quality

In the Barratta catchment, the gauge site (119101A) has accompanying water quality load measurements overlapping model simulations for DIN of 5 years, and 4 years for Diuron and atrazine.

For DIN:

- The estimated mean annual observed DIN concentration is 0.286 mg/L, and at 100% modelled DIN, the mean annual concentration for matching years is 1.145 mg/L, associated with a total modelled load of 1255 t.
- Through application of the Python notebook calculations, the delivery ratio of DIN to apply in both surface and drainage is 0.25. Allowing for other catchment sources of DIN, the delivery ratio becomes **0.2**.

For Diuron:

- The estimated mean annual observed Diuron concentration is 0.219 ug/L, and at 100% modelled Diuron, the mean annual concentration for matching years is 1.62 ug/L, associated with a total modelled load of 1401 kg.
- Through application of the Python notebook calculations, the delivery ratio of Diuron to apply in both surface and drainage is **0.135**.

For atrazine:

- The estimated mean annual observed atrazine concentration is 1.01 ug/L, and at 100% modelled atrazine, the mean annual concentration for matching years is 1.355 ug/L, associated with a total modelled load of 1172 kg.
- Through application of the Python notebook calculations, the delivery ratio of atrazine to apply in both surface and drainage is **0.75**.

Table 5-7. Summary DIN performance for the Barratta model

Year end	Measured DIN (t)	Modelled DIN (t)	Measured mg/L	Modelled mg/L	Measured ML	Modelled ML
30/06/2010	103.0	68.1	0.420	0.294	245486	231396
30/06/2011	68.0	98.7	0.113	0.248	600261	398180
30/06/2012	67.1	61.2	0.206	0.264	325917	232100
30/06/2013	93.1	46.3	0.730	0.367	127452	126059
30/06/2014	76.2	38.8	0.619	0.357	123084	108622
Total	407.4	313.1	0.286	0.286	1422200	1096358

Table 5-8. Summary atrazine and Diuron performance for the Barratta model

Year end	Meas. atrazine (kg)	Mod. atrazine (kg)	Meas. diuron (kg)	Mod. diuron (kg)	Meas. atrazine (ug/L)	Mod. atrazine (ug/L)	Meas. diuron (ug/L)	Mod. diuron (ug/L)	Meas. Flow ML	Mod flow ML
30/06/2011	290.0	475.9	46.0	75.6	0.48312	1.19521	0.07663	0.18985	600261	398180
30/06/2012	220.0	141.2	60.0	44.5	0.67502	0.60839	0.18410	0.19159	325917	232100
30/06/2013	520.0	144.8	80.0	35.6	4.07997	1.14903	0.62769	0.28260	127452	126059
30/06/2014	160.0	122.2	72.0	33.5	1.29993	1.12496	0.58497	0.30840	123084	108622

total	1190.0	884.2	258.0	189.2	1.011	1.022	0.219	0.219	1176714	864962

Graphical outputs associated with the application of these delivery ratios are time series plots of modelled and measured concentrations, and box plots of water quality constituent concentrations. *Figure 5-15* shows a significant improvement in DIN concentration distribution resulting from the new model, but still fails to appropriately capture the variability in concentrations through time.

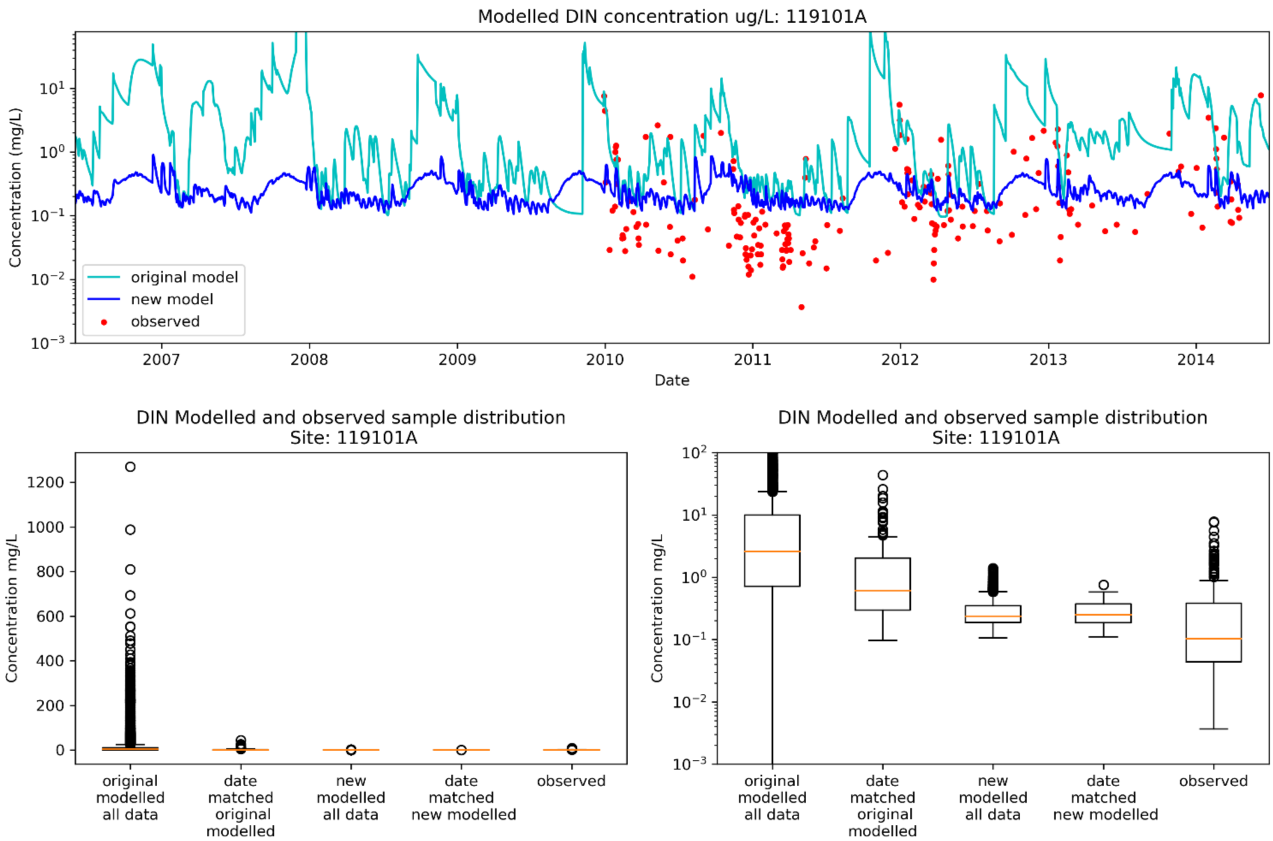


Figure 5-15. Barratta modelled and measured daily DIN concentration time series and box plots for matching days

Daily time series for DIN in the Barratta show:

- The modelled range of DIN tends to not fall below 0.1 mg/L, but occurs regularly in the observations. Lowering the background concentration applied in the model (event mean concentrations (EMCs) and dry weather concentrations (DWCs) of 0.1 mg/L) would likely address this.
- The day-matched box plots of DIN show similar median ranges; however, the long tail of high outliers in the observations is not captured by the new model.

Overall, the modelled mean annual DIN concentration is 0.286 mg/L and estimated mean annual DIN concentration is 0.286 mg/L (total estimated load/total estimated flow) for matching years at gauge 119101A.

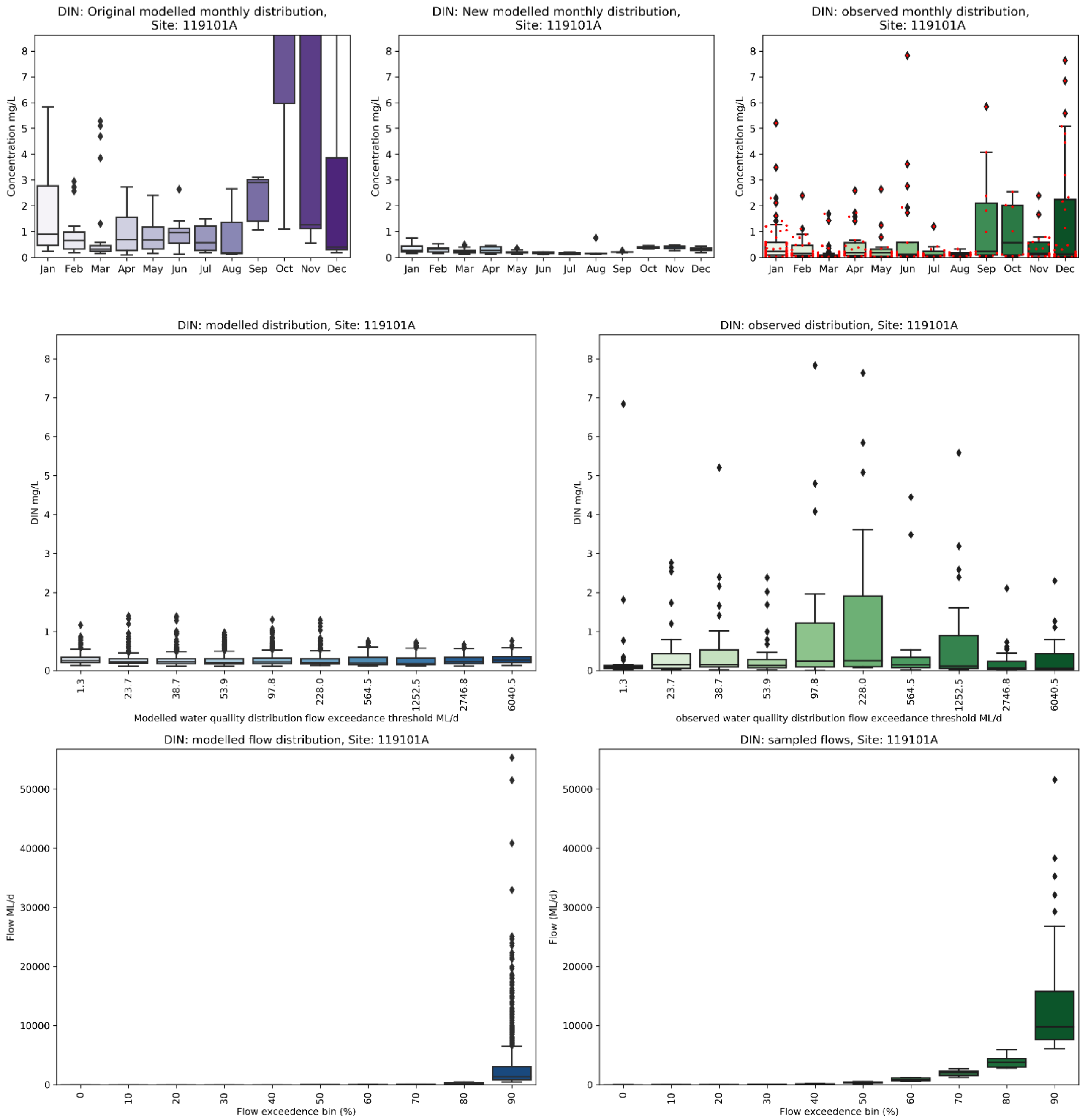


Figure 5-16. Barratta modelled and measured DIN concentration for months and flow bands

The monthly DIN box plots (Figure 5-16, upper plot) show elevated median observed concentrations in October; however, considerable scatter can lead to very high concentrations of DIN in almost any month. Slightly elevated concentrations in October are also present in the modelled data, but the variability is not captured. The new model shows a significant improvement compared to originally modelled data.

When paired with flow data, the measured DIN concentrations tend to show the most variability in mid-range flows. Modelling shows virtually no change in the concentration with flow and sampling is biased toward higher flow ranges as expected. Similar plots for atrazine and Diuron are shown below.

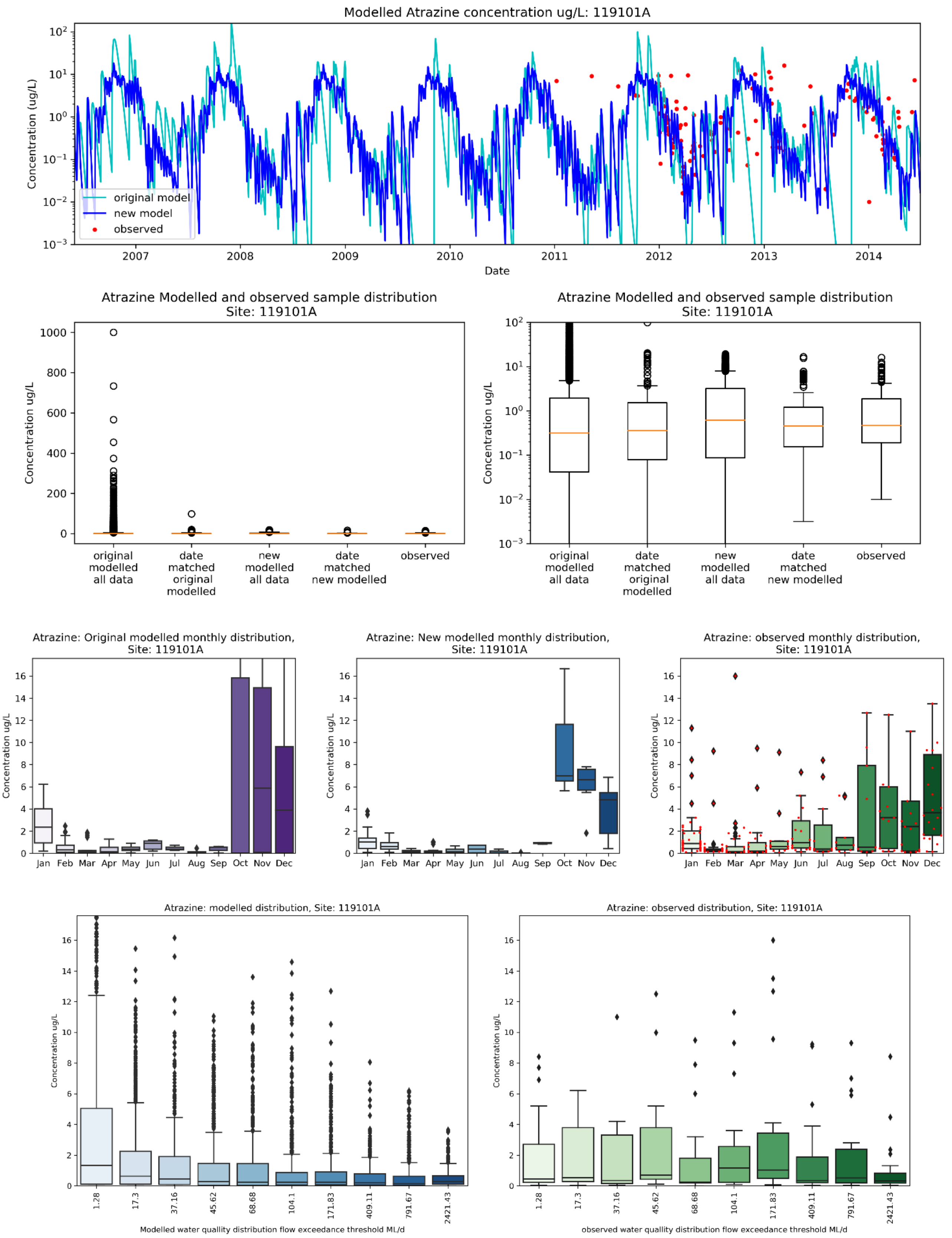


Figure 5-17. Barratta modelled and measured atrazine concentration

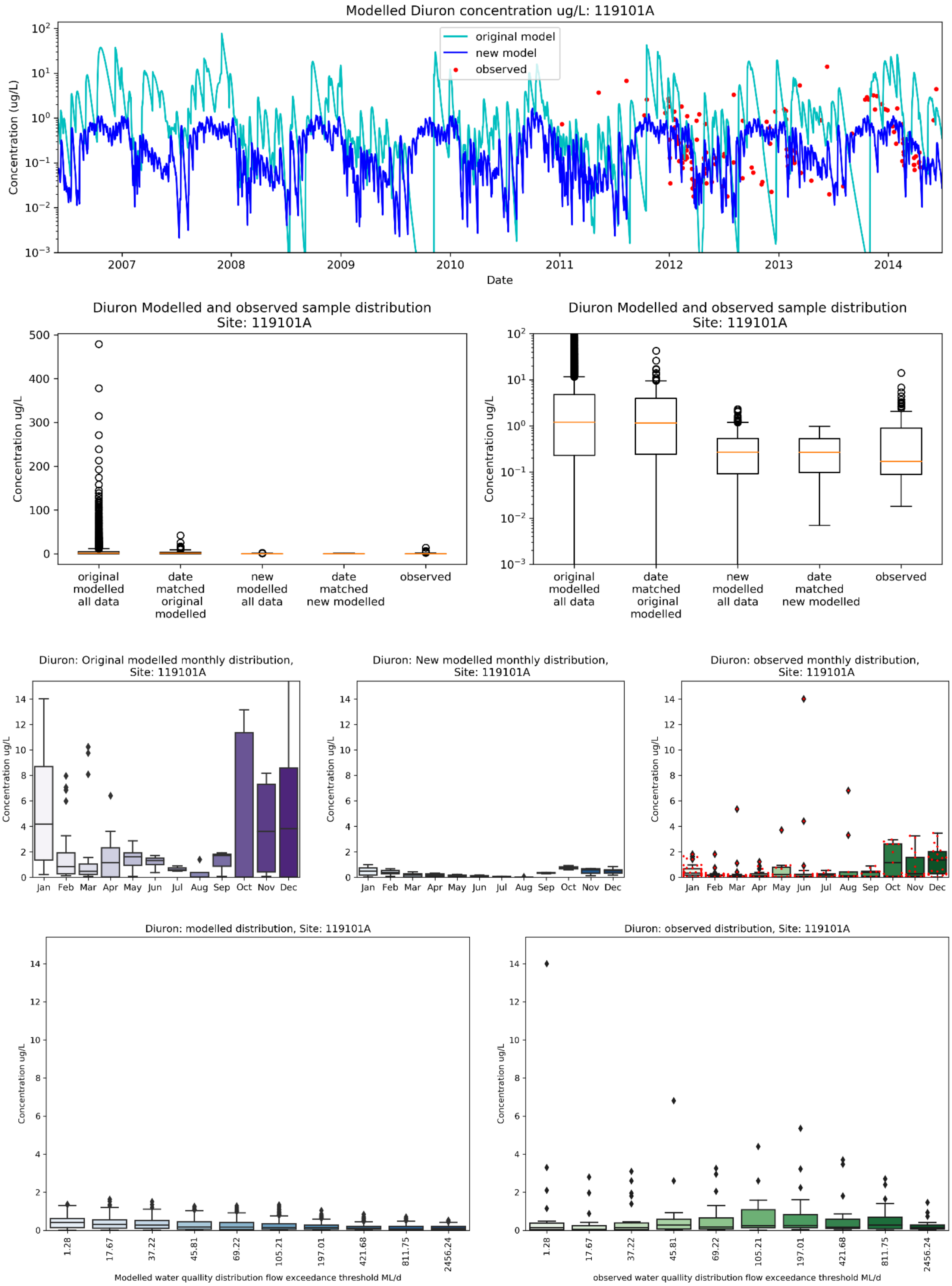


Figure 5-18. Barratta modelled and measured Diuron concentration

Box plots for atrazine show some agreement between the range of modelled data and measured data. The peak concentrations in October, November and December are reflected in the observations. The same cannot be said for Diuron. Very little variability is shown in model results compared to observations, although some agreement with the elevated October concentrations is evident in both modelled and measured data.

As with DIN, the new model approach offers a significant improvement in the representation of realistic constituent concentrations compared to previous model results. In all cases, both the date matched and all model constituent distributions are closer to the observed ranges than the previously modelled time series.

5.4 Summary of potential impact of proposed linkages

The proposed Paddock to Source integration method has the following general impacts on model hydrology:

- Daily NSE correlation impacts across all gauges bar one (Barratta) were slightly improved. Improvements ranged from 0 to 0.11 in the daily NSE. Barratta Creek showed a marginal decline of 0.04 compared to the original calibration for post-cane development with APSIM compared to original hydrology, but resulted in less model bias for both pre- and post-cane catchment conditions.
- Monthly NSE correlation impacts across all gauges were largely maintained or slightly improved. This suggests that the seasonality of model flows is not impacted by the direct import of APSIM runoff.
- The introduction of APSIM flows with regional delivery ratios generally resulted in the reduction in bias of modelled streamflow of up to 6%.

These outcomes suggests that the proposed method is capable of capturing the overall volume of runoff, and daily and monthly runoff patterns, and even providing marginal improvements in statistical model fit.

The proposed Paddock to Source integration method has the following general impacts on model water quality:

- Mean annual modelled concentrations of DIN, Diuron and atrazine can be matched with total measured concentrations using the proposed methods of hydrology import and associated constituent mass import with a delivery ratio.
- Year-to-year loads generally do not match across all constituents, with some constituents appearing to be limited in available mass such as Barratta DIN.
- Generally, water quality concentration sample distributions are within the same order of magnitude as the measured concentrations. The data suggests that the timing of concentration peaks may need some further adjustment through APSIM or through the implementation of a dynamic monthly scale delivery ratio.

The following chapter presents further summary and discussion of the results and introduces the results of an additional model considered in this study.

6 RESULTS DISCUSSION

This chapter presents additional analysis of the results for the Pioneer and Barratta catchments in addition to results from the Tully–Johnstone catchment. The analysis is intended to inform and guide discussion surrounding approaches to considering the landscape position on the potential contribution of flows and constituents to the stream.

6.1 Summary plugin hydrology parameters and contribution to stream

Summary plugin hydrology parameters for all regions investigated in this study are presented in *Table 6-1*. Noticeably, the regions with significant proportions of cane areas are associated with relatively high drainage delivery ratios (>0.8), indicating the majority of APSIM-estimated runoff and drainage is required to achieve similar hydrology at gauge sites compared to the original models. Notably, the drainage store emptying ratios are also clustered around the 0.03 level. The drainage store emptying ratio is the amount of drainage to deliver to the stream from the total drainage store each time step. This represents a significant lag of drainage flows.

Similarly, the surface store emptying ratios are all close to 1, indicating virtually no lag from simulation of the surface runoff to the stream network.

Table 6-1. Plugin hydrology parameter summary

Catchment	Representative gauges	Hydrologic region	Sugarcane area (ha)	Total region area (ha)	% Cane	Surface delivery ratio	Drainage delivery ratio	Surface store emptying ratio	Drainage store emptying ratio
Tully	113006A	1	11979	127144	15.0%	1	1	1	0.0318
South Johnstone	112101B	2	4463	73791	15.6%	1	0.907	0.9998	0.0227
South Johnstone	112102A	6	11507	102805	4.3%	1	0.712	0.9749	0.0325
North Johnstone	112004A	4	19053	94755	12.6%	1	0.983	1	0.0386
Pioneer	125004A	2	611	65957	1%	1	0.58	1	0.04
Pioneer	125005A	3	9326	36126	25.7%	1	0.97	1	0.04
Pioneer	125016A	1	26330	64212	40%	1	0.81	0.99	0.04
Burdekin	119101A	1	40099	121916	33%	1	0.2	0.99	0.13

The drainage delivery ratios in relation to the surface runoff component can be represented in a simple scaled flow diagram (Sankey diagram), also generated by the Python notebook. Example diagrams are shown below for Barratta, Pioneer and Tully and provide a visual representation of the relative proportions of APSIM-generated surface and drainage runoff, and how these flows are applied in the Source model. These plots provide an indication of the relative importance of the different components of the water balance.

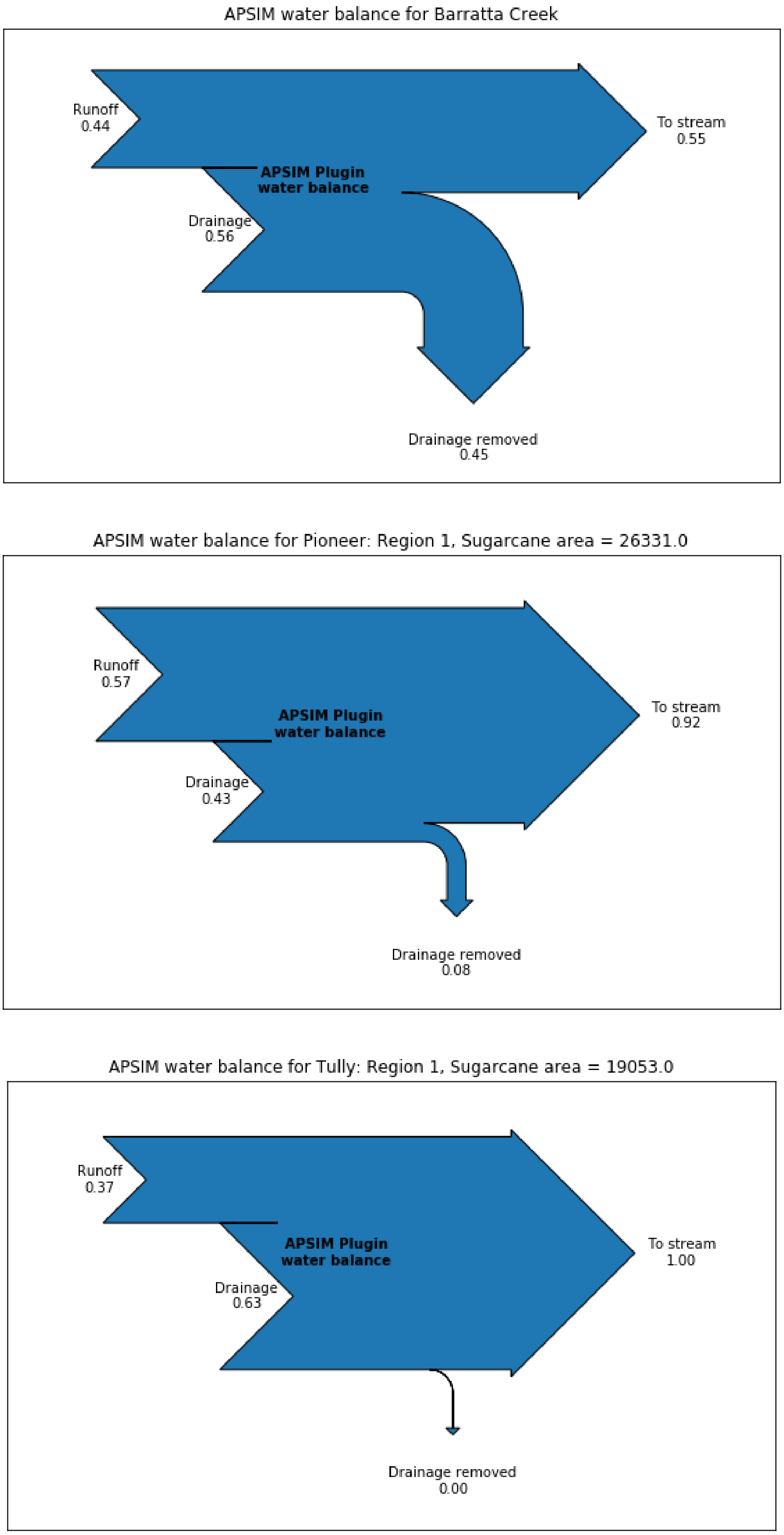


Figure 6-1. Water balance components of Barratta (irrigated cane) Pioneer and Tully (rain-fed) using APSIM-generated flows and applied plugin delivery ratios

The flow diagrams in Figure 6-1 highlight the significant amount of water that needs to be removed from the drainage flows in Barratta Creek to obtain reasonable mass balance at the gauge. Such a large loss term, if real, should be associated with some measurable long-term increase in groundwater levels in the catchment. Preliminary investigations on groundwater levels in the Barratta Creek catchment suggest some long-term increases in groundwater levels away from the creek (Mona Park groundwater). However, a true long-term trend would need to involve investigating more gauges over a longer period of time. A more detailed analysis and mass balance should be undertaken to investigate if such a large APSIM drainage term is justified.

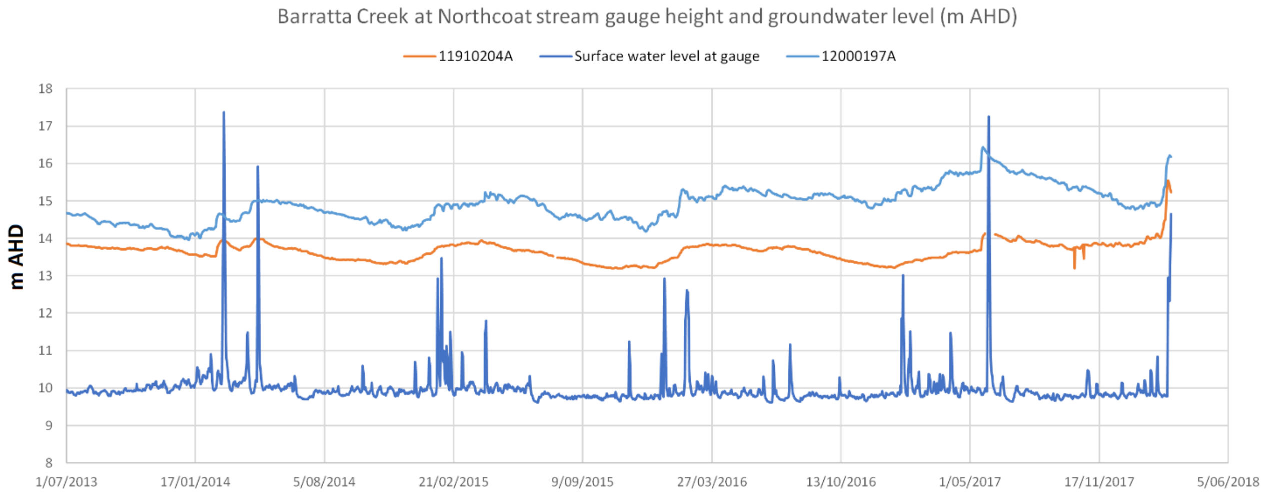


Figure 6-2. Barratta creek gauge height, 11910204A groundwater (close to stream, edge of cane) and 12000197A Mona Park groundwater (several km from stream, centre of cane)

The runoff term in the Barratta Creek water balance is currently sent directly to the stream; however, some of the runoff may be from irrigation and some from rainfall. In the case of irrigation runoff, it is conceivable that a proportion of this may go to form 'run-on' to nearby land, channels and drains prior to arriving in the main stream network and gauge. While not currently implemented, it may be worthwhile considering implementing a routine to allow run-on from irrigated cane to return some of this term to drainage.

In the Pioneer, typically only a small amount of drainage has been removed to obtain a reasonable mass balance at gauges. The groundwater response in this catchment is typically much more pronounced (*Figure 6-3*), rising and falling up to 4 m every season, dwarfing any potential contribution from APSIM drainage.

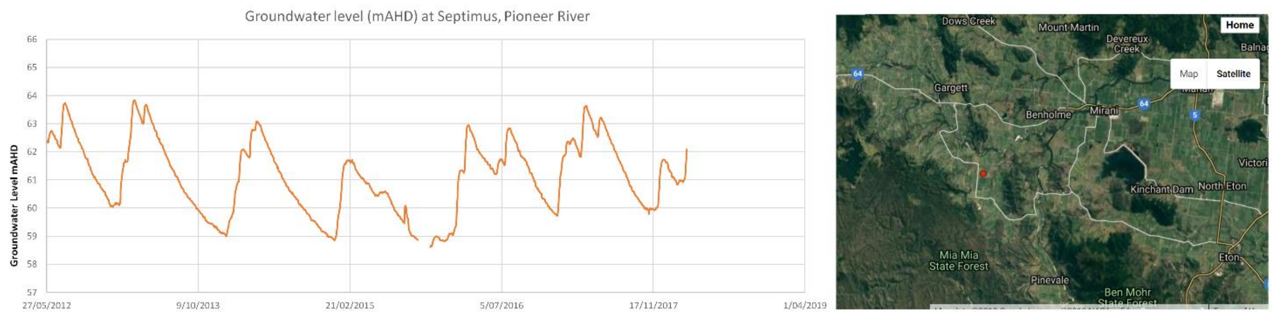


Figure 6-3. Pioneer groundwater level at Septimus (mAHD)

The two very different groundwater responses between the Pioneer and Barratta catchments may be influenced by soil, slope and drainage contribution from the APSIM model. The empirical equations derived by Rassam and Littleboy (2003), reviewed in Appendix B, relating these key elements may help in determining the validity of the drainage parameters, particularly for those areas under irrigation.

The remaining hydrology parameters of the surface store emptying ratio and drainage store emptying ratio have been adopted from the Sacramento model parameters. These parameters do not change the mass balance, but do have some bearing on the timing of flows:

- Surface store emptying parameters close to 1 indicate almost all surface runoff makes it to the stream in the first time step (i.e. no delay), allowing other routing parameter in the model links to further attenuate the flows. This is entirely consistent with the Sacramento model parameters, and suggests that the subcatchment sizes in the models are small enough to match the daily time step scale. Further routing then happens in the stream network, rather than in the plugin.

- Drainage store emptying ratios are typically between 0.02 and 0.04. This rate of 'emptying' may be correlated with the lowering of the groundwater levels after the wet season. The soil type, slope and distance to stream are likely to contribute to the estimation of these parameters; however, given that it is a fitting parameter rather than a mass balance parameter, an approximation may suffice. Direct correlation with groundwater levels is problematic, however. The Sacramento groundwater stores and APSIM sugarcane stores are not linked—their fluxes may contribute to observed groundwater levels, but the amount stored (mm) is not directly relatable because the area over where it is applied is not the same.

6.2 Summary plugin water quality parameters and contribution to stream

Summary plugin water quality parameters for all regions investigated in this study are presented in *Table 6-2*. Applied DIN delivery ratios ranged from 0.2 to 0.65, indicating that the mass of DIN constituent applied in the model was of a similar order of magnitude to obtain a reasonable agreement in the models.

Pesticide delivery ratios ranged from 0.14 to 11.5, indicating the mass of pesticide constituent required more adjustment than DIN to obtain agreement with mean annual constituent concentrations.

Table 6-2. Plugin water quality parameter summary

Catchment	Sugarcane area (ha)	Total region area (ha)	% Cane	DIN delivery ratio*	DIN drainage	Atrazine sediment**	Atrazine water**	Diuron sediment**	Diuron water**
Tully–Johnstone	47002	398495	12%	0.65	0.65	11.50	11.50	1.40	1.40
Combined Pioneer	101711	593588	17%	0.27	0.27	3.00	3.00	0.32	0.32
Burdekin	40099	121916	33%	0.20	0.20	0.75	0.75	0.14	0.14

**The DIN delivery ratio was applied to both surface and drainage proportions*

*** The pesticide delivery ratios was applied to both sediment and water phase.*

The constituent mass balance can also be represented in a Sankey diagram. Example diagrams are shown below for Barratta and Pioneer catchments for DIN, atrazine and Diuron.

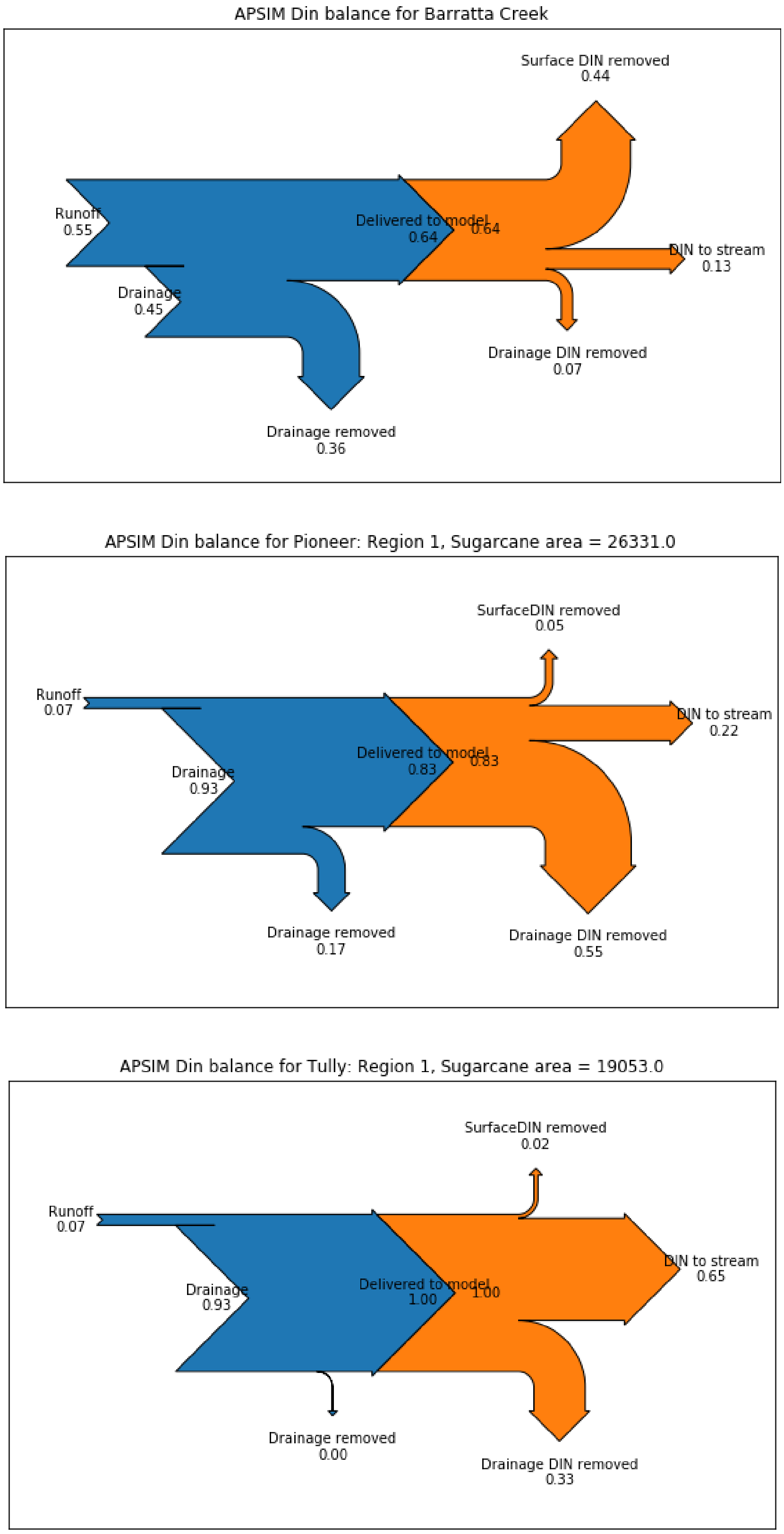


Figure 6-4. DIN mass balance components of Barratta (upper: irrigated cane) Pioneer and Tully (middle and lower: rain-fed) showing blue hydrology influenced DIN balance and orange water quality influenced DIN balance

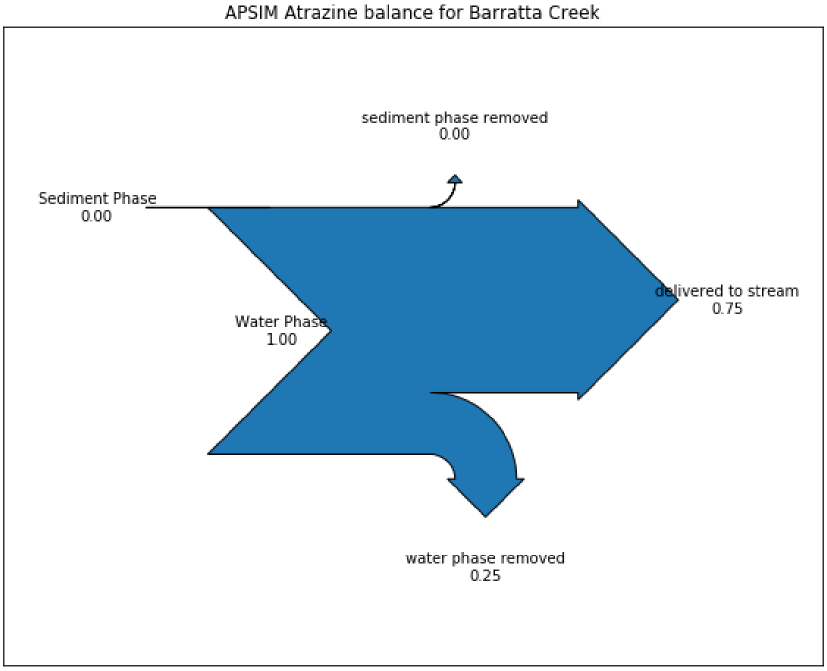
The Barratta and Pioneer DIN mass balance plots (*Figure 6-4*) show the dominant DIN pathways being different between the two examples. In the rain-fed Pioneer model, the majority of DIN is in the drainage water leading to the dominant DIN removal pathway via groundwater discharge to stream. In Barratta, a higher proportion of DIN is associated with surface runoff, which is delivered straight to the stream. The dominant pathway for DIN removal to match observed mean annual concentrations is via a surface flow delivery ratio.

The differences in DIN delivery and removal are influenced by the concentration of DIN in surface runoff in the Barratta Creek models. *Figure 6-1* showed that the distribution of flows between surface and drainage discharge was similar in both catchments. Despite this similarity, *Figure 6-4* shows the distribution of DIN in these flow pathways to be very different. Almost all of the DIN is in the drainage flows in the Pioneer model. More than half of the DIN is in the surface flows in the Barratta model.

The removal of the majority of DIN in the surface flow pathway in the Barratta model presents a conceptual problem of how this can be justified (i.e. what process influenced by the landscape position could that much DIN reduction be attributed to?). In the case of the Pioneer, the key DIN reduction could conceivably be the result of denitrification in the riparian zone, in which case, the extent of riparian zones (buffers) around cane areas may be a key factor in the reduction of DIN from paddock to stream.

The Barratta and Pioneer atrazine mass balance plots (*Figure 6-5*) show that some atrazine in Barratta had to be lost to achieve mean annual concentration targets. The opposite had to happen in the Pioneer, where the modelled mass of atrazine did not match concentration targets, requiring an upscaling (x3) to achieve the require result. The sediment phase pathway is negligible compared to the water phase pathway.

The Barratta and Pioneer Diuron mass balance plots (*Figure 6-6*) show that the majority of Diuron had to be lost to achieve mean annual concentration targets in both catchments. Similar to atrazine, the sediment phase pathway is negligible compared to the water phase pathway. The sediment phase pathway may have opened options for the consideration of riparian buffers or sedimentation for the attenuation of constituents associated with this phase; however, with such small components associated with this phase, it is not worthwhile considering it further.



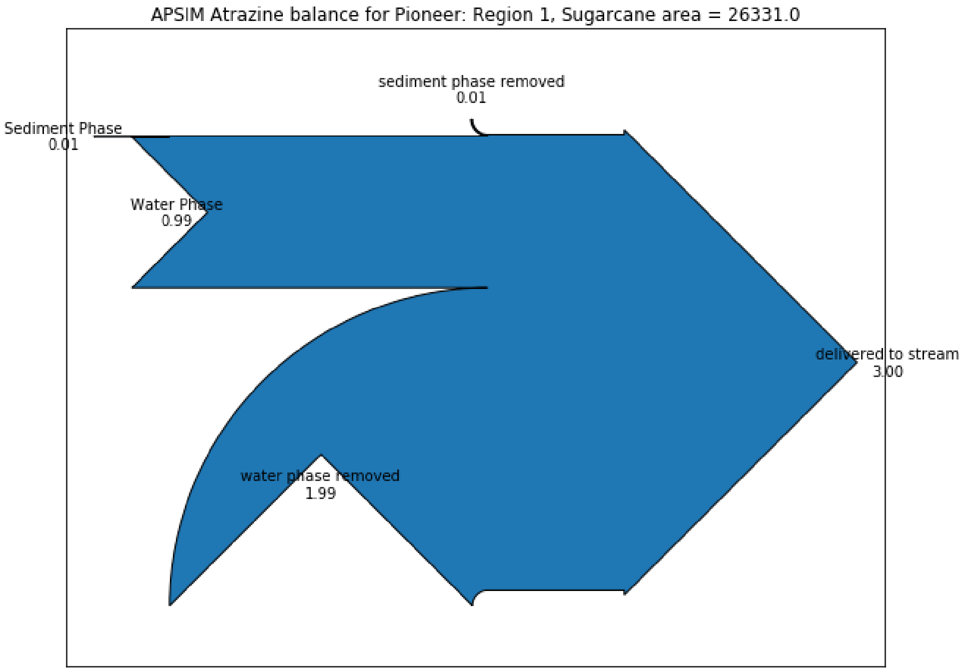
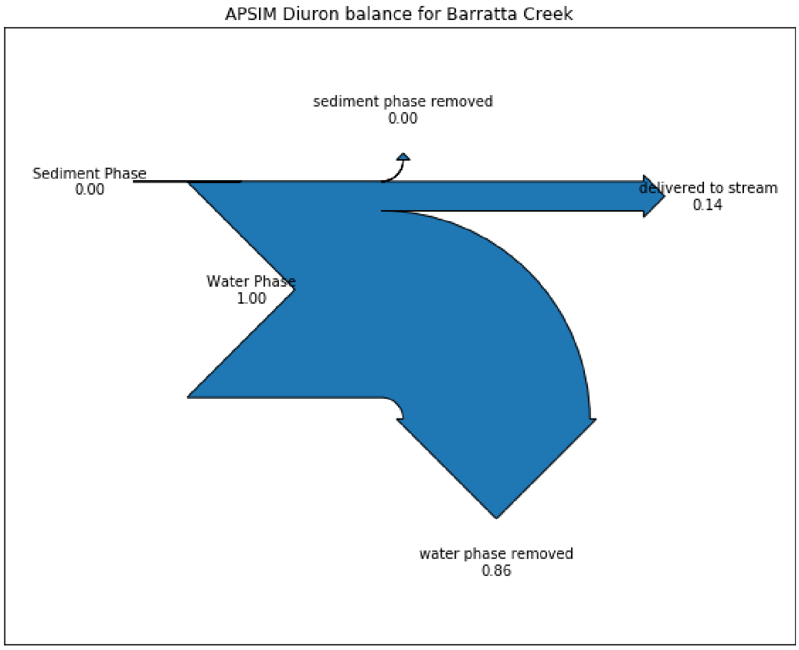


Figure 6-5. Atrazine mass balance components of Barratta (upper: irrigated cane) and Pioneer (lower: rain-fed) using APSIM-generated flows and applied plugin delivery ratios



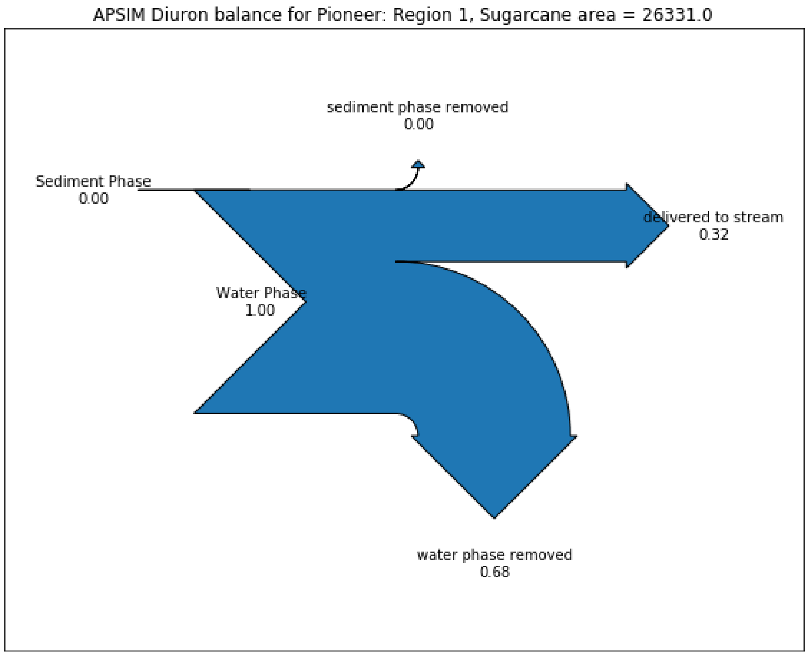


Figure 6-6. Diuron mass balance components of Barratta (upper: irrigated cane) and Pioneer (lower: rain-fed) using APSIM-generated flows and applied plugin delivery ratios

The removal of pesticides in the surface flow pathway presents a conceptual problem of how this can be justified from a process point of view, in a similar way to the removal of DIN in the surface pathway for Barratta Creek. The delivery ratio in this case is probably best interpreted as a means to adjust the amounts applied in the APSIM models, rather than to represent a process. In this case, it may be appropriate to utilise both the global and monthly delivery ratios to adjust both the overall load and approximate timing of pesticide constituents to better represent pesticide load concentrations and frequency. For example, atrazine in the Pioneer peaks in December and January, but is modelled to occur in June, July and January (*Figure 6-7*).

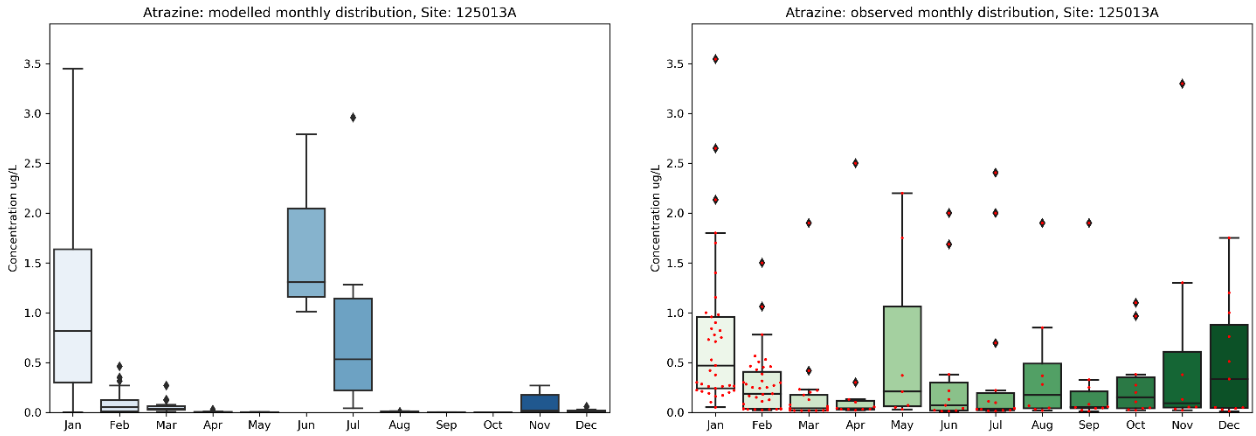


Figure 6-7.Measured and modelled monthly atrazine distribution in the Pioneer

6.3 General discussion

6.3.1 Surface water delivery mechanisms

At this stage of model development, all surface water is delivered to the stream and is allowed to pass through a linear storage to attenuate flows. It would appear, however, that this attenuation mechanism is not required. A similar mechanism is barely used in Sacramento to attenuate and delay flows. This indicates that the subcatchments in the models are of small enough size to respond in the space of a day, and that water delivered to the stream network can be routed in this component of the model rather than in the FU. In this perspective, constituent treatment measures between the paddock and stream network are most likely limited to those involving filtration.

At this stage of model development, it would appear from the range of delivery ratios obtained for the atrazine and Diuron across the three study catchments that the current modelled timing and quantity of application requires further investigation and possible adjustment. The current plugin and assessment tools can be used to scale monthly applications that fit the current hydrology and statistical observations. Checking to see if these adjusted application rates are plausible in paddock scale models may be the first step to refining the models further.

Ideally, the surface water phase delivery ratios should be 1, unless some mechanism is identified that targets water phase constituents on a daily time step, otherwise the surface water flows at the FU level may themselves be attenuated—something that is not present in the original models. It follows that, if there is some physical process that attenuates surface water flows (including the constituents), it may be conceivable that dissolved phase constituents are also attenuated *at similar rates or scales*. If this can be established, then appropriate mass balance or decay (half-life) parameters may be appropriately assigned in the surface water phase to account for physical diversion of flows or the time spent in the diversion. In some instances, in-stream routing and decay for constituents is already implemented in the models once water enters the main stream network.

Without attenuation in the surface flows between FU and stream network, the ideal setting for the surface constituent delivery ratio should also be 1, unless we presume that the mass delivered from APSIM-generated time series requires adjusting.

The importance of the surface delivery ratio is therefore to scale inputs rather than represent a physical process.

In the case of irrigated sugar cane, the current plugin treats irrigation runoff the same way it treats runoff resulting from rainfall. This results in higher frequency water deliveries to the stream compared to surrounding FUs (*Figure 6-8*). These 'return flows' are not scaled in any way; however, there may be a case to investigate attenuation and infiltration of the return flows prior to entering the main stream network (such as captured in pits and re-used). Such a concept may operate in a similar way to 'directly connected impervious areas' vs 'non-connected impervious areas' in urban runoff modelling. Impervious areas run off more frequently, but observing every peak at a gauge often requires a high proportion of connectedness via impervious channels.

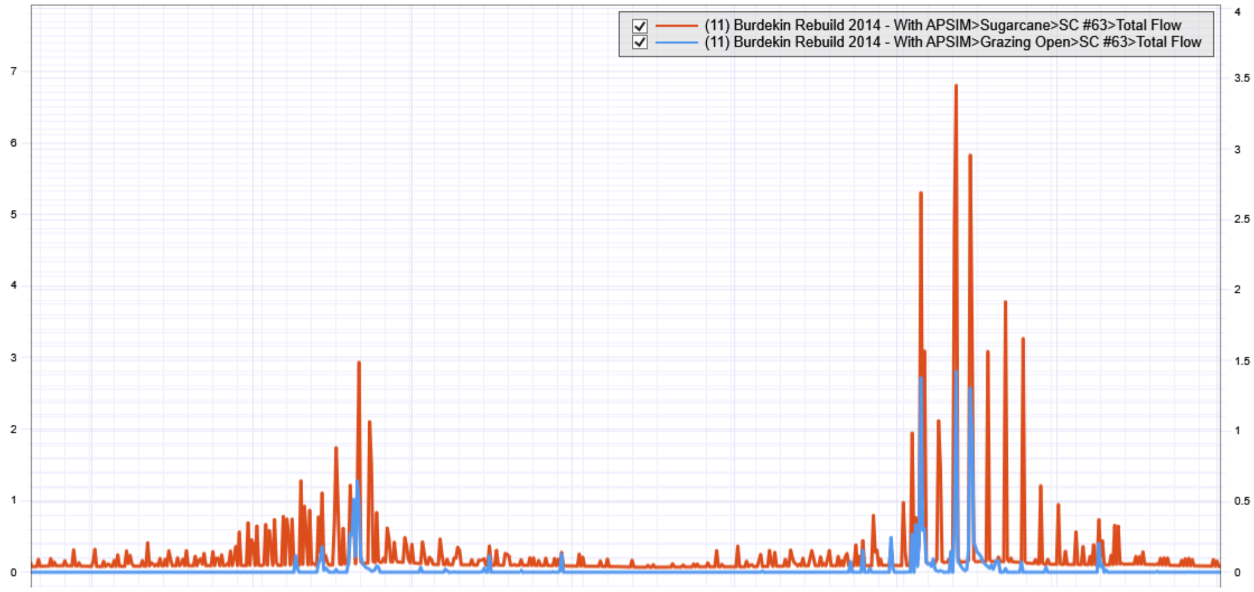


Figure 6-8. Modelled sugarcane runoff (red) and grazing runoff (blue) for the a subcatchment in Barratta Creek

Irrigation area connectedness may be a function of:

- distance to stream
- presence of a drainage network and/or collection pond/sump
- length of drainage collection network and size of drainage collection storages
- slope
- proportion of catchment under irrigation compared to other land uses
- presence and width of stream buffers
- groundwater elevation in relation to the stream.

The relative importance of each of these factors is difficult to quantify with just one study catchment and limited mapping. In terms of attenuation and infiltration of surface runoff:

- The length of drainage collection network and size of drainage collection storages combined with the overland path length and slope to the stream are likely to be influential factors in determining the potential for irrigation runoff potential.

- The rate at which irrigation runoff may then infiltrate to groundwater in the collection and drainage system may depend on antecedent soil moisture conditions, soil type and slope of connecting pathway.

Figure 6-9 and *Figure 6-10* show an example of the irrigation drain connections in Barratta Creek, upstream of the stream gauge and modelled and measured flows.

Figure 6-9. Irrigation area connectedness in Barratta Creek

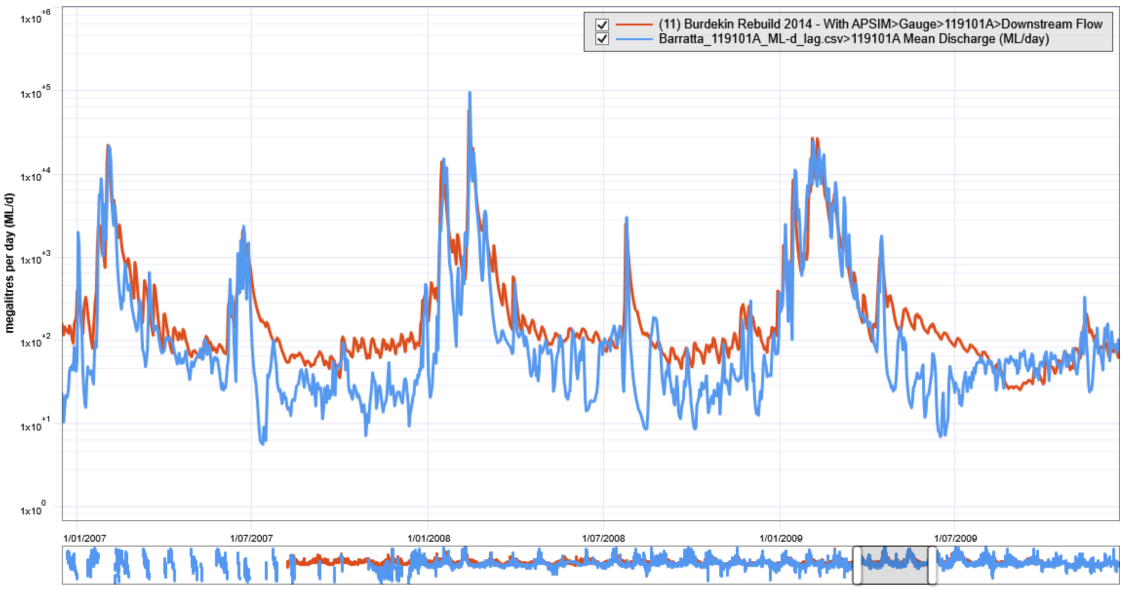


Figure 6-10. Barratta modelled and recorded irrigation runoff events (log scale)

Connections between the paddocks and the creek can be long or short, but often involve long drains between cane paddocks, potentially a storage below the paddock at the end of a collection drain followed by an overland flow path, before entering the main stream network. During rainfall-induced runoff events, this pathway is likely to be saturated or full, and facilitates the translation of paddock runoff with minimal losses. When dry, however, some or all of the irrigation runoff may be retained (e.g. captured or infiltrated to groundwater). Such a mechanism may reduce the frequency and scale of irrigation runoff, bringing it more into line with gauge records and offering a mechanism to filter, decay or attenuate surface runoff and constituents in irrigation areas. More catchments/gauges with irrigated cane areas should be investigated if this type of process is to be incorporated in the future.

6.3.2 Drainage water attenuation and delivery

The importance of the drainage delivery ratio is to remove some of the drainage water to deep drainage and achieve mass balance at the gauge. This parameter also reduces the amount of DIN available to the model in direct proportion to the removal of drainage water.

For non-irrigated areas representing significant catchment proportions investigated for this study, the proportion of drainage water delivered to the stream ranged between 0.7 and 1. Typically for these areas, the proportion of drainage is less than the surface runoff. This parameter is similar to the *SIDE* and *SSOUT* parameters in Sacramento, which have values of around 0.1 for some parts of the Tully, Pioneer and Barratta. Some consistency should be retained between the drainage delivery parameter and the *SIDE* and *SSOUT* parameters.

The importance of the attenuation of the remaining drainage store is to delay flows to mimic recession flows (baseflows) in the catchment. To ensure a similar recession to that already modelled in Sacramento, a similar recession parameter is recommended in the model application approach. This coincides with the *LZSK* and *LZPK* parameters.

Ideally, the drainage delivery ratio and drainage store delivery ratio may be linked with:

- soil type
- slope
- groundwater slope
- distance from paddock to stream.

However, as the Sacramento and sugarcane groundwater stores are not linked to a common groundwater store, inferring real parameters from physical catchment characteristics may be very difficult. The Sacramento model calibrations provide sufficient starting points for these parameters in non-irrigated cane areas.

6.3.3 Drainage constituent delivery ratio

Currently, only the DIN constituent is modelled in the drainage water. Delivery of DIN to the stream is undertaken via a delivery ratio. In rain-fed cane, the DIN mass balance indicates the drainage pathway as being dominant, therefore the DIN delivery ratio is key to delivering the majority of DIN load to the catchment outlet.

Bristow et al. (1998) summarise the nitrogen cycle and potential nitrogen balance elements for sugarcane cropping systems. From the leached pool of N, denitrification appears to be a significant removal pathway, potentially accounting for somewhere between 40% and 80% of estimated leached nitrogen in one study (*Figure 6-11*). This range happens to coincide with the range of delivery ratio from Barratta, Pioneer and Tully model applications.

Table 19 Nitrogen (N) balance (kg N ha^{-1}) for sugarcane (1992–1995) (taken from Prove et al. 1997).

Source	Plant crop 1992–93		1st Ratoon crop 1993–94		2nd Ratoon crop 1994–95	
	Flat profile, cultivated	Mounded profile, min tillage	Flat profile, surface urea	Mounded profile, split-row urea	Flat profile, surface urea	Mounded profile, surface nitram
Input (+)						
Fertiliser	+170	+170	+160	+160	+160	+107
Rainfall[A]	+6	+6	+10	+10	+7	+7
Recycled > 60 cm[B]	+8	+8	+3	+1	+1	+7
Sinks (±)						
Δ Profile mineral N[C]	−1 ± 3	−2 ± 2	+5 ± 2	+1 ± 4	−3 ± 1	+7 ± 3
Δ Easily mineralised N[C]	+54 ± 12	+52 ± 6	+19 ± 7	+20 ± 7	+20 ± 9	−2 ± 8
Δ Harvest Residues[D]	−115 ± 18	−91 ± 9	+7 ± 5	+11 ± 8	+17 ± 5	−5 ± 17
Loss (−)						
N leached > 60 cm[E]	−54 ± 25	−56 ± 7	−18 ± 8	−30 ± 14	−7 ± 3	−46 ± 9
Run-off	< −1	−3	−2	−6	−4	−6
Bedload	0	−1	0	0	0	0
Output (−)						
Millable cane	−79 ± 14	−96 ± 10	−63 ± 6	−73 ± 6	−53 ± 4	−75 ± 8
Estimated gaseous losses	0	0	−120	−39	−128	0
Voltatilisation[G]	nm	nm	−60	−9	nm	nm
Denitrification[H]	nm	nm	−7	−24	nm	nm
Unaccounted loss[I] **(−) or input (+)**	+11	+21	−54	−6	−128	+6

[A] Estimated from rainfall and N concentration of 0.252 mg N L^{-1}, as measured for the plant crop.
[B] It was assumed that 15% of leached N was recycled by roots at depths greater than 60 cm.
[C] Delta profile values at harvest for 0–60 cm, on the basis of 1:3 (row:inter-row) with the exception of the first ratoon split-row treatment which was based on 1:4. Bulk density of 1g cm^{-3} assumed.
[D] Delta values after harvest for tops, trash and cane left on the surface and stool with roots below ground.
[E] Spatial representation of row:inter-row samples as for (c) above except for the second ratoon mounded, nitram treatment for which 1:1 was used.
[F] Includes both particulate and dissolved total N.
[G] Determined using a micro-meteorological technique.
[H] Estimated by ^{15}N balance for 11-month period.
[I] Obtained by difference. This term includes 10 kg N ha^{-1} lost by the crop during the 5.5 to 11 month period as determined by the ^{15}N mass balance.
nm = not measured.

Figure 6-11. Nitrogen balance for sugarcane cropping systems (extracted from Bristow et al. 1998)

Factors that influence the conditions for denitrification include temperatures above 10 degrees, anaerobic conditions and organic matter, and may be infrequent solitary events (Bristow et al. 1998). Shallow groundwater tables and riparian zones with organic material may therefore influence the potential for denitrification to influence the choice of DIN delivery ratio.

The conditions for denitrification are therefore likely to be the most important for influencing the selection of the drainage DIN delivery ratio.

7 CONCLUSIONS AND RECOMMENDATIONS

The linkage between daily time step paddock scale models (APSIM) and large-scale Source models is currently being undertaken by redistributing monthly loads generated from APSIM across the Sacramento-generated hydrology of the Source model. This approach retains the hydrology of the Source model and loads generated by paddock scale models, but can result in distortions in modelled paddock scale constituent concentrations. This is because paddock scale processes such as irrigation can impact on how much and how often runoff and constituent loads are produced from sugar cane compared to other land uses. Redistributing these loads across a different hydrological response can lead to unrealistic water quality concentrations.

The objective of this project was to investigate alternative methods of paddock and catchment scale model integration that maintain model hydrology and load calibrations while improving the model representation of constituent concentrations.

A trial and error approach was adopted to test alternative methods of integration, which were implemented as plugins to Source. A review of models and methods (Appendix B) to integrate paddock scale models to the catchment scale revealed a number of suitable approaches. The review revealed common elements whereby some representation of surface flow routing and baseflow (groundwater store) routing is generally required to translate 1-D APSIM-generated flows to catchment flows. This approach was also consistent with the Sacramento models currently implemented in Source. No review was undertaken on common modelling approaches for the translation of pesticide and DIN loads to catchment outlets. A mass balance and delivery ratio approach was adopted similar to the current approach. The new approach was implemented in a Source plugin.

Evaluation of the plugin shows that direct import of the APSIM flows and constituent loads have a small but manageable impact on overall hydrologic performance. Constituent loads (DIN, atrazine and Diuron) can also be suitably adjusted to agree with measured catchment loads while maintaining reasonable constituent concentration profiles. To assist model users to trial the plugin, a suite of tools have been developed in a Python notebook to estimate plugin parameters and produce outputs for visual assessment.

In rain-fed sugar cane, the key modelled DIN pathways are removal of DIN in the drainage water, possibly as a result of denitrification. Understanding this process is most important in this case.

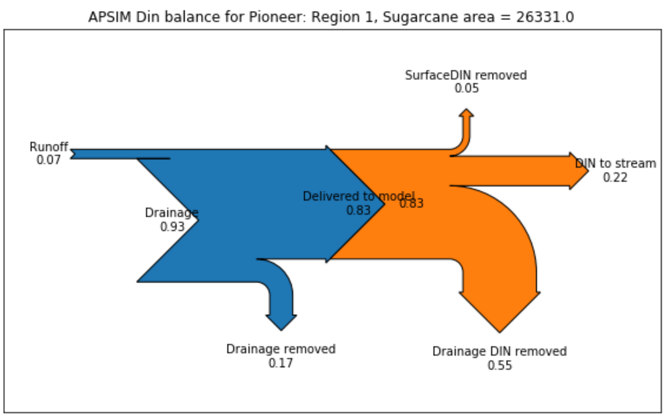


Figure 7-1. The drainage removal pathway is the largest sink for DIN in rain-fed cane areas

In irrigated sugar cane, the surface flow pathway appears to be the significant contributor of DIN; however, further model refinements have been identified to account for the disconnection of sugarcane areas with the stream drainage network, accounting for the position of the paddock in the landscape and potentially attenuating this pathway.

For atrazine and Diuron, the water phase surface flow pathway is dominant. The connectedness of the paddock to the stream will also impact on these constituents; however, adjustments to the delivery ratio are likely to reflect scaling of application of these constituents rather than any treatment process. It follows that if paddock scale loads are adjusted for timing and quantity in the paddock model, the delivery ratio for constituents across surface flows should be the approximately same and close to 1.

7.1 Recommendations

7.1.1 Model structure updates, testing and application

1. The plugin should be tested across more parameters and across more catchments, particularly irrigated sugarcane areas.

2. The plugin should be enhanced and modified to explore the concept of run-on before runoff to curtail the frequency of DIN and flow delivery to the stream in irrigated cane areas. The connectedness of surface flows from irrigated sugar cane should be accounted for in the model and tested across more irrigated cane areas. The addition should account for drainage channel storage and losses prior to entering the stream network and include constituent accounting. Test the plugin across more irrigated cane areas.

3. The models investigated for this project should be updated and extended to allow more water quality data to be compared. This extension should cover 2014–2018, representing a period for standard model validation approaches to applied plugin parameters.

4. The project should explore the key conditions for the denitrification pathway and consider parameters for the estimation of the drainage delivery ratio for DIN that may be applicable in the model.

5. The project should consider undertaking more detailed model application guidance by summarising a decision tree for parameter selection and providing guidance on what to adjust/check to achieve better fit to loads, flows, recession flows or concentrations.

6. The project should undertake further investigation using GIS and survey data for selected areas to investigate the plausibility of selected drainage parameters under irrigated cane areas. The empirical equations derived by Rassam and Littleboy (2003) presented in Appendix B relating these key elements may help in determining the validity of these drainage parameters. Ultimately, the plugin is there to provide a linkage of hydrology first and foremost, so some of the representation of seasonality and flow attenuation and groundwater accumulation may be better outside of the plugin, or in a different plugin or regional groundwater model

7.1.2 Notebook and general data analysis

1. The project should provide additional Python notebook training for modellers to implement the range of tools developed for this project.

2. The project should review the consistency in model structure, naming conventions and model simulation periods which are important for automated tools. The project should audit models to ensure gauges are identified within the model structure and included in the right locations with the right names etc. The project should also consider extending the models to cover more recent periods (last 4 years).

3. The project should consider the development of an application programming interface (API) for the water information portal to automate retrieval of up to date streamflow data and speed up model evaluation and testing.

7.1.3 Water quality modelling and data analysis

1. DES should review load calculation methods and uncertainties—these greatly influence mean annual concentrations, which are used to adjust model delivery ratios. Some uncertainty bounds around these estimates would be useful to guide parameter selection and consistency across models.

2. DES should review and lower the recommended background concentrations applied in the models (EMCs and DWCs). The modelled range of DIN tends to not fall below 0.1 mg/L in the models, but occurs regularly in the observations.

3. DES should review appropriateness of the use of water quality constituents in the data analysis—some water quality parameters have between two and four separate entries in the water quality database, denoting different analysis, collection methods or possibly detection limits. In this project, all data are treated as equal in value and weight; however, a review may be appropriate and guidance delivered to modellers on the appropriateness of the data for use in statistical model matching.

4. The project should review and compare the monthly modelled and monthly sampled data showing discrepancies in when the constituents may have been applied in APSIM compared to when they have been applied in reality. This data should be summarised and delivered to APSIM modellers in the form of monthly delivery ratio adjustments to achieve model fit to determine if the required application rates to achieve model fit are plausible.

5. The project should investigate, review and recommend statistical methods to describe model fit and performance for water quality modelling, particularly the multiple objectives of annual loads, annual concentrations and individual sample matching/distributions.

6. The project should investigate and review the likelihood and occurrence of pesticide constituents entering the groundwater and being released back to the stream as background concentrations, in addition to plausible pesticide delivery ratios in surface flows. The project should investigate model methods and approaches to allow this to happen and achieve a more even distribution of pesticides throughout the year and contribution to stream.

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Appendices

9 APPENDIX A: PLUGIN CODE

9.1 Hydrology

```
using Dynamic_SedNet.Models.Rainfall;
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using TIME.Core;
using TIME.Core.Metadata;
using TIME.Models;

namespace ObservedPaddockHydrologyModel
{
    [Serializable, Aka("Observed Paddock Hydrology Model With Storage")]
    public class PaddockModelStorage : RainfallRunoffModel,
IDynSedNet_RRModel_AlternativeProc_Interface
    {
        public PaddockModelStorage()
        {

        }

        //Need to have rainfall and pet objects so that the automated tools designed to
populate DynSedNet_RRModelShell
        //detect this model
        //Rainfall taken care of already by RainfallRunoffModel

        [Input, Aka("PET"), CalculationUnits(CommonUnits.millimetres)]
        public double Pet { get; set; }

        [Input, Aka("Irrigation"), CalculationUnits(CommonUnits.millimetres)]
        public double Irrigation { get; set; }

        /// <summary>
        /// The maximum available surface runoff depth from paddock model, in mm.
        /// </summary>
        [Input, Minimum(0), CalculationUnits(CommonUnits.millimetres), Aka("Max available
surface runoff")]
        public double maxAvailableSurfaceRunoff { get; set; }


        /// <summary>
        /// The maximum available drainage from paddock model, in mm.
        /// </summary>
        [Input, Minimum(0), CalculationUnits(CommonUnits.millimetres), Aka("Max available
drainage")]
        public double maxAvailableDrainage { get; set; }

        [Parameter, Aka("Proportion of available surface runoff delivered to Source")]
        public double surfaceRunoffDeliveryRatio
        {
            get { return _surfaceRunoffDeliveryRatio; }
            set { _surfaceRunoffDeliveryRatio = value; }
        }

        private double _surfaceRunoffDeliveryRatio;
```

```
        [Parameter, Aka("Proportion of available drainage runoff delivered to Source")]
        public double drainageDeliveryRatio
        {
            get { return _drainageDeliveryRatio; }
            set { _drainageDeliveryRatio = value; }
        }

        private double _drainageDeliveryRatio;

 //add a parameter for the proportion of available drainage delivered to Source that is goes
to deep drainage and
 //is not seen at the gauge

 [Parameter, Aka("Proportion of available drainage runoff that goes to deep drainage
(ungauged)")]
 public double DeepDrainageDeliveryRatio
 {
 get { return _DeepDrainageDeliveryRatio; }
 set { _DeepDrainageDeliveryRatio = value; }
 }

 private double _DeepDrainageDeliveryRatio;



 [State, Aka("Rainfall Contributed Surface Runoff Depth"),
CalculationUnits(CommonUnits.millimetres)]
        public double rainContributedRunoff
        {
            get;
            set;
        }


        [State, Aka("Irrigation Contributed Surface Runoff Depth"),
CalculationUnits(CommonUnits.millimetres)]
        public double irrigationContributedRunoff
        {
            get;
            set;
        }


        [State, Aka("Actual surface runoff depth"),
CalculationUnits(CommonUnits.millimetres)]
        public double actualSurfaceRunoffDepth
        {
            get;
            set;
        }


        [State, Aka("Actual drainage runoff depth"),
CalculationUnits(CommonUnits.millimetres)]
        public double actualDrainageRunoffDepth
        {
            get;
            set;
        }

        [State, Aka("Cumulative Rainfall Contributed Runoff Volume"),
CalculationUnits(CommonUnits.cubicMetres)]
        public double cumulativeRainfallRunoffVol
```

```
        {
            get;
            set;
        }
        public const string rainContributedRunoffVarName = "cumulativeRainfallRunoffVol";

        [State, Aka("Cumulative Irrigation Contributed Runoff Volume"),
CalculationUnits(CommonUnits.cubicMetres)]
        public double cumulativeIrrigationRunoffVol
        {
            get;
            set;
        }
        public const string irrigationContributedRunoffVarName =
"cumulativeIrrigationRunoffVol";

        //add 6 more variables for the storage routed flow time series.
        //2 for the surface and drainage store volumes
        //2 more for the surface and drainage store volumes discharges
        //2 for the surface and drainage store volumes at the end of the time step

        [State, Aka("Drainage Storage"), CalculationUnits(CommonUnits.millimetres)]
        public double DrainageStorage
        {
            get;
            set;
        }

        [State, Aka("Surface Storage"), CalculationUnits(CommonUnits.millimetres)]
        public double SurfaceStorage
        {
            get;
            set;
        }

        [State, Aka("Drainage Storage To Stream"), CalculationUnits(CommonUnits.millimetres)]
        public double DrainageDischargeToStream
        {
            get;
            set;
        }

 [State, Aka("Gauged Drainage Runoff Depth"), CalculationUnits(CommonUnits.millimetres)]
 public double gaugedDrainageRunoffDepth
 {
 get;
 set;
 }


 [State, Aka("Surface Storage To Stream"), CalculationUnits(CommonUnits.millimetres)]
        public double SurfaceDischargeToStream
        {
            get;
            set;
        }

        [State, Aka("Drainage Storage Previous TimeStep"),
CalculationUnits(CommonUnits.millimetres)]
        public double DrainageStoragePrevious
        {
            get;
            set;
        }
```

```
        [State, Aka("Surface Storage Previous TimeStep"),
CalculationUnits(CommonUnits.millimetres)]
        public double SurfaceStoragePrevious
        {
            get;
            set;
        }


        //add some more parameters for the storage routing
        //add a surface store emptying proportion - the proportion of the surface store thet
empties in a time step

        [Parameter, Aka("Proportion of available surface store delivered to the stream as
quick flow")]
        public double surfaceStoreDeliveryRatio
        {
            get { return _surfaceStoreDeliveryRatio; }
            set { _surfaceStoreDeliveryRatio = value; }
        }

        private double _surfaceStoreDeliveryRatio;

 //add a drainage store emptying proportion - the proportion of the groundwater store thet
empties in a time step

 [Parameter, Aka("Proportion of available drainage store delivered to the stream as slow
flow")]
        public double drainageStoreDeliveryRatio
        {
            get { return _drainageStoreDeliveryRatio; }
            set { _drainageStoreDeliveryRatio = value; }
        }

        private double _drainageStoreDeliveryRatio;






        //This from the interface
        public Dictionary<string, string> alternativeOtherProcessMap
        {
            get { return new Dictionary<string, string>() { { "Cumulative Rainfall Contributed
Runoff", rainContributedRunoffVarName }, { "Cumulative Irrigation Contributed Runoff",
irrigationContributedRunoffVarName } }; }
        }


        public override void runTimeStep()
        {
            //StandardFunctionalUnit subtracts baseflow from runoff to get quickflow, so we
combine them
            //as per:
            ////var conversionFactor = ConversionFactorCache.Get(theTimeStepInSeconds,
RAINFALL_RUNOFF_OUTPUT_UNIT, DEFAULT_OUTPUT_UNITS) * _areaInSquareMeters;
            ////_quickFlow = (_rrmodel.runoff - _rrmodel.baseflow) * conversionFactor;
            ////_slowFlow = _rrmodel.baseflow * conversionFactor;

            //Deal with surface runoff first

            actualSurfaceRunoffDepth = maxAvailableSurfaceRunoff * surfaceRunoffDeliveryRatio;

            SurfaceStorage = SurfaceStoragePrevious + actualSurfaceRunoffDepth;
```

```
            SurfaceDischargeToStream = surfaceStoreDeliveryRatio * SurfaceStorage;
            SurfaceStoragePrevious = SurfaceStorage - SurfaceDischargeToStream;

            //now deal with drainage Runoff

            actualDrainageRunoffDepth = maxAvailableDrainage * drainageDeliveryRatio;

 //partition actual drainage runoff depth between deep drainage not seen at the gauge and
discharge to stream from groundwater

 gaugedDrainageRunoffDepth = actualDrainageRunoffDepth * DeepDrainageDeliveryRatio;

 //now delay the groundwater response using a linear store

 DrainageStorage = DrainageStoragePrevious + gaugedDrainageRunoffDepth;
            DrainageDischargeToStream = drainageStoreDeliveryRatio * DrainageStorage;
            DrainageStoragePrevious = DrainageStorage - DrainageDischargeToStream;

            //now calculate the outflow terms from the FU to the river network

            runoff = SurfaceDischargeToStream + DrainageDischargeToStream;
            baseflow = DrainageDischargeToStream;

            //some other side calculations

            double rainToTotalInputRatio = 0;
            if (rainfall + Irrigation > 0)
            {
                rainToTotalInputRatio = rainfall / (rainfall + Irrigation);
            }

            //Totals for alternative reporting
            //Of course, if FU area is zero, these mm totals might be a bit misleading

            rainContributedRunoff = actualSurfaceRunoffDepth * rainToTotalInputRatio;
            irrigationContributedRunoff = actualSurfaceRunoffDepth - rainContributedRunoff;

            cumulativeRainfallRunoffVol += (rainContributedRunoff / 1000) *
this.FunctionalUnitArea;
            cumulativeIrrigationRunoffVol += (irrigationContributedRunoff / 1000) *
this.FunctionalUnitArea;

        }

        //need to reset the drainage and surface stores to zero

        public override void reset()
        {
            cumulativeIrrigationRunoffVol = 0;
            cumulativeRainfallRunoffVol = 0;
            SurfaceStoragePrevious = 0.0;
            DrainageStoragePrevious = 0.0;
        }

        // other redundant stuff??

        public override void initStoresFull()
        {

        }

        [Output, Aka("Mass Balance"), CalculationUnits(CommonUnits.cubicMetres)]
        public override double MassBalance
        {
            get { return 0; }
```

```
      }

   }
}
```

9.2 DIN

```
using RiverSystem;
using RiverSystem.Catchments.Models.ContaminantGenerationModels;
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using TIME.Core;
using TIME.Core.Metadata;

namespace ObservedPaddockHydrologyModel
{
 [Serializable, Aka("APSIM Daily WQ time series importer with storage for DIN")]
 public class PaddockWQStorageDIN : StandardConstituentGenerationModel
 {

 public PaddockWQStorageDIN()
 {

 }

 //parameters for the monthly surface delivery ratios of constituents - for calibration
purposes to feed back to APSIM adjustment

 [Parameter, Aka("Surface Delivery ratio - January")]
 public double SDRJan
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Delivery ratio - February")]
 public double SDRFeb
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Delivery ratio - March")]
 public double SDRMar
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Delivery ratio - April")]
 public double SDRApr
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Delivery ratio - May")]
 public double SDRMay
 {
 get;
 set;
 }
```

```
[Parameter, Aka("Surface Delivery ratio - June")]
public double SDRJun
{
get;
set;
}

[Parameter, Aka("Surface Delivery ratio - July")]
public double SDRJul
{
get;
set;
}

[Parameter, Aka("Surface Delivery ratio - August")]
public double SDRAug
{
get;
set;
}

[Parameter, Aka("Surface Delivery ratio - September")]
public double SDRSep
{
get;
set;
}

[Parameter, Aka("Surface Delivery Ratio - October")]
public double SDROct
{
get;
set;
}

[Parameter, Aka("Surface Delivery Ratio - November")]
public double SDRNov
{
get;
set;
}

[Parameter, Aka("Surface Delivery ratio - December")]
public double SDRDec
{
get;
set;
}

//parameters for the monthly drainage delivery rations of constituents - for calibration
purposes to feed back to APSIM adjustment

[Parameter, Aka("Drainage Delivery ratio - January")]
public double DDRJan
{
get;
set;
}

[Parameter, Aka("Drainage Delivery ratio - February")]
public double DDRFeb
{
get;
set;
```

```
}

[Parameter, Aka("Drainage Delivery ratio - March")]
public double DDRMar
{
get;
set;
}

[Parameter, Aka("Drainage Delivery ratio - April")]
public double DDRApr
{
get;
set;
}

[Parameter, Aka("Drainage Delivery ratio - May")]
public double DDRMay
{
get;
set;
}

[Parameter, Aka("Drainage Delivery ratio - June")]
public double DDRJun
{
get;
set;
}

[Parameter, Aka("Drainage Delivery ratio - July")]
public double DDRJul
{
get;
set;
}

[Parameter, Aka("Drainage Delivery ratio - August")]
public double DDRAug
{
get;
set;
}

[Parameter, Aka("Drainage Delivery ratio - September")]
public double DDRSep
{
get;
set;
}

[Parameter, Aka("Drainage Delivery Ratio - October")]
public double DDROct
{
get;
set;
}

[Parameter, Aka("Drainage Delivery Ratio - November")]
public double DDRNov
{
get;
set;
}
```

```
 [Parameter, Aka("Drainage Delivery ratio - December")]
 public double DDRDec
 {
 get;
 set;
 }

 // now get the surface and drainage time series in from APSIM. APSIM units are kg/ha for
all constituents
 // care needs to be taken for the units of pesticides


 // The maximum available constituent from paddock model, in kg/ha

 [Input, Minimum(0), Aka("Max available surface runoff constituent")]
 public double maxAvailableSurfaceconstituent { get; set; }

 [Parameter, Aka("Available surface runoff constituent")]
 public double AvailableSurfaceConstituent { get; set; }


 // The maximum available drainage from paddock model, in kg/ha (this unit is not available,
so no CalculationUnits(CommonUnits.))

 [Input, Minimum(0), CalculationUnits(CommonUnits.millimetres), Aka("Max available drainage
constituent")]
 public double maxAvailableDrainageconstituent { get; set; }

 [Parameter, Aka("Available Drainage runoff constituent")]
 public double AvailableDrainageConstituent { get; set; }


 // create some variables for the monthly delivery ratios

 [State, Aka("Applied Surface Dleivery Ratio")]
 public double _appliedSDR;

 [State, Aka("Applied Drainage Delivery Ratio")]
 public double _appliedDDR;

 //add a parameter for the proportion of available drainage delivered to Source that goes to
deep drainage and
 //is not seen at the gauge - a water that is lost assumes the constituent goes with it

 [Parameter, Aka("Proportion of available drainage constituent that goes to deep drainage
(ungauged)")]
 public double DeepDrainageConstituentDeliveryRatio
 {
 get { return _DeepDrainageConstituentDeliveryRatio; }
 set { _DeepDrainageConstituentDeliveryRatio = value; }
 }

 private double _DeepDrainageConstituentDeliveryRatio;

 //add 7 more variables for the storage routed constituent time series.
 //2 for the surface and drainage /constituent stores
 //2 more for the surface and drainage store constituent releases
 //2 for the surface and drainage constituent stores at the end of the time step
 //1 for the drainage store constituent loss to groundwater same as per hydrology

 [State, Aka("Drainage WQ Storage"), CalculationUnits(CommonUnits.millimetres)]
 public double DrainageWQStorage
 {
 get;
 set;
```

```
}

[State, Aka("Surface WQ Storage"), CalculationUnits(CommonUnits.millimetres)]
public double SurfaceWQStorage
{
get;
set;
}

[State, Aka("Drainage WQ Storage To Stream"), CalculationUnits(CommonUnits.millimetres)]
public double DrainageWQDischargeToStream
{
get;
set;
}

[State, Aka("Gauged Drainage Runoff Depth"), CalculationUnits(CommonUnits.millimetres)]
public double gaugedDrainageWQ
{
get;
set;
}


[State, Aka("Surface Storage To Stream"), CalculationUnits(CommonUnits.millimetres)]
public double SurfaceWQDischargeToStream
{
get;
set;
}

[State, Aka("Drainage Storage Previous TimeStep"),
CalculationUnits(CommonUnits.millimetres)]
public double DrainageWQStoragePrevious
{
get;
set;
}

[State, Aka("Surface Storage Previous TimeStep"),
CalculationUnits(CommonUnits.millimetres)]
public double SurfaceWQStoragePrevious
{
get;
set;
}


//add 2 more parameters for the storage routing
//add a surface store emptying proportion - the proportion of the surface store thet
empties in a time step

[Parameter, Aka("Proportion of available surface store delivered to the stream as quick
flow WQ")]
public double surfaceWQStoreDeliveryRatio
{
get { return _surfaceWQStoreDeliveryRatio; }
set { _surfaceWQStoreDeliveryRatio = value; }
}

private double _surfaceWQStoreDeliveryRatio;

//add a drainage store emptying proportion - the proportion of the groundwater store thet
empties in a time step
```

```
[Parameter, Aka("Proportion of available drainage store delivered to the stream as slow
flow WQ")]
public double drainageWQStoreDeliveryRatio
{
get { return _drainageWQStoreDeliveryRatio; }
set { _drainageWQStoreDeliveryRatio = value; }
}

private double _drainageWQStoreDeliveryRatio;



private const double MG_PER_LITER_TO_KG_PER_M3 = UnitConversion.MG_PER_LITRE_TO_KG_PER_M3;

public override void runTimeStep(DateTime now, double theTimeStepInSeconds)
{

int theMonth = now.Month;

_appliedSDR = 1;
_appliedDDR = 1;

switch (theMonth)
{
case 1:
_appliedSDR = SDRJan;
_appliedDDR = DDRJan;
break;
case 2:
_appliedSDR = SDRFeb;
_appliedDDR = DDRFeb;
break;
case 3:
_appliedSDR = SDRMar;
_appliedDDR = DDRMar;
break;
case 4:
_appliedSDR = SDRApr;
_appliedDDR = DDRApr;
break;
case 5:
_appliedSDR = SDRMay;
_appliedDDR = DDRMay;
break;
case 6:
_appliedSDR = SDRJun;
_appliedDDR = DDRJun;
break;
case 7:
_appliedSDR = SDRJul;
_appliedDDR = DDRJul;
break;
case 8:
_appliedSDR = SDRAug;
_appliedDDR = DDRAug;
break;
case 9:
_appliedSDR = SDRSep;
_appliedDDR = DDRSep;
break;
case 10:
_appliedSDR = SDROct;
_appliedDDR = DDROct;
break;
```

```
 case 11:
 _appliedSDR = SDRNov;
 _appliedDDR = DDRNov;
 break;
 case 12:
 _appliedSDR = SDRDec;
 _appliedDDR = DDRDec;
 break;

 }

 //Deal with surface WQ first. get the max available constituent, apply the monthly delivery
ratio and convert to kg/ha/d to kg/s

 AvailableSurfaceConstituent = maxAvailableSurfaceconstituent * _appliedSDR *
this.areaInSquareMeters /10000/86400 ;

 SurfaceWQStorage = SurfaceWQStoragePrevious + AvailableSurfaceConstituent;
 SurfaceWQDischargeToStream = surfaceWQStoreDeliveryRatio * SurfaceWQStorage;
 SurfaceWQStoragePrevious = SurfaceWQStorage - SurfaceWQDischargeToStream;

 //now deal with drainage Runoff

 AvailableDrainageConstituent = maxAvailableDrainageconstituent * _appliedDDR *
this.areaInSquareMeters / 10000/86400;

 //partition actual drainage runoff depth between deep drainage not seen at the gauge and
discharge to stream from groundwater

 gaugedDrainageWQ = AvailableDrainageConstituent * DeepDrainageConstituentDeliveryRatio ;

 //now delay the groundwater response using a linear store

 DrainageWQStorage = DrainageWQStoragePrevious + gaugedDrainageWQ;
 DrainageWQDischargeToStream = drainageWQStoreDeliveryRatio * DrainageWQStorage;
 DrainageWQStoragePrevious = DrainageWQStorage - DrainageWQDischargeToStream;

 //now calculate the outflow constituents

 quickflowConstituent = SurfaceWQDischargeToStream;
 slowflowConstituent = DrainageWQDischargeToStream;

 // double _eventMeanConcentrationSI = MG_PER_LITER_TO_KG_PER_M3 * _appliedEMC;
 // double _dryMeanConcentrationSI = MG_PER_LITER_TO_KG_PER_M3 * _appliedDWC;


 // the concentration can be applied to a volume or a flux indifferently, here:
 // kg/s = [kg/m^3]*[m^3/s]
 // quickflowConstituent = _eventMeanConcentrationSI * quickflow;
 // slowflowConstituent = _dryMeanConcentrationSI * slowflow;
 }


 }
}
```

9.3 Pesticides

```
using RiverSystem;
using RiverSystem.Catchments.Models.ContaminantGenerationModels;
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
```

```
using TIME.Core;
using TIME.Core.Metadata;

namespace ObservedPaddockHydrologyModel
{
 [Serializable, Aka("APSIM Daily WQ time series importer with storage for Pesticides")]
 public class PaddockWQStorageP : StandardConstituentGenerationModel
 {

 public PaddockWQStorageP()
 {

 }

 //parameters for the monthly Surface Water Delivery Ratios of constituents - for
calibration purposes to feed back to APSIM adjustment

 [Parameter, Aka("Surface Water Delivery Ratio - January")]
 public double SDRJan
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Water Delivery Ratio - February")]
 public double SDRFeb
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Water Delivery Ratio - March")]
 public double SDRMar
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Water Delivery Ratio - April")]
 public double SDRApr
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Water Delivery Ratio - May")]
 public double SDRMay
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Water Delivery Ratio - June")]
 public double SDRJun
 {
 get;
 set;
 }

 [Parameter, Aka("Surface Water Delivery Ratio - July")]
 public double SDRJul
 {
 get;
 set;
 }
```

```
[Parameter, Aka("Surface Water Delivery Ratio - August")]
public double SDRAug
{
get;
set;
}

[Parameter, Aka("Surface Water Delivery Ratio - September")]
public double SDRSep
{
get;
set;
}

[Parameter, Aka("Surface Water Delivery Ratio - October")]
public double SDROct
{
get;
set;
}

[Parameter, Aka("Surface Water Delivery Ratio - November")]
public double SDRNov
{
get;
set;
}

[Parameter, Aka("Surface Water Delivery Ratio - December")]
public double SDRDec
{
get;
set;
}

//parameters for the monthly Sediment Phase Delivery Rations of constituents - for
calibration purposes to feed back to APSIM adjustment

[Parameter, Aka("Sediment Phase Delivery Ratio - January")]
public double DDRJan
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - February")]
public double DDRFeb
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - March")]
public double DDRMar
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - April")]
public double DDRApr
{
get;
set;
```

```
}

[Parameter, Aka("Sediment Phase Delivery Ratio - May")]
public double DDRMay
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - June")]
public double DDRJun
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - July")]
public double DDRJul
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - August")]
public double DDRAug
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - September")]
public double DDRSep
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - October")]
public double DDROct
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - November")]
public double DDRNov
{
get;
set;
}

[Parameter, Aka("Sediment Phase Delivery Ratio - December")]
public double DDRDec
{
get;
set;
}

// now get the surface and drainage time series in from APSIM. APSIM units are kg/ha for
all constituents
// care needs to be taken for the units of pesticides


// The maximum available constituent from paddock model, in kg/ha
```

```
[Input, Minimum(0), Aka("Max available water phase runoff constituent")]
public double maxAvailableSurfaceconstituent { get; set; }

[Parameter, Aka("Available surface water phase runoff constituent")]
public double AvailableSurfaceConstituent { get; set; }


// The maximum available drainage from paddock model, in kg/ha (this unit is not available,
so no CalculationUnits(CommonUnits.))

[Input, Minimum(0), CalculationUnits(CommonUnits.millimetres), Aka("Max available sediment
phase constituent")]
public double maxAvailableDrainageconstituent { get; set; }

[Parameter, Aka("Available sediment phase runoff constituent")]
public double AvailableDrainageConstituent { get; set; }


// create some variables for the monthly delivery ratios

[State, Aka("Applied Surface Water Phase Delivery Ratio")]
public double _appliedSDR;

[State, Aka("Applied Sediment Phase Delivery Ratio")]
public double _appliedDDR;

//add a parameter for the proportion of available drainage delivered to Source that goes to
deep drainage and
//is not seen at the gauge - a water that is lost assumes the constituent goes with it

[Parameter, Aka("Proportion of available constituent that goes to deep drainage
(ungauged)")]
public double DeepDrainageConstituentDeliveryRatio
{
get { return _DeepDrainageConstituentDeliveryRatio; }
set { _DeepDrainageConstituentDeliveryRatio = value; }
}

private double _DeepDrainageConstituentDeliveryRatio;

//add 7 more variables for the storage routed constituent time series.
//2 for the surface and drainage /constituent stores
//2 more for the surface and drainage store constituent releases
//2 for the surface and drainage constituent stores at the end of the time step
//1 for the drainage store constituent loss to groundwater same as per hydrology

[State, Aka("Drainage WQ Storage"), CalculationUnits(CommonUnits.millimetres)]
public double DrainageWQStorage
{
get;
set;
}

[State, Aka("Surface WQ Storage"), CalculationUnits(CommonUnits.millimetres)]
public double SurfaceWQStorage
{
get;
set;
}

[State, Aka("Drainage WQ Storage To Stream"), CalculationUnits(CommonUnits.millimetres)]
public double DrainageWQDischargeToStream
{
get;
set;
```

```
 }

 [State, Aka("Gauged Drainage Runoff Depth"), CalculationUnits(CommonUnits.millimetres)]
 public double gaugedDrainageWQ
 {
 get;
 set;
 }


 [State, Aka("Surface Storage To Stream"), CalculationUnits(CommonUnits.millimetres)]
 public double SurfaceWQDischargeToStream
 {
 get;
 set;
 }

 [State, Aka("Drainage Storage Previous TimeStep"),
CalculationUnits(CommonUnits.millimetres)]
 public double DrainageWQStoragePrevious
 {
 get;
 set;
 }

 [State, Aka("Surface Storage Previous TimeStep"),
CalculationUnits(CommonUnits.millimetres)]
 public double SurfaceWQStoragePrevious
 {
 get;
 set;
 }


 //add 2 more parameters for the storage routing
 //add a surface store emptying proportion - the proportion of the surface store thet
empties in a time step

 [Parameter, Aka("Proportion of available surface store delivered to the stream as quick
flow WQ")]
 public double surfaceWQStoreDeliveryRatio
 {
 get { return _surfaceWQStoreDeliveryRatio; }
 set { _surfaceWQStoreDeliveryRatio = value; }
 }

 private double _surfaceWQStoreDeliveryRatio;

 //add a drainage store emptying proportion - the proportion of the groundwater store thet
empties in a time step

 [Parameter, Aka("Proportion of available drainage store delivered to the stream as slow
flow WQ")]
 public double drainageWQStoreDeliveryRatio
 {
 get { return _drainageWQStoreDeliveryRatio; }
 set { _drainageWQStoreDeliveryRatio = value; }
 }

 private double _drainageWQStoreDeliveryRatio;



 private const double MG_PER_LITER_TO_KG_PER_M3 = UnitConversion.MG_PER_LITRE_TO_KG_PER_M3;
```

```
public override void runTimeStep(DateTime now, double theTimeStepInSeconds)
{

int theMonth = now.Month;

_appliedSDR = 1;
_appliedDDR = 1;

switch (theMonth)
{
case 1:
_appliedSDR = SDRJan;
_appliedDDR = DDRJan;
break;
case 2:
_appliedSDR = SDRFeb;
_appliedDDR = DDRFeb;
break;
case 3:
_appliedSDR = SDRMar;
_appliedDDR = DDRMar;
break;
case 4:
_appliedSDR = SDRApr;
_appliedDDR = DDRApr;
break;
case 5:
_appliedSDR = SDRMay;
_appliedDDR = DDRMay;
break;
case 6:
_appliedSDR = SDRJun;
_appliedDDR = DDRJun;
break;
case 7:
_appliedSDR = SDRJul;
_appliedDDR = DDRJul;
break;
case 8:
_appliedSDR = SDRAug;
_appliedDDR = DDRAug;
break;
case 9:
_appliedSDR = SDRSep;
_appliedDDR = DDRSep;
break;
case 10:
_appliedSDR = SDROct;
_appliedDDR = DDROct;
break;
case 11:
_appliedSDR = SDRNov;
_appliedDDR = DDRNov;
break;
case 12:
_appliedSDR = SDRDec;
_appliedDDR = DDRDec;
break;

}

//Deal with surface WQ first. get the max available constituent, apply the monthly delivery
ratio and convert to g/ha/d to kg/s
```

```
 AvailableSurfaceConstituent = maxAvailableSurfaceconstituent * _appliedSDR *
this.areaInSquareMeters / 10000 / 1000/86400 + maxAvailableDrainageconstituent * _appliedDDR
* this.areaInSquareMeters / 10000 / 1000 / 86400;

 SurfaceWQStorage = SurfaceWQStoragePrevious + AvailableSurfaceConstituent;
 SurfaceWQDischargeToStream = surfaceWQStoreDeliveryRatio * SurfaceWQStorage;
 SurfaceWQStoragePrevious = SurfaceWQStorage - SurfaceWQDischargeToStream;

 //now deal with drainage Runoff

 AvailableDrainageConstituent = 0 * _appliedDDR * this.areaInSquareMeters / 10000 /
1000/86400;

 //partition actual drainage runoff depth between deep drainage not seen at the gauge and
discharge to stream from groundwater

 gaugedDrainageWQ = AvailableDrainageConstituent * DeepDrainageConstituentDeliveryRatio;

 //now delay the groundwater response using a linear store

 DrainageWQStorage = DrainageWQStoragePrevious + gaugedDrainageWQ;
 DrainageWQDischargeToStream = drainageWQStoreDeliveryRatio * DrainageWQStorage;
 DrainageWQStoragePrevious = DrainageWQStorage - DrainageWQDischargeToStream;

 //now calculate the outflow concentration terms from the FU to the river network. We are
looking for kg/s units here
 //units are in kg/ha currently

 // runoff = SurfaceDischargeToStream + DrainageDischargeToStream;
 // baseflow = DrainageDischargeToStream;

 quickflowConstituent = SurfaceWQDischargeToStream;
 slowflowConstituent = DrainageWQDischargeToStream;

 // double _eventMeanConcentrationSI = MG_PER_LITER_TO_KG_PER_M3 * _appliedEMC;
 // double _dryMeanConcentrationSI = MG_PER_LITER_TO_KG_PER_M3 * _appliedDWC;


 // the concentration can be applied to a volume or a flux indifferently, here:
 // kg/s = [kg/m^3]*[m^3/s]
 // quickflowConstituent = _eventMeanConcentrationSI * quickflow;
 // slowflowConstituent = _dryMeanConcentrationSI * slowflow;
 }


 }
}
```

10 APPENDIX B: BASIN SCALE APPLICATION OF PADDOCK SCALE (1-D) MODELS

Basin scale applications using tools such as Source coupled with APSIM tend to utilise APSIM constituent load generation derived from cropping systems modelling such as in the GBR reef modelling (McCloskey et al. 2017). In some cases, APSIM water balance and crop systems model components have been used to parameterise Source crop models to indicate water demands (Petheram et al. 2016, Lerat et al. 2013). The more direct use of APSIM water balance to simulate daily streamflow at the catchment scale appears limited; however, some examples are available for review.

Paydar and Gallant (2007) and Wang et al. (2009) describe an application of FLUSH, a tool designed to allow 1-D models such as APSIM to operate on a catchment scale by allowing the movement of water from upslope to downslope across the landscape. Runoff and drainage from upslope areas are added to downslope APSIM models as run-on and subsurface interflow. APSIM units at the bottom of the slope then generate surface runoff and baseflow. A proportion of runoff from upstream areas could be passed as channelised flow rather than run-on. In addition to the APSIM model linkages, the study described by Paydar and Gallant (2007) also incorporated a groundwater model in the valley floor, which took recharge from APSIM, and where discharge to the stream was a function of piezometric head.

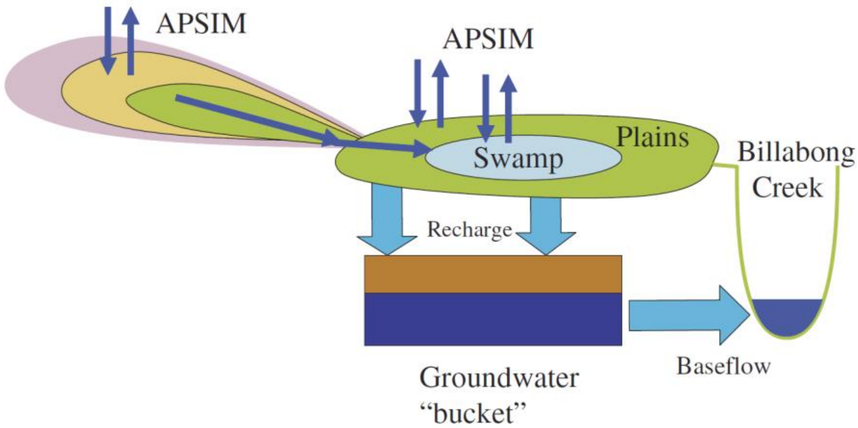


Figure 10-1. Conceptual model of an APSIM catchment model application (Paydar & Gallant 2007)

The groundwater 'bucket' is described in more detail below. The discharge from the groundwater system is given by Equation 1:

$$q = \frac{30KhX}{L} \qquad \text{Equation 1}$$

where q = monthly discharge from the groundwater system (m3/month), K = hydraulic conductivity, h = piezometric head, X = cross-section area of the groundwater flow, and L = distance of the head to the creek

The piezometric head for a period is calculated as:

$$h_{t+\Delta t} = \frac{ARL}{30XK}(1 - e^{-\propto\Delta t}) + h_t e^{-\propto\Delta t} \qquad \text{Equation 2}$$

$$\propto = \frac{30XK}{AL\mu} \qquad \text{Equation 3}$$

where R = recharge (m/month), μ = specific yield, and A is the area of the groundwater bucket (m2). During a period of no recharge, Equation 2 simplifies and α can be found.

The FLUSH model does not appear to be used extensively, and is evaluated over a monthly time step as this reflects the groundwater response time.

At the roots of the APSIM water balance model is the PERFECT model (Littleboy et al. 1992, APSIM 2018), which has been widely used in the past to provide the basis for the 1-D water balance for models such as 2CSalt (Stenson, Littleboy and Gilfedder 2005). 2CSalt has been used to generate catchment scale water balances in Australian catchments such as coastal NSW (Littleboy, Sayers and Dela-Cruz, 2009); however, the results are interpreted on an annual or monthly scale.

Gilfedder et al. (2009) describe an adaptation of 2CSalt to Watercast, the precursor to Source, which is still available as a plugin to current Source versions called GWLag (eWater 2018). GWLag appears to be a model well suited to the current application. The key underlying algorithms are summarised below.

α	scaling term for groundwater response time
β	lateral flow response time
γ	varying the split between lateral flow and recharge
P	scaling of 1D water balance outputs
D	loss to deep regional aquifers
L	other loss from stream

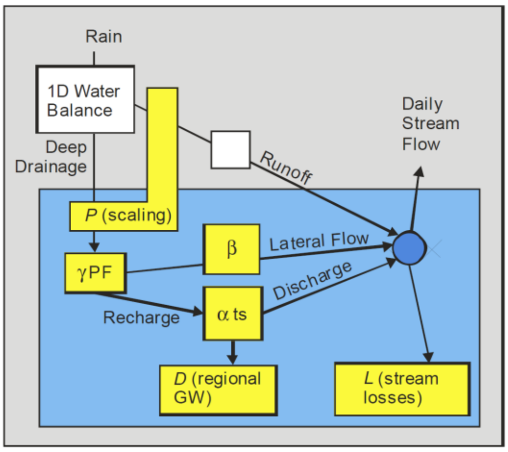


Figure 10-2. Watercast Groundwater Model (Gilfedder at al. 2009)

In GWLag (eWater 2018):

- The deep drainage and runoff time series from the 1-D water balance are optionally scaled (linear) to account for potential inconsistencies in rainfall in the 1-D model.
- A calculated partitioning factor is used to split the deep drainage into groundwater recharge and lateral flow. Estimating the partitioning factor requires the slope angle and hydraulic conductivity ratio of soils. Rassam and Littleboy (2003) proposed an empirical equation relating the slope angle and hydraulic conductivity ratio of a duplex soil to the lateral drainage fraction (Rh) as shown below.

$$R_h = \frac{a + cLn(K_r) + eLn(\theta) + g(Ln(K_r))^2 + i(Ln(\theta))^2 + kLn(K_r)Ln(\theta)}{1 + bLn(K_r) + dLn(\theta) + f(Ln(K_r))^2 + h(Ln(\theta))^2 + jLn(K_r)Ln(\theta)}$$

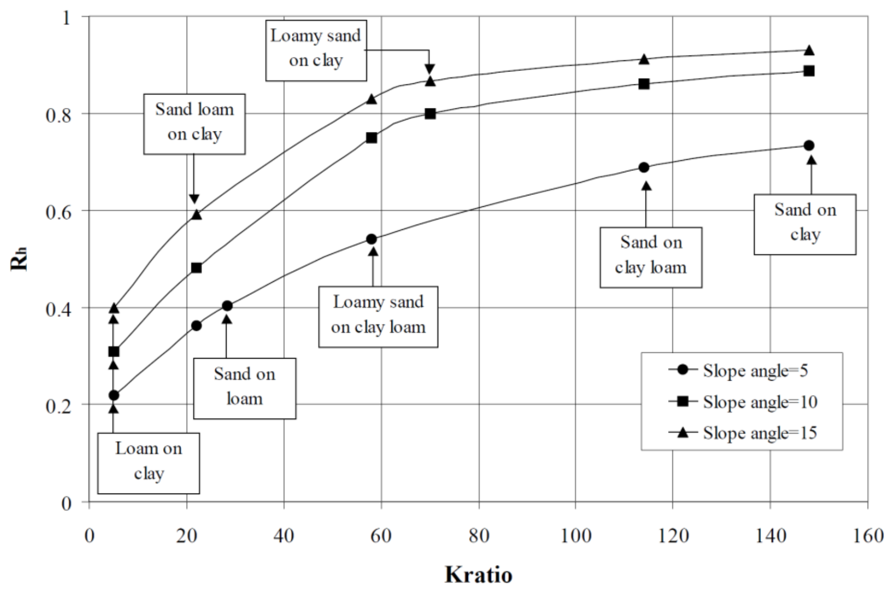


Figure 10-3. Empirical relationship for the lateral drainage fraction (extracted from Rassam & Littleboy 2003)

- The numerous fitting parameters are described in Rassam & Littleboy (2003), in addition to tabulated values of the hydraulic conductivity ratio (K_r) for various soil systems.
- Linear storages are used to calculate the groundwater and lateral flow discharge to the stream network.
- Three types of losses are incorporated in the model: loss to deep drainage, in-stream losses and groundwater pumpage losses.

Gilfedder et al. (2009) report an application of the GWLag module on a catchment in the Murrumbidgee. The application was simulated on a monthly time step and involved a 20-year warm-up period to allow the groundwater storages to reach equilibrium.

The 1-D model representations in catchment scale context of Paydar and Gallant (2007) and GWLag (Gilfedder et al. 2009) both operate on a monthly time step, implying that the entire catchment is modelled in the same way (contributing to the groundwater stores), and link the groundwater response to some physical catchment properties: area, hydraulic conductivity, piezometric head in FLUSH, and slope and hydraulic conductivity and other aquifer properties in GWLag. In both approaches, surface runoff from the 1-D model is translated to the stream, and drainage is delivered to a groundwater store to be slowly released to the stream as baseflow. In GWLag, several mechanisms are included to remove water from the system to achieve mass balance at the gauge.

Recall from Section 2.1 the conceptual components in the Sacramento model in addition to those in APSIM:

- Direct runoff and interflow pass through a unit hydrograph model to delay and lag the flows.
- The outflow from the lower zone soil moisture stores is determined by a coefficient to delay or lag the outflow from this component of the model.
- Baseflow loss and channel loss allow the Sacramento model to remove some water to groundwater to achieve mass balance at gauge sites.

The direct runoff has the option of being delayed to better match daily flows. This is not a feature in FLUSH or GWLag because these are monthly time step models. Sacramento delays the outflow from the groundwater store, using a simplified mechanism compared to FLUSH or GWLag. Lastly, baseflow and channel loss in Sacramento demonstrates a mechanism similar to GWLag.

The Sacramento model approach to drainage from the two groundwater stores (eWater 2018) is simpler than GWLag or FLUSH. Outflow from the lower zone free water primary and lower zone free water supplementary stores is determined by a coefficient (LZSK and LZPK) applied to each storage, effectively draining a percentage of the storage at a given time step.

Given that the Sacramento approach to modelling the drainage from the groundwater stores is already implemented in the GBR Source models, and approaches by FLUSH and GWLag don’t include many other many other elements at a conceptual level, it makes sense to trial the simple Sacramento approach to implement APSIM first, before trying to implement more complex groundwater modelling.

11 APPENDIX C: PLUGIN IMPLEMENTATION GUIDE

The following steps demonstrate how to implement the trial plugin through the Source user interface.

11.1.1 Step 1: Load the plugin

- Copy the ObservedPaddockHydrologyModel.dll file to your plugins directory in Source (V4.1.2. used for this project).
- Load the plugin through the plugin manager and make sure that it has loaded.

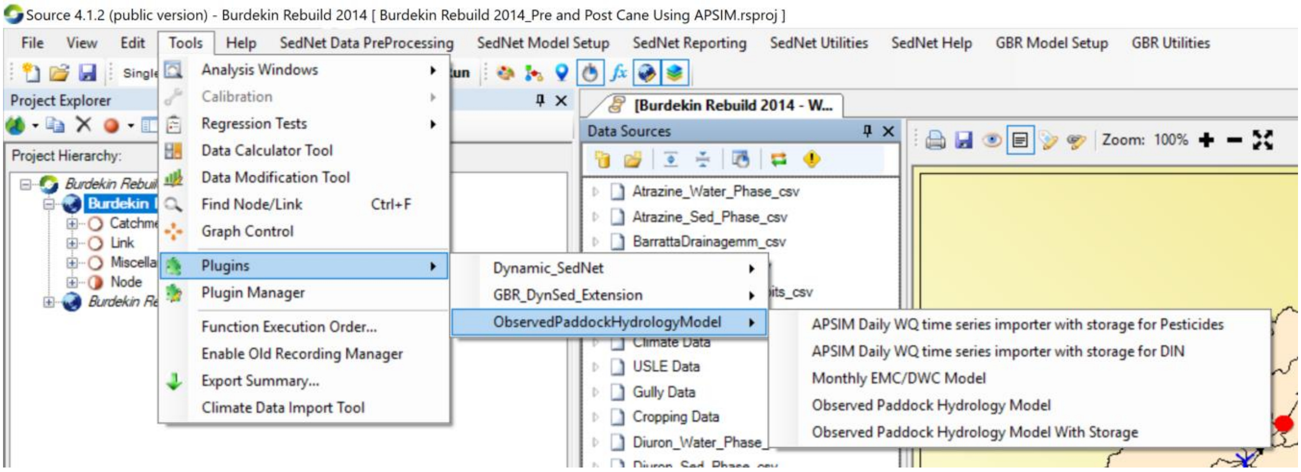


Figure 11-1. The ObservedPaddockHydrologyModel.dll plugin when loaded into Source

11.1.2 Step 2: Load in your APSIM flow and water quality data

- The Python notebook outputs accumulated files suitable for import through the Source 'Data Sources' window.

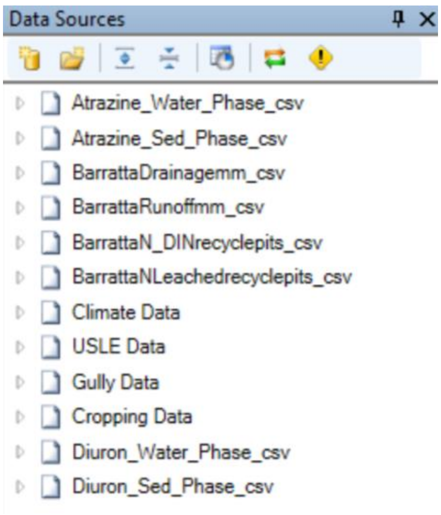


Figure 11-2. Load the APSIM hydrology and water quality time series data

11.1.3 Step 3: Change the sugarcane FU hydrology model

- Set the sugarcane FU hydrology model to 'Observed Paddock Hydrology Model With Storage'.

- After this is done, export the table to help with the next step.

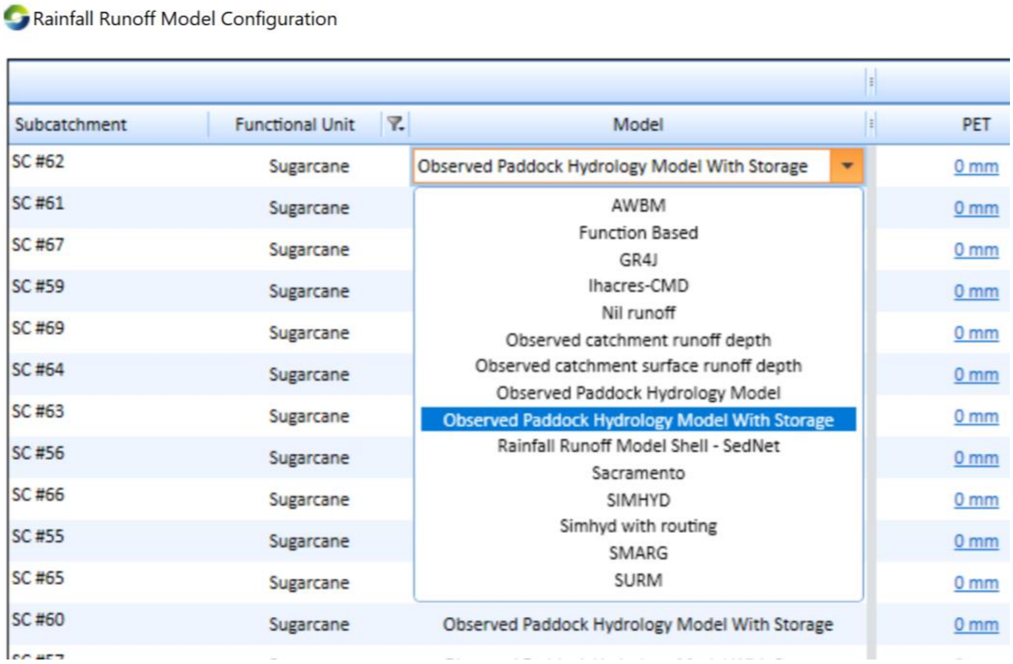


Figure 11-3. Set the sugarcane FU hydrology model

11.1.4 Step 4: Construct the hydrology input parameter table

- The exported table from Step 3 can be populated first with the appropriate file name string for the 'Max available surface runoff' and 'Max available drainage'. These files need to be consistent with those loaded in Step 2.

Table 11-1. Step 4a: Set the surface and drainage time series to the APSIM-generated data

Subcatchment	Functional Unit	Model	Input Data-PET	Input Data-Rainfall	Input Data-Irrigation	Input Data-Max available surface runoff	Input Data-Max available drainage
SC #62	Sugarcane	Observed Paddock Hydrology Model With Storage	0	0	0	BarrattaRunoffmm_csv.SC #62 Runoff (mm)	BarrattaDrainagemm_csv.SC #62 Drainage (mm)
SC #61	Sugarcane	Observed Paddock Hydrology Model With Storage	0	0	0	BarrattaRunoffmm_csv.SC #61 Runoff (mm)	BarrattaDrainagemm_csv.SC #61 Drainage (mm)
SC #67	Sugarcane	Observed Paddock Hydrology Model With Storage	0	0	0	0	0
SC #59	Sugarcane	Observed Paddock Hydrology Model With Storage	0	0	0	BarrattaRunoffmm_csv.SC #59 Runoff (mm)	BarrattaDrainagemm_csv.SC #59 Drainage (mm)

The second half of the table sets the parameters:

- The 'Proportion of available surface runoff delivered to Source' and 'Proportion of available drainage runoff delivered to Source' should always be 1 unless the modeller is scaling the entire time series to account for difference in rainfall applied to APSIM compared to that of the Source model. Typically, the rainfall used in APSIM is the same as that used in Source; however, this parameter allows for adjustment if required.

- 'Proportion of available drainage runoff that goes to deep drainage store' is (1-DR).

- 'Proportion of available surface store delivered to the stream as quick flow' is SSE = surface store emptying ratio—the percentage of the surface store delivered to the stream in a time step, typically close to 1 and similar in value to the UH1 parameter in the Sacramento model.

- 'Proportion of available drainage store delivered to the stream as slow flow' is DSE = drainage store emptying ratio—the percentage of drainage store delivered to the stream in a time step, typically between 0.03 and 0.1 and similar to the LZFK and LZPK values in the Sacramaneto model.

Table 11-2. Step 4b: Set the surface and drainage delivery and storage parameters

Observed Paddock Hydrology Model With Storage-Proportion of available surface runoff delivered to Source	Observed Paddock Hydrology Model With Storage-Proportion of available drainage runoff delivered to Source	Observed Paddock Hydrology Model With Storage-Proportion of available drainage runoff that goes to deep drainage (ungauged)	Observed Paddock Hydrology Model With Storage-Proportion of available surface store delivered to the stream as quick flow	Observed Paddock Hydrology Model With Storage-Proportion of available drainage store delivered to the stream as slow flow
1	1	0.2	0.95	0.01
1	1	0.2	0.95	0.01
0	0	0	0	0
1	1	0.2	0.95	0.01

- The DR, SSE and DSE parameters are calculated by the Python notebook and can be entered into the csv file and reloaded into Source.

11.1.5 Step 5: Set up the N_DIN constituent model

- Set the N_DIN constituent model to 'APSIM Daily WQ time series importer with storage for DIN', then export the csv file for editing and setting time series files.

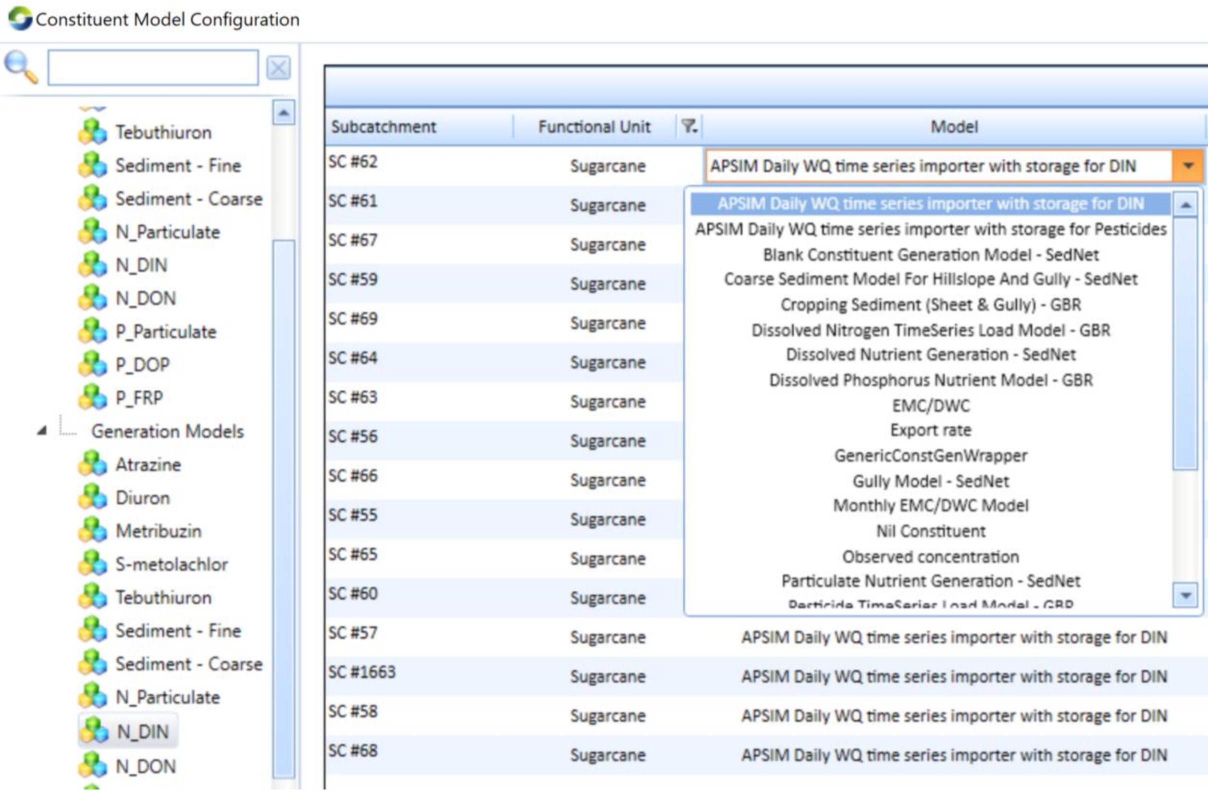


Figure 11-4. Set the sugarcane FU N_DIN model

- The exported table can be populated first with the appropriate file name string for the 'Input Data-Max available surface runoff constituent' and 'Input Data-Max available drainage constituent'. These files correspond to the APSIM kg/d time series for surface and drainage DIN loaded in Step 2.

- Next, populate the 'Surface Delivery ratios' and 'Drainage Delivery ratios' with the estimated amount of DIN to apply. These can be set on a monthly basis if required and can be different for surface and drainage.

- The last five parameters should be taken from the Hydrology import file: Available surface runoff constituent (1), Available drainage runoff constituent (1), Proportion of available drainage constituent that goes to deep drainage (ungauged), Proportion of available surface store delivered to the stream as quick flow WQ, Proportion of available drainage store delivered to the stream as slow flow WQ.

11.1.6 Step 6: Set up the pesticide constituent models

- Set the pesticide constituent models to 'APSIM Daily WQ time series importer with storage for Pesticides', then export the csv file for editing and setting time series files.

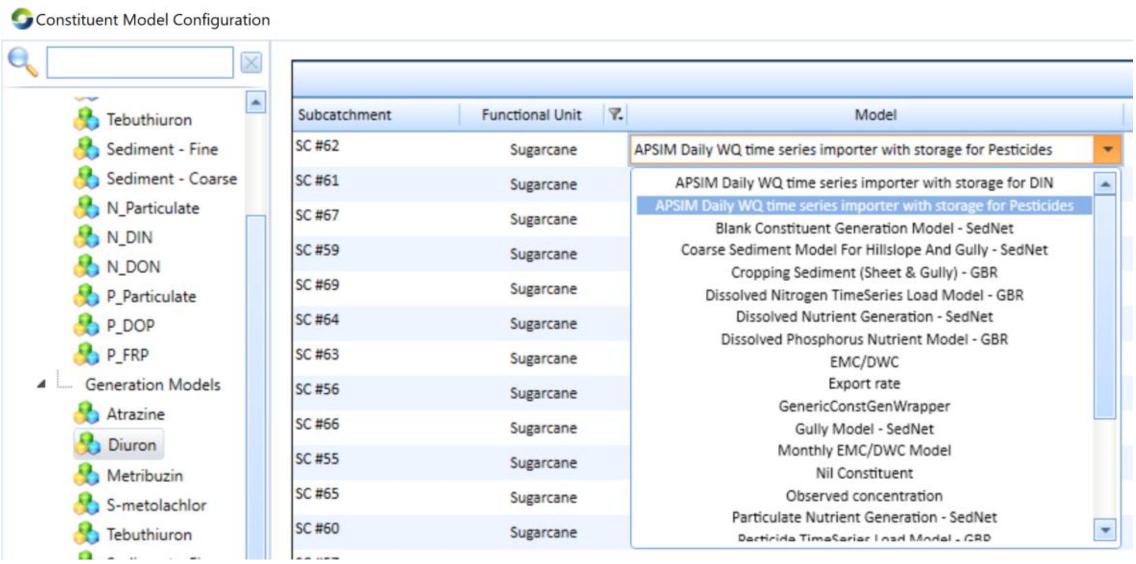


Figure 11-5. Set the sugarcane FU pesticide model

- The exported table can be populated with the appropriate file name string for the 'Input Data- Max available water phase runoff constituent' and 'Input Data- Max available sediment phase runoff constituent'. These files correspond to the APSIM g/d time series for surface and particulate pesticides loaded in Step 2.

- Next, populate the 'Water Delivery ratios' and 'Sediment Phase Delivery ratios' with the estimated amount to apply. These can be set on a monthly basis if required.

- As with DIN, the last five parameters should be taken from the Hydrology import file: Available surface runoff constituent (1), Available drainage runoff constituent (1), Proportion of available drainage constituent that goes to deep drainage (ungauged), Proportion of available surface store delivered to the stream as quick flow WQ, Proportion of available drainage store delivered to the stream as slow flow WQ.

12 APPENDIX D: NOTEBOOK INPUT FILE REQUIREMENTS

12.1 Observed data

Obs_gauges: The observed gauge data in ML/d. Typically collated for all sites in the model. The quality code column is optional. No data is represented by a blank, not -9999.

File type: csv

Date format: mm/dd/yyyy

Example Obs_gauges

Date	112002A Discharge (ML/day)	112002A Quality	112004A Discharge (ML/day)	112004A Quality
1/01/1970		151	1106.27	9
1/02/1970		151	1115.81	9
1/03/1970		151	952.68	9
1/04/1970		151	866.75	9
1/05/1970		151	809.29	9
1/06/1970		151	793.23	9

12.2 Modelled data

Mod_gauges: The modelled time series data corresponding to gauge data in ML/d. Typically output for all sites in the model. Column headings have been shortened from original model output. Keep to this style. The date column is typically modified to be mm/dd/yyyy.

File type: csv

Date format: mm/dd/yyyy

Example Mod_gauges

Date	1120049 Modelled ML/d	112101B Modelled ML/d	112102A Modelled ML/d
1/01/1986	0	0	0
1/02/1986	0	0	0.9330328
1/03/1986	22.92376197	3.13E-05	17.36998223
1/04/1986	31.9556015	4.66E-18	6.681344158
1/05/1986	44.14212958	2.44E-18	1.966434062
1/06/1986	55.82562828	0	0.917446138

12.3 APSIM dates

APSIMDates: The date string column in mm/dd/yyyy corresponding to APSIM model time series data.

File type: csv

Date format: mm/dd/yyyy

APSIMDates

Date
1/01/1986
1/02/1986

1/03/1986
1/04/1986
1/05/1986
1/06/1986

12.4 Sacramento modelled sugarcane runoff

Sac_cane: The sugarcane FU-based output time series for runoff and baseflow from the Source model, as modelled by Sacramento. The units are in mm. As with other files, change the date format to mm/dd/yyyy.

File type: csv

Date format: mm/dd/yyyy

Sac_cane

Date	sugarcane > SC #134 > Runoff	sugarcane > SC #135 > Baseflow	sugarcane > SC #135 > Runoff	sugarcane > SC #136 > Baseflow
1/01/1986	0	0	0	0
1/02/1986	0	0	0.003595	0
1/03/1986	0.294687	0	2.774614	0
1/04/1986	0	0	0	0
1/05/1986	0.096709	0	0	0
1/06/1986	0.085707	0	4.69E-05	0

12.5 Source model FU-based areas, region list and Sacramento parameters

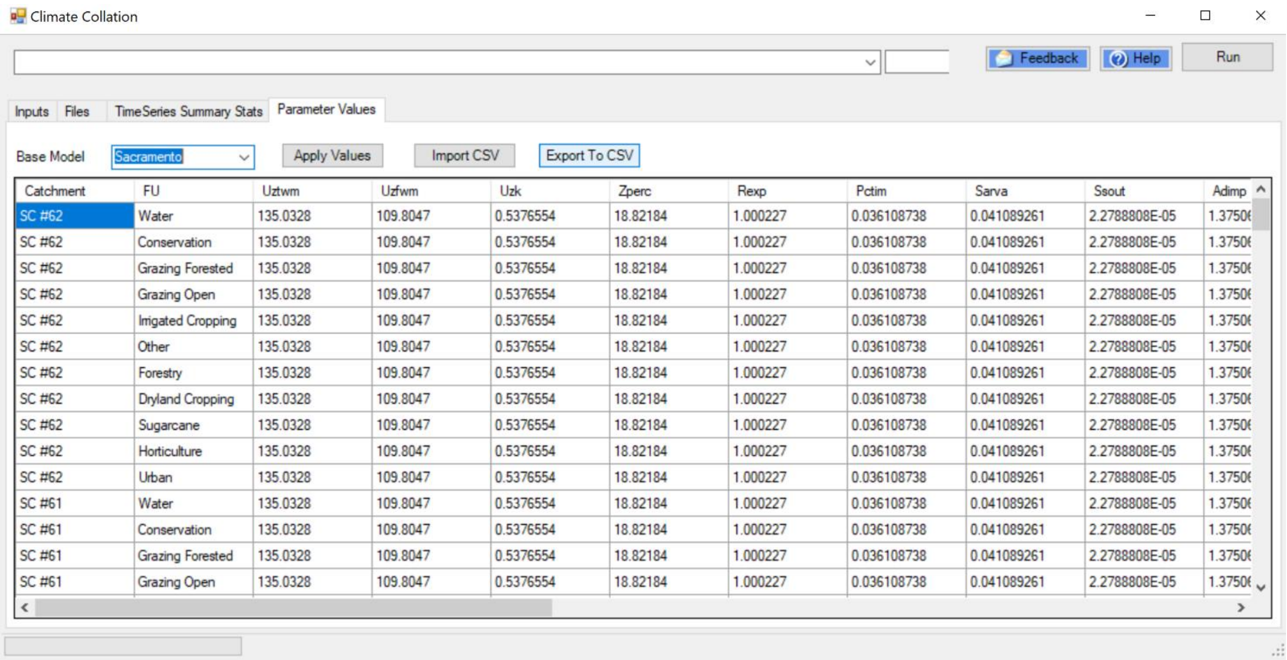
areas_ha: The FU-based sugarcane area in ha, region and Sacramento parameters. Typically modify the file from the Source model. Group regions according to differences in the Sacramento parameters.

File type: csv

areas_ha

Subcatchment	FU	Region	Area_ha	Uztwm	Uzfwm	Uzk	Zperc
SC #184	sugarcane	1	388.9029998	12.66403	76.56598	0.999752	165.5445
SC #185	sugarcane	1	0.172593823	12.66403	76.56598	0.999752	165.5445
SC #186	sugarcane	1	1669.47015	12.66403	76.56598	0.999752	165.5445
SC #183	sugarcane	1	1521.048043	12.66403	76.56598	0.999752	165.5445
SC #389	sugarcane	2	74.75594506	34.35436	101.2319	0.204414	26.15735
SC #158	sugarcane	6	48.40426924	75.65576	112.004	0.304178	13.72783
SC #159	sugarcane	6	1506.947714	75.65576	112.004	0.304178	13.72783
SC #166	sugarcane	1	1609.116964	12.66403	76.56598	0.999752	165.5445

Grab the data from the model through the climate collation screen, filter for Sugarcane, add and populate the Region and Area_ha columns.



12.6 Source modelled flows at gauges using APSIM input

mod_aps_gauges: The new modelled time series data corresponding to gauge data in ML/d. Typically output for all sites in the model. Column headings have been shortened from original model output. Keep to this style. The date column is typically modified to be mm/dd/yyyy.

File type: csv

Date format: mm/dd/yyyy

mod_aps_gauges

Date	1120049 Modelled ML/d	112101B Modelled ML/d	112102A Modelled ML/d
1/01/1986	0	0	0
1/02/1986	0	0	0.9330328
1/03/1986	22.92376197	3.13E-05	17.36998223
1/04/1986	31.9556015	4.66E-18	6.681344158
1/05/1986	44.14212958	2.44E-18	1.966434062
1/06/1986	55.82562828	0	0.917446138

12.7 Source-modelled DIN at gauges using APSIM input

modelled_din: The modelled DIN time series in ***kg/d***. Typically output for all sites in the model. Typically, 100% APSIM surface and baseflow delivery ratio is used first to generate this series, allowing calculation of % drainage DIN followed by adjusted delivery ratio time series. The date column is typically modified to be mm/dd/yyyy.

File type: csv

Date format: mm/dd/yyyy

Modelled_din

Date	(1) WetTropics_DS_2015>Gauge>1120049>Constituents>N_DIN>Downstream Flow Mass	(1) WetTropics_DS_2015>Gauge>112101B>Constituents>N_DIN>Downstream Flow Mass	(1) WetTropics_DS_2015>Gauge>112102A>Constituents>N_DIN>Downstream Flow Mass
1/01/1986	5.64E-06	1.80E-06	0.000361
1/02/1986	3.39E-05	6.97E-06	0.146649
1/03/1986	2.815364	7.79E-05	4.858162
1/04/1986	4.073617	0.000103	1.664767
1/05/1986	5.966442	0.000134	0.481133
1/06/1986	7.977417	0.000173	0.196631

12.8 Annual water quality loads

WQ_Annual_Loads: The 'nutrient loads and discharge' tab from the water quality database annually supplied by DES (from ALLGBRI5_2006_16_MASTERRESULTS44.xlsx).

The required modifications include extracting this data as a single csv file and adding the column Year_end with an appropriate date in mm/dd/yyyy format.

File type: csv

Date format: mm/dd/yyyy for the Year_end column

WQ_Annual_Loads

Order	Year	Year_end	Basin	Gauging station	River and site name	Representivity 5%	n	Method	Discharge (ML)	Annual average (ML)	Total suspended solids (t)
1	2006-07	06/30/2007	Normanby	105107A	Normanby River at Kalpowar Crossing	Excellent	60	Average Load (linear interpolation of concentration)	1765705	1765735	58518
1	2007-08	06/30/2008	Normanby	105107A	Normanby River at Kalpowar Crossing	Good	31	Average Load (linear interpolation of concentration)	3649220	2707485	206429
1	2008-09	06/30/2009	Normanby	105107A	Normanby River at Kalpowar Crossing	Good	39	Beale Ratio	2349685	2588224	100584
1	2009-10	06/30/2010	Normanby	105107A	Normanby River at Kalpowar Crossing	Good	8	Beale Ratio	2927302	2673072	173214
1	2010-11	06/30/2011	Normanby	105107A	Normanby River at Kalpowar Crossing	Moderate	22	Beale Ratio	5960435	3330550	268468
1	2011-12	06/30/2012	Normanby	105107A	Normanby River at Kalpowar Crossing	Good	39	Average Load (linear interpolation of concentration)	1162420	2969195	46207
1	2013-14	06/30/2014	Normanby	105107A	Normanby River at Kalpowar Crossing	Good	27	Beale Ratio	2635686	2784819	142838
1	2014-15	06/30/2015	Normanby	105107A	Normanby River at Kalpowar Crossing	Good	31	Average Load (linear interpolation of concentration)	1556336	2648322	29173
1	2015-16	06/30/2016	Normanby	105107A	Normanby River at Kalpowar Crossing	Moderate	40	Beale Ratio	1784562	2561946	61715.35
2	2006-07	06/30/2007	Barron	110001D	Barron River at Myola	Moderate	65	Average Load (linear interpolation of concentration)	470249	732265	69280

2	2007-08	06/30/2008	Barron	110001D	Barron River at Myola	Excellent	140	Beale Ratio	1582454	748616	383139

12.9 Annual water quality loads for pesticides

WQ_Annual_Loads: The 'Pesticides Loads' tab from the water quality database annually supplied by DES (from ALLGBRI5_2006_16_MASTERRESULTS44.xlsx).

The required modifications include extracting this data as a single csv file and adding the column Year_end with an appropriate date in mm/dd/yyyy format.

I also found that I needed to remove most of the other columns and all the other sites and parameters other than Diuron and atrazine for this analysis; however, the problem is likely to be in the commas in names of the parameters in the headings for some of the constituents, as I found later in the notebook.

File type: csv

Date format: mm/dd/yyyy for the Year_end column

WQ_Annual_Loads

Year_end	Basin	Gauging station	River and site name	Total Atrazine mass load (kg)	Total Diuron mass load (kg)
06/30/2016	Johnstone	1120054	Johnstone River at Coquette Point	20	45
06/30/2014	Johnstone	1120049	North Johnstone River at Old Bruce Highway Bridge (Goondi)	21	34
06/30/2015	Johnstone	1120049	North Johnstone River at Old Bruce Highway Bridge (Goondi)	0.14	25
06/30/2016	Johnstone	1120049	North Johnstone River at Old Bruce Highway Bridge (Goondi)	0.73	4.6
06/30/2011	Johnstone	112004A	North Johnstone River at Tung Oil	28	29
06/30/2012	Johnstone	112004A	North Johnstone River at Tung Oil	14	16
06/30/2011	Tully	113006A	Tully River at Euramo	110	220
06/30/2012	Tully	113006A	Tully River at Euramo	150	240
06/30/2013	Tully	113006A	Tully River at Euramo	190	570
06/30/2014	Tully	113006A	Tully River at Euramo	250	240
06/30/2015	Tully	113006A	Tully River at Euramo	130	140
06/30/2016	Tully	113006A	Tully River at Euramo	51	140

12.10 Water quality concentrations

WQ_Conc: The 'Concentrations' tab from the water quality database annuallly supplied by DES (from ALLGBRI5_2006_16_MASTERRESULTS44.xlsx).

The required modifications include:

1. extracting this data as a single csv file
2. removing many characters like ° and @ and the commas in all column headings—the table below shows changes
3. adding a column called 'DIN (mg/L derived)'
4. changing 'Date time' column heading to 'Date_time' to make code easier.

File type: csv

Date format: Should have been mm/dd/yyyy in the Date_time column—need to check validity

Column heading changes

New headings	Original headings	New headings	Original headings
Station	Station	Total phosphorus (mg/L) (2360.2)	Total phosphorus (mg/L) (2360.2)
Station name	Station name	Quality	Quality
Sample number	Sample number	Filterable reactive phosphorus (mg/L) (2365.2)	Filterable reactive phosphorus (mg/L) (2365.2)
Sample Type	Sample Type	Quality	Quality
Date	Date	Dissolved Kjeldahl phosphorus (mg/L) (2368.2)	Dissolved Kjeldahl phosphorus (mg/L) (2368.2)
Time	Time	Quality	Quality
Sample source	Sample source	Dissolved organic phosphorus (mg/L) (2370.2)	Dissolved organic phosphorus (mg/L) (2370.2)
Collection Authority	Collection Authority	Quality	Quality
Cellection method	Cellection method	Particulate phosphorus (mg/L) (2375.2)	Particulate phosphorus (mg/L) (2375.2)
Preservation method 1	Preservation method 1	Quality	Quality
Preservation method 2	Preservation method 2	Total organic carbon (mg/L) (3021.2)	Total organic carbon (mg/L) (3021.2)
Lab reference	Lab reference	Quality	Quality
Date_time	Date time	Imidacloprid (µg/L) (3186)	Imidacloprid (µg/L) (3186)
Conductivity (2010.2)	Conductivity @ 25°C (µS/cm) (2010.2)	Quality	Quality
Quality	Quality	Imidacloprid (LLOR) (µg/L) (3186.01)	Imidacloprid (LLOR) (µg/L) (3186.01)
Conductivity (2010.5)	Conductivity @ 25°C (FLD) (µS/cm) (2010.5)	Quality	Quality
Quality	Quality	Imidacloprid metabolites (µg/L) (3351)	Imidacloprid metabolites (µg/L) (3351)
Turbidity (NTU) (2030.2)	Turbidity (NTU) (2030.2)	Quality	Quality
Quality	Quality	Imidacloprid metabolites (LLOR) (µg/L) (3351.01)	Imidacloprid metabolites (LLOR) (µg/L) (3351.01)
Turbidity (NTU) (2030.5)	Turbidity (NTU) (2030.5)	Quality	Quality
Quality	Quality	Total Imidacloprid (µg/L) (3352)	Total Imidacloprid (µg/L) (3352)
pH (2100.2)	pH @ 25°C (pH units) (2100.2)	Quality	Quality
Quality	Quality	Total Imidacloprid (LLOR) (µg/L) (3352.01)	Total Imidacloprid (LLOR) (µg/L) (3352.01)
pH (2100.5)	pH @ 25°C (FLD) (pH units) (2100.5)	Quality	Quality
Quality	Quality	3 4-Dichloroaniline (µg/L) (3353)	3,4-Dichloroaniline (µg/L) (3353)
Total suspended solids (mg/L) (2172.2)	Total suspended solids (mg/L) (2172.2)	Quality	Quality
Quality	Quality	3 4-Dichloroaniline (LLOR) (µg/L) (3353.01)	3,4-Dichloroaniline (LLOR) (µg/L) (3353.01)
Particulate nitrogen (mg/L) (2330.2)	Particulate nitrogen (mg/L) (2330.2)	Quality	Quality
Quality	Quality	Clothianidin (µg/L) (3354)	Clothianidin (µg/L) (3354)
Total Kjeldahl nitrogen (mg/L) (2336.2)	Total Kjeldahl nitrogen (mg/L) (2336.2)	Quality	Quality
Quality	Quality	Clothianidin (LLOR) (µg/L) (3354.01)	Clothianidin (LLOR) (µg/L) (3354.01)
Total nitrogen (mg/L) (2337.2)	Total nitrogen (mg/L) (2337.2)	Quality	Quality
Quality	Quality	Thiamethoxam (µg/L) (3355)	Thiamethoxam (µg/L) (3355)
Oxidised nitrogen (mg/L) (2343.2)	Oxidised nitrogen (mg/L) (2343.2)	Quality	Quality
Quality	Quality	Thiamethoxam (LLOR) (µg/L) (3355.01)	Thiamethoxam (LLOR) (µg/L) (3355.01)
Ammonium nitrogen (mg/L) (2345.2)	Ammonium nitrogen (mg/L) (2345.2)	Quality	Quality
Quality	Quality	Total Diuron (µg/L) (3356)	Total Diuron (µg/L) (3356)
Dissolved Kjeldahl nitrogen (mg/L) (2350.2)	Dissolved Kjeldahl nitrogen (mg/L) (2350.2)	Quality	Quality
Quality	Quality	Total Diuron (LLOR) (µg/L) (3356.01)	Total Diuron (LLOR) (µg/L) (3356.01)
Dissolved organic nitrogen (mg/L) (2356.2)	Dissolved organic nitrogen (mg/L) (2356.2)	Quality	Quality

Quality	Quality	Total Acetamiprid (KHSP1A) (µg/L) (3548)	Total Acetamiprid (KHSP1A) (µg/L) (3548)
DIN (mg/L derived)		Quality	Quality
New headings	Original headings	New headings	Original headings
Methoxyfenozide (KHSP1B) (µg/L) (3549)	Methoxyfenozide (KHSP1B) (µg/L) (3549)	Simazine (LLOR) (µg/L) (4021.01)	Simazine (LLOR) (µg/L) (4021.01)
Quality	Quality	Quality	Quality
Acetamiprid (KHSP1K) (µg/L) (3550)	Acetamiprid (KHSP1K) (µg/L) (3550)	Simazine (µg/L) (4021.02)	Simazine (µg/L) (4021.02)
Quality	Quality	Quality	Quality
Imazapic (KHSP95) (µg/L) (3551)	Imazapic (KHSP95) (µg/L) (3551)	Atrazine (µg/L) (4024)	Atrazine (µg/L) (4024)
Quality	Quality	Quality	Quality
Imazapyr (KHSP96) (µg/L) (3552)	Imazapyr (KHSP96) (µg/L) (3552)	Atrazine (LLOR) (µg/L) (4024.01)	Atrazine (LLOR) (µg/L) (4024.01)
Quality	Quality	Quality	Quality
Imazapic metabolites (µg/L) (3553)	Imazapic metabolites (µg/L) (3553)	Atrazine (µg/L) (4024.02)	Atrazine (µg/L) (4024.02)
Quality	Quality	Quality	Quality
N-Demethyl Acetamiprid (KHSP98) (µg/L) (3554)	N-Demethyl Acetamiprid (KHSP98) (µg/L) (3554)	Prometryn (µg/L) (4025)	Prometryn (µg/L) (4025)
Quality	Quality	Quality	Quality
Thiacloprid (KHSP99) (µg/L) (3555)	Thiacloprid (KHSP99) (µg/L) (3555)	Prometryn (LLOR) (µg/L) (4025.01)	Prometryn (LLOR) (µg/L) (4025.01)
Quality	Quality	Quality	Quality
Imazapic (KHSP1C) (µg/L) (3556)	Imazapic (KHSP1C) (µg/L) (3556)	Prometryn (µg/L) (4025.02)	Prometryn (µg/L) (4025.02)
Quality	Quality	Quality	Quality
Imazapyr (KHSP1D) (µg/L) (3557)	Imazapyr (KHSP1D) (µg/L) (3557)	Terbuthylazine (µg/L) (4026)	Terbuthylazine (µg/L) (4026)
Quality	Quality	Quality	Quality
N-Demethyl Acetamiprid (KHSP1F) (µg/L) (3559)	N-Demethyl Acetamiprid (KHSP1F) (µg/L) (3559)	Terbuthylazine (µg/L) (4026.01)	Terbuthylazine (µg/L) (4026.01)
Quality	Quality	Quality	Quality
Thiacloprid (KHSP1G) (µg/L) (3560)	Thiacloprid (KHSP1G) (µg/L) (3560)	Terbutryn (µg/L) (4027)	Terbutryn (µg/L) (4027)
Quality	Quality	Quality	Quality
Total Acetamiprid (KHSP1H) (µg/L) (3561)	Total Acetamiprid (KHSP1H) (µg/L) (3561)	Terbutryn (LLOR) (µg/L) (4027.01)	Terbutryn (LLOR) (µg/L) (4027.01)
Quality	Quality	Quality	Quality
Methoxyfenozide (KHSP1I) (µg/L) (3562)	Methoxyfenozide (KHSP1I) (µg/L) (3562)	Terbutryn (µg/L) (4027.02)	Terbutryn (µg/L) (4027.02)
Quality	Quality	Quality	Quality
Acetamiprid (KHSP1J) (µg/L) (3563)	Acetamiprid (KHSP1J) (µg/L) (3563)	Desisopropylatrazine (µg/L) (4034)	Desisopropylatrazine (µg/L) (4034)
Quality	Quality	Quality	Quality
Ametryn (µg/L) (4018)	Ametryn (µg/L) (4018)	Desisopropylatrazine (LLOR) (µg/L) (4034.01)	Desisopropylatrazine (LLOR) (µg/L) (4034.01)
Quality	Quality	Quality	Quality
Ametryn (LLOR) (µg/L) (4018.01)	Ametryn (LLOR) (µg/L) (4018.01)	Desisopropylatrazine (µg/L) (4034.02)	Desisopropylatrazine (µg/L) (4034.02)
Quality	Quality	Quality	Quality
Ametryn (µg/L) (4018.02)	Ametryn (µg/L) (4018.02)	Desethylatrazine (µg/L) (4035)	Desethylatrazine (µg/L) (4035)
Quality	Quality	Quality	Quality
Tebuthiuron (µg/L) (4019)	Tebuthiuron (µg/L) (4019)	Desethylatrazine (LLOR) (µg/L) (4035.01)	Desethylatrazine (LLOR) (µg/L) (4035.01)
Quality	Quality	Quality	Quality
Tebuthiuron (LLOR) (µg/L) (4019.01)	Tebuthiuron (LLOR) (µg/L) (4019.01)	Desethylatrazine (µg/L) (4035.02)	Desethylatrazine (µg/L) (4035.02)
Quality	Quality	Quality	Quality
Tebuthiuron (µg/L) (4019.02)	Tebuthiuron (µg/L) (4019.02)	Floumetron (µg/L) (4221)	Floumetron (µg/L) (4221)
Quality	Quality	Quality	Quality
Simazine (µg/L) (4021)	Simazine (µg/L) (4021)	Floumetron (LLOR) (µg/L) (4221.01)	Floumetron (LLOR) (µg/L) (4221.01)
Quality	Quality	Quality	Quality

New headings	Original headings	New headings	Original headings
Floumetron (µg/L) (4221.02)	Floumetron (µg/L) (4221.02)	Metolachlor (LLOR) (µg/L) (4637.01)	Metolachlor (LLOR) (µg/L) (4637.01)
Quality	Quality	Quality	Quality
Diuron (LLOR) (µg/L) (4222.01)	Diuron (LLOR) (µg/L) (4222.01)	Metolachlor (µg/L) (4637.02)	Metolachlor (µg/L) (4637.02)
Quality	Quality	Quality	Quality
Diuron (µg/L) (4222.02)	Diuron (µg/L) (4222.02)	Haloxyfop (µg/L) (4638)	Haloxyfop (µg/L) (4638)
Quality	Quality	Quality	Quality
Metsulfuron-methyl (µg/L) (4230)	Metsulfuron-methyl (µg/L) (4230)	Haloxyfop (µg/L) (4638.01)	Haloxyfop (µg/L) (4638.01)
Quality	Quality	Quality	Quality
Metsulfuron-methyl (µg/L) (4230.01)	Metsulfuron-methyl (µg/L) (4230.01)	Hexazinone (µg/L) (4642)	Hexazinone (µg/L) (4642)
Quality	Quality	Quality	Quality
MCPB (µg/L) (4420)	MCPB (µg/L) (4420)	Hexazinone (LLOR) (µg/L) (4642.01)	Hexazinone (LLOR) (µg/L) (4642.01)
Quality	Quality	Quality	Quality
MCPB (µg/L) (4420.01)	MCPB (µg/L) (4420.01)	Hexazinone (µg/L) (4642.02)	Hexazinone (µg/L) (4642.02)
Quality	Quality	Quality	Quality
Mecoprop (µg/L) (4421)	Mecoprop (µg/L) (4421)	AMPA (µg/L) (4644)	AMPA (µg/L) (4644)
Quality	Quality	Quality	Quality
Mecoprop (µg/L) (4421.01)	Mecoprop (µg/L) (4421.01)	Total Glyphosate (µg/L) (4645)	Total Glyphosate (µg/L) (4645)
Quality	Quality	Quality	Quality
MCPA (µg/L) (4422)	MCPA (µg/L) (4422)	Metribuzin (µg/L) (4650)	Metribuzin (µg/L) (4650)
Quality	Quality	Quality	Quality
MCPA (µg/L) (4422)	MCPA (µg/L) (4422)	Metribuzin (µg/L) (LLOR) (4650.01)	Metribuzin (µg/L) (LLOR) (4650.01)
Quality	Quality	Quality	Quality
2 4-DB (µg/L) (4427)	2,4-DB (µg/L) (4427)	Metribuzin (µg/L) (4650.02)	Metribuzin (µg/L) (4650.02)
Quality	Quality	Quality	Quality
Triclopyr (µg/L) (4442)	Triclopyr (µg/L) (4442)	Acifluorfen (µg/L) (4930)	Acifluorfen (µg/L) (4930)
Quality	Quality	Quality	Quality
Triclopyr (µg/L) (4442.01)	Triclopyr (µg/L) (4442.01)	Acifluorfen (µg/L) (4930.01)	Acifluorfen (µg/L) (4930.01)
Quality	Quality	Quality	Quality
Fluroxypyr (µg/L) (4443)	Fluroxypyr (µg/L) (4443)	Clomazone (µg/L) (4931)	Clomazone (µg/L) (4931)
Quality	Quality	Quality	Quality
Fluroxypyr (µg/L) (4443.01)	Fluroxypyr (µg/L) (4443.01)	Clomazone (µg/L) (4931.01)	Clomazone (µg/L) (4931.01)
Quality	Quality	Quality	Quality
Glyphosate (µg/L) (4623)	Glyphosate (µg/L) (4623)	Cyanazine (µg/L) (4932)	Cyanazine (µg/L) (4932)
Quality	Quality	Quality	Quality
Bromacil (µg/L) (4634)	Bromacil (µg/L) (4634)	Cyanazine (µg/L) (4932.01)	Cyanazine (µg/L) (4932.01)
Quality	Quality	Quality	Quality
Bromacil (LLOR) (µg/L) (4634.01)	Bromacil (LLOR) (µg/L) (4634.01)	Ethametsulfuron methyl (µg/L) (4933)	Ethametsulfuron methyl (µg/L) (4933)
Quality	Quality	Quality	Quality
Bromacil (µg/L) (4634.02)	Bromacil (µg/L) (4634.02)	Ethametsulfuron methyl (µg/L) (4933.01)	Ethametsulfuron methyl (µg/L) (4933.01)
Quality	Quality	Quality	Quality
Metolachlor (µg/L) (4637)	Metolachlor (µg/L) (4637)	Flusilazole (µg/L) (4934)	Flusilazole (µg/L) (4934)
Quality	Quality	Quality	Quality

New headings	Original headings	New headings	Original headings

Flusilazole (µg/L) (4934.01)	Flusilazole (µg/L) (4934.01)	Trifloxysulfuron (µg/L) (4945)	Trifloxysulfuron (µg/L) (4945)
Quality	Quality	Quality	Quality
Imazethapyr (µg/L) (4935)	Imazethapyr (µg/L) (4935)	Trifloxysulfuron (µg/L) (4945.01)	Trifloxysulfuron (µg/L) (4945.01)
Quality	Quality	Quality	Quality
Imazethapyr (µg/L) (4935.01)	Imazethapyr (µg/L) (4935.01)	2 4-D (µg/L) (5025)	2,4-D (µg/L) (5025)
Quality	Quality	Quality	Quality
Isoxaflutole (µg/L) (4936)	Isoxaflutole (µg/L) (4936)	2 4-D (µg/L) (5025.01)	2,4-D (µg/L) (5025.01)
Quality	Quality	Quality	Quality
Isoxaflutole (µg/L) (4936.01)	Isoxaflutole (µg/L) (4936.01)	2 4-DB (µg/L) (5026)	2,4-DB (µg/L) (5026)
Quality	Quality	Quality	Quality
Mesosulfuron methyl (µg/L) (4937)	Mesosulfuron methyl (µg/L) (4937)	2 4-DB (µg/L) (5026.01)	2,4-DB (µg/L) (5026.01)
Quality	Quality		Quality
Mesosulfuron methyl (µg/L) (4937.01)	Mesosulfuron methyl (µg/L) (4937.01)		
Quality	Quality		
Napropamide (µg/L) (4938)	Napropamide (µg/L) (4938)		
Quality	Quality		
Napropamide (µg/L) (4938.01)	Napropamide (µg/L) (4938.01)		
Quality	Quality		
Propachlor (µg/L) (4939)	Propachlor (µg/L) (4939)		
Quality	Quality		
Propachlor (µg/L) (4939.01)	Propachlor (µg/L) (4939.01)		
Quality	Quality		
Propazin-2-hydroxy (µg/L) (4940)	Propazin-2-hydroxy (µg/L) (4940)		
Quality	Quality		
Propazin-2-hydroxy (µg/L) (4940.01)	Propazin-2-hydroxy (µg/L) (4940.01)		
Quality	Quality		
Sethoxydim (including Clethodim) (µg/L) (4941)	Sethoxydim (including Clethodim) (µg/L) (4941)		
Quality	Quality		
Sethoxydim (including Clethodim) (µg/L) (4941.01)	Sethoxydim (including Clethodim) (µg/L) (4941.01)		
Quality	Quality		
Sulfosulfuron (µg/L) (4942)	Sulfosulfuron (µg/L) (4942)		
Quality	Quality		
Sulfosulfuron (µg/L) (4942.01)	Sulfosulfuron (µg/L) (4942.01)		
Quality	Quality		
Terbuthylazine desethyl (µg/L) (4943)	Terbuthylazine desethyl (µg/L) (4943)		
Quality	Quality		
Terbuthylazine desethyl (µg/L) (4943.01)	Terbuthylazine desethyl (µg/L) (4943.01)		
Quality	Quality		
Total Imazapic (µg/L) (4944)	Total Imazapic (µg/L) (4944)		
Quality	Quality		
Total Imazapic (µg/L) (4944.01)	Total Imazapic (µg/L) (4944.01)		
Quality	Quality		

12.11 Other input data files for selected programs

dfsitelist: The gauge site list for comparison against DIN.

dfsitelistpesticides: The gauge site list for comparison against pesticides.

File type: csv

Example:

location
113006A
112004A
112101B
113015A

dfparameterlist: The parameter string to look for in column headings for DIN. Note: other parameters in the mg/L units may also be searched for and used in this program, not just DIN.

File type: csv

Example:

parameter
DIN

dfparameterlistpesticides: The parameter string to look for in column headings for pesticides. Note: other parameters in the ug/L units may also be searched for and used in this program.

File type: csv

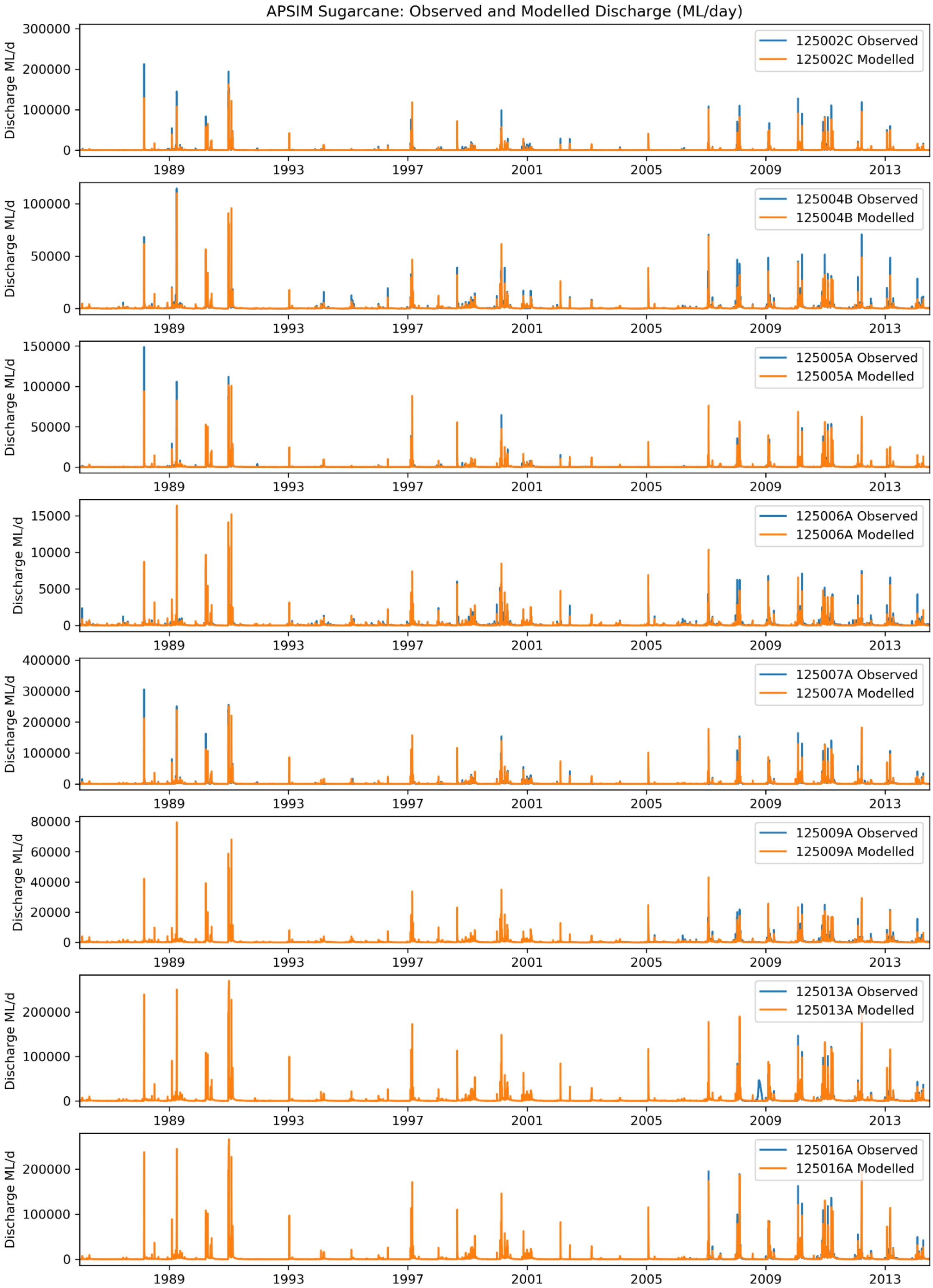
Example:

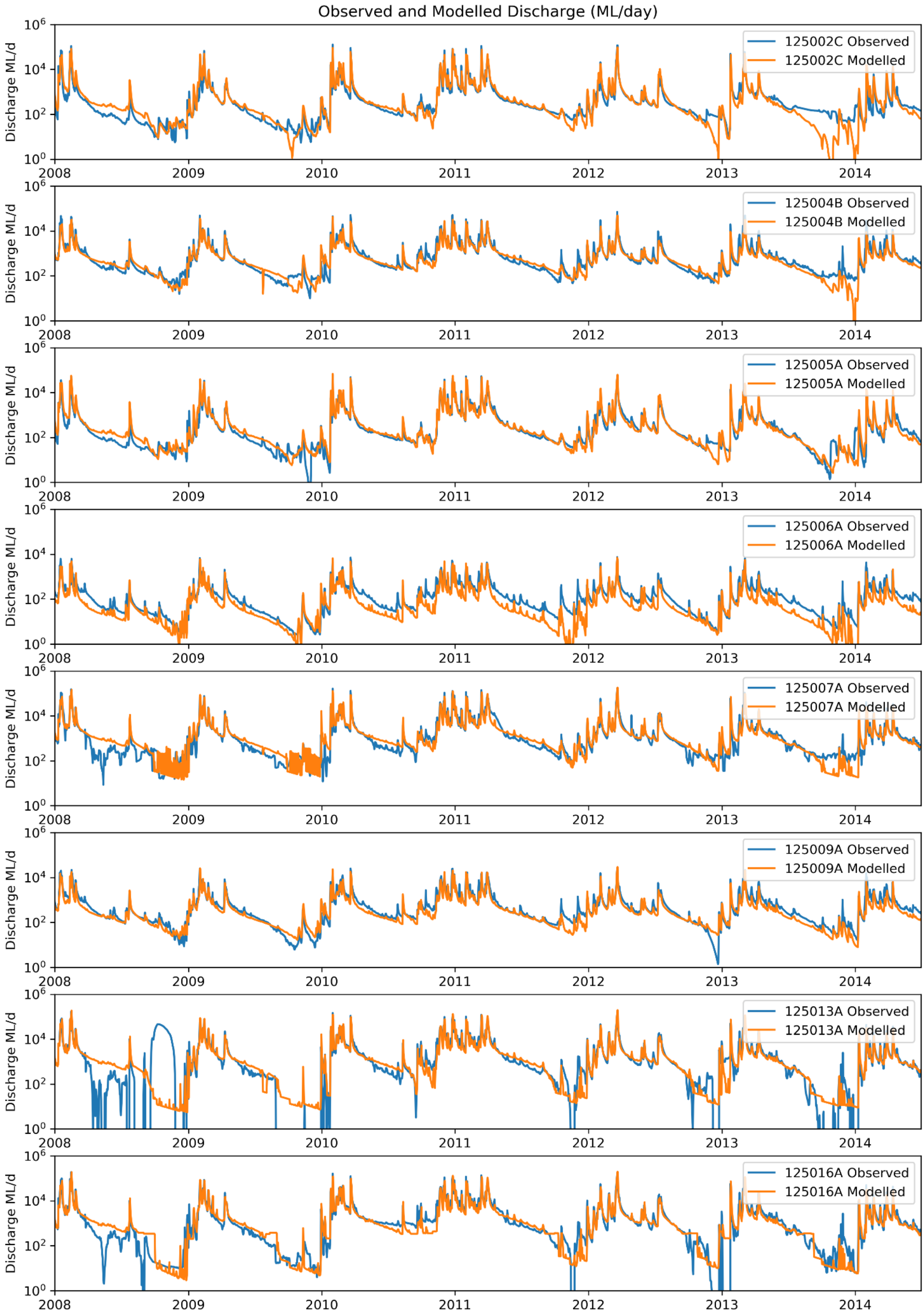
parameter
Diuron
Atrazine

13 APPENDIX E: MODEL CALIBRATION OUTPUTS

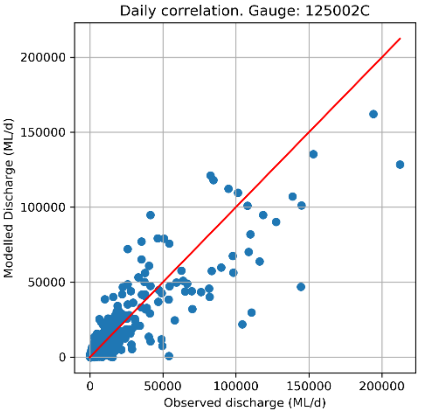
13.1 Pioneer catchment

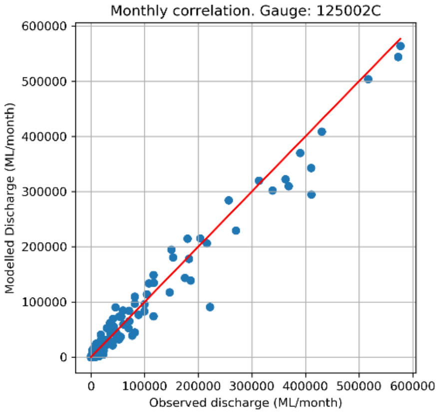
13.1.1 Hydrology performance plots

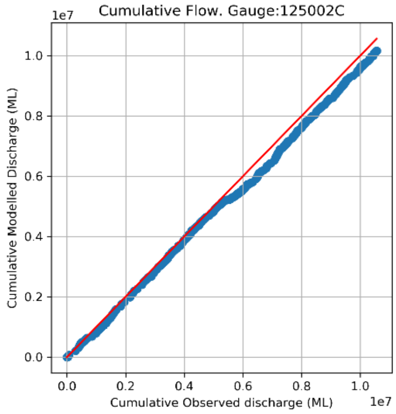


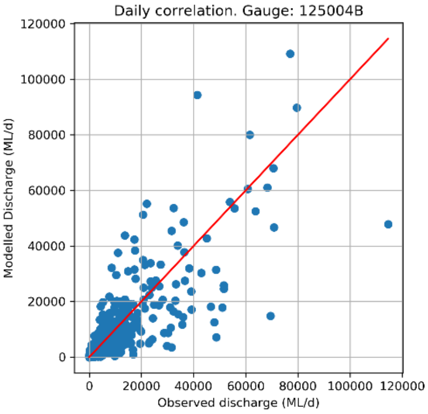


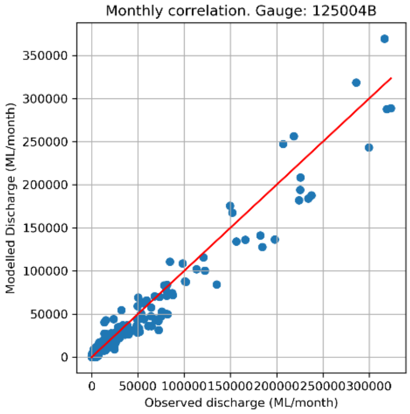
Observed and Modelled Discharge (ML/day)
Discharge ML/d
125002C Observed
125002C Modelled
125004B Observed
125004B Modelled
125005A Observed
125005A Modelled
125006A Observed
125006A Modelled
125007A Observed
125007A Modelled
125009A Observed
125009A Modelled
125013A Observed
125013A Modelled
125016A Observed
125016A Modelled
2008
2009
2010
2011
2012
2013
2014

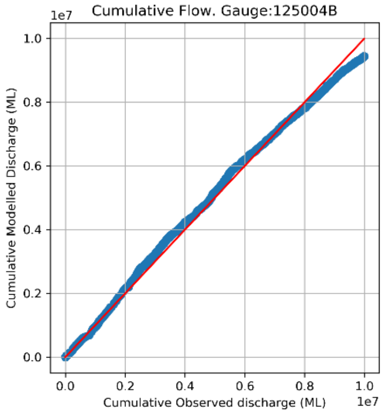

Daily correlation. Gauge: 125002C
Modelled Discharge (ML/d)
Observed discharge (ML/d)

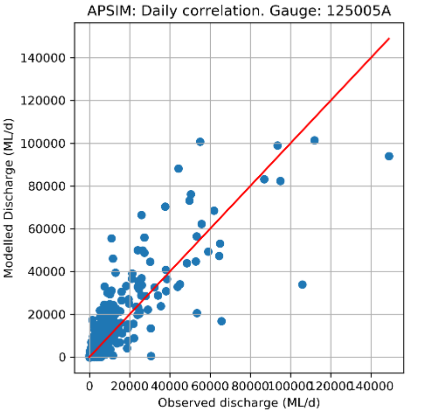

Monthly correlation. Gauge: 125002C
Modelled Discharge (ML/month)
Observed discharge (ML/month)

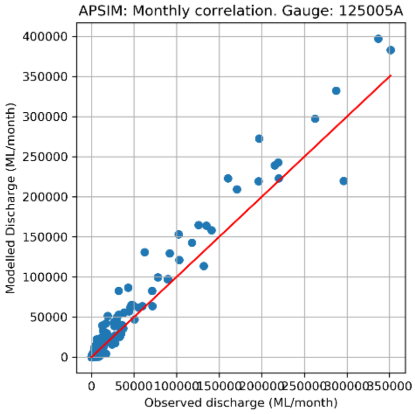

Cumulative Flow. Gauge:125002C
1e7
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)

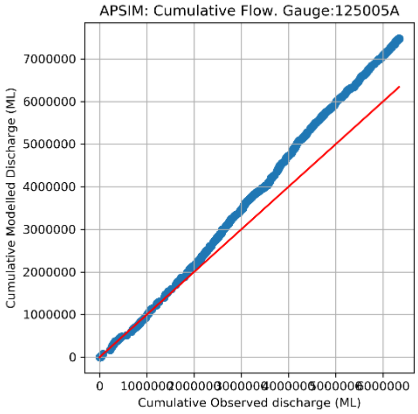

Daily correlation. Gauge: 125004B
Modelled Discharge (ML/d)
Observed discharge (ML/d)

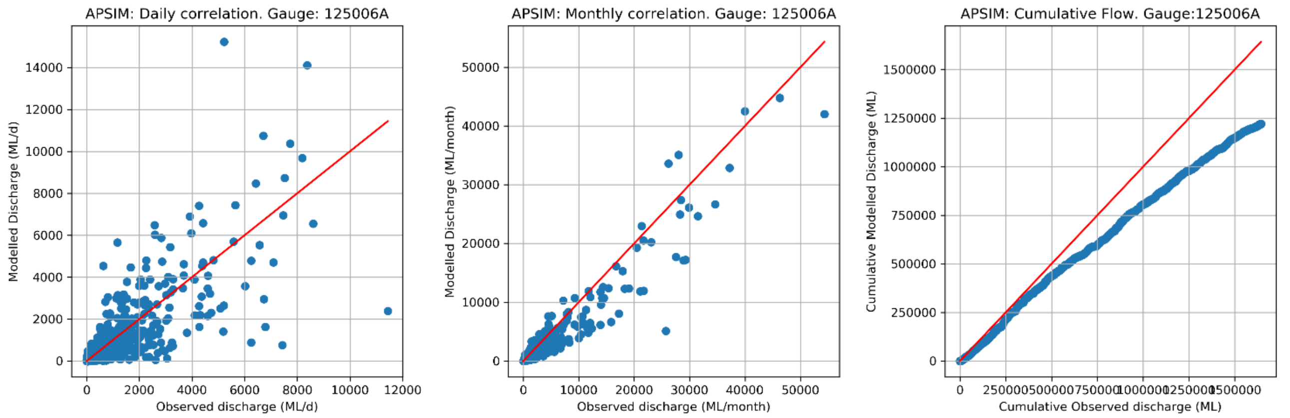

Monthly correlation. Gauge: 125004B
Modelled Discharge (ML/month)
Observed discharge (ML/month)

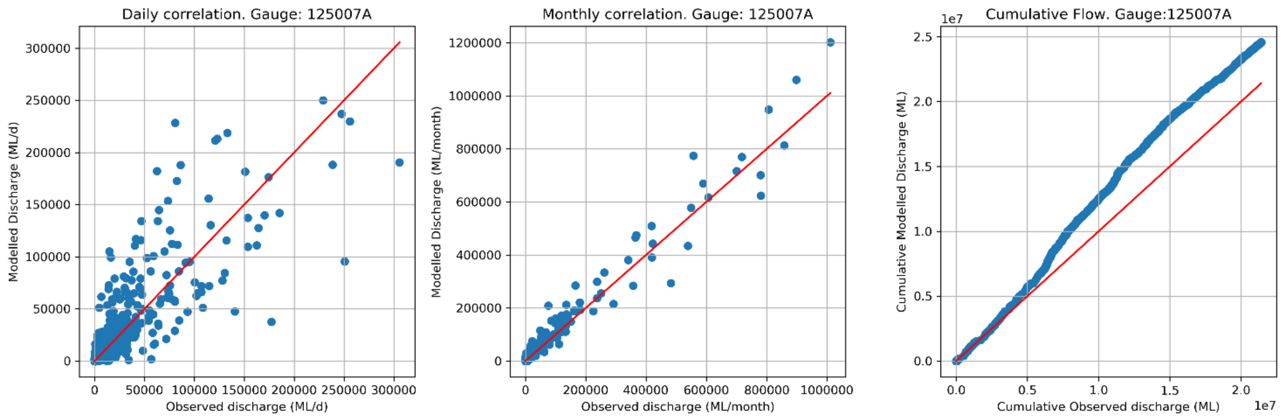

Cumulative Flow. Gauge:125004B
1e7
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)

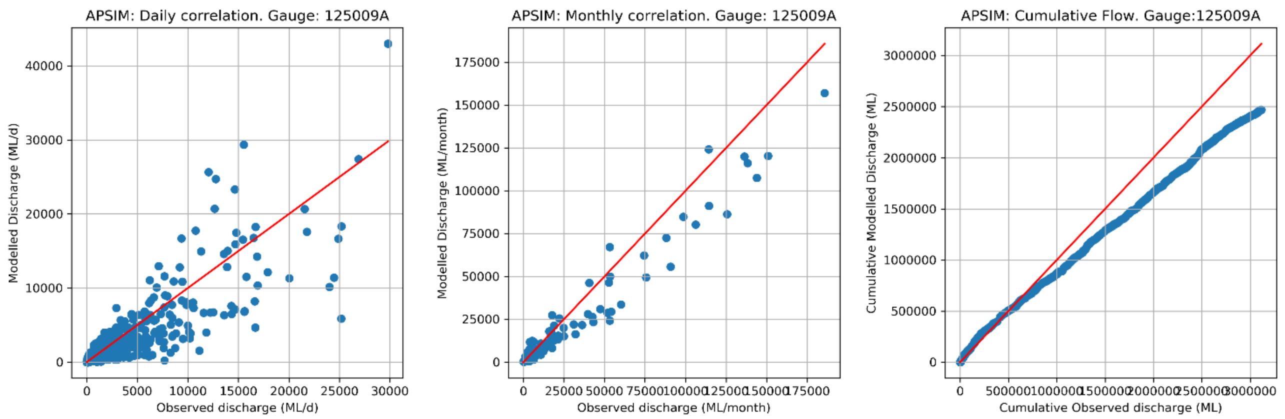

APSIM: Daily correlation. Gauge: 125005A
Modelled Discharge (ML/d)
Observed discharge (ML/d)

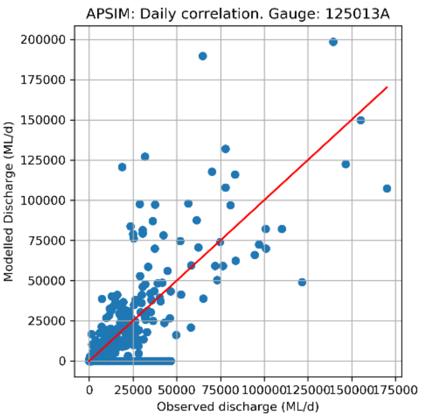

APSIM: Monthly correlation. Gauge: 125005A
Modelled Discharge (ML/month)
Observed discharge (ML/month)

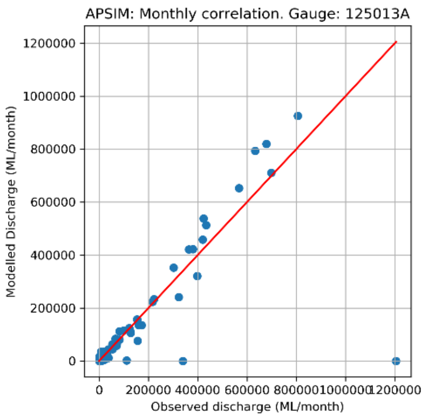

APSIM: Cumulative Flow. Gauge:125005A
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)

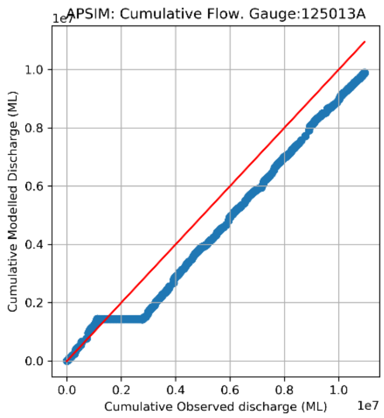

APSIM: Daily correlation. Gauge: 125006A
Modelled Discharge (ML/d)
Observed discharge (ML/d)
APSIM: Monthly correlation. Gauge: 125006A
Modelled Discharge (ML/month)
Observed discharge (ML/month)
APSIM: Cumulative Flow. Gauge:125006A
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)

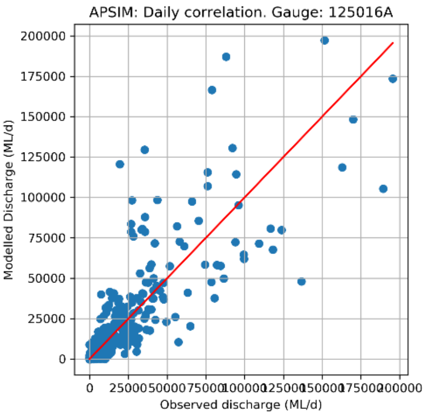

Daily correlation. Gauge: 125007A
Modelled Discharge (ML/d)
Observed discharge (ML/d)
Monthly correlation. Gauge: 125007A
Modelled Discharge (ML/month)
Observed discharge (ML/month)
Cumulative Flow. Gauge:125007A
1e7
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)
1e7

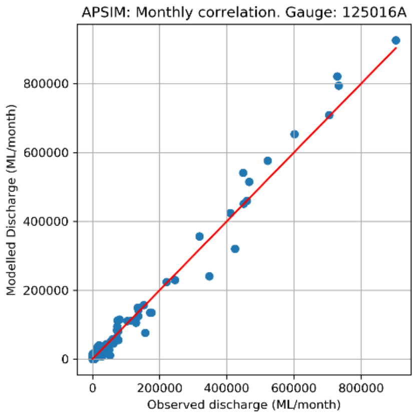

APSIM: Daily correlation. Gauge: 125009A
Modelled Discharge (ML/d)
Observed discharge (ML/d)
APSIM: Monthly correlation. Gauge: 125009A
Modelled Discharge (ML/month)
Observed discharge (ML/month)
APSIM: Cumulative Flow. Gauge:125009A
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)

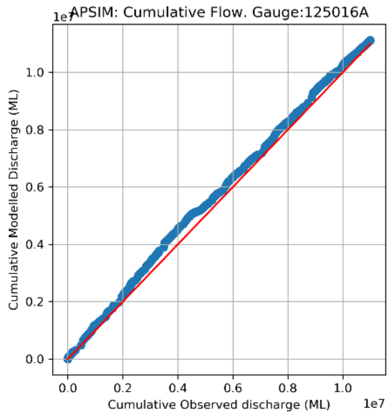

APSIM: Daily correlation. Gauge: 125013A
Modelled Discharge (ML/d)
Observed discharge (ML/d)

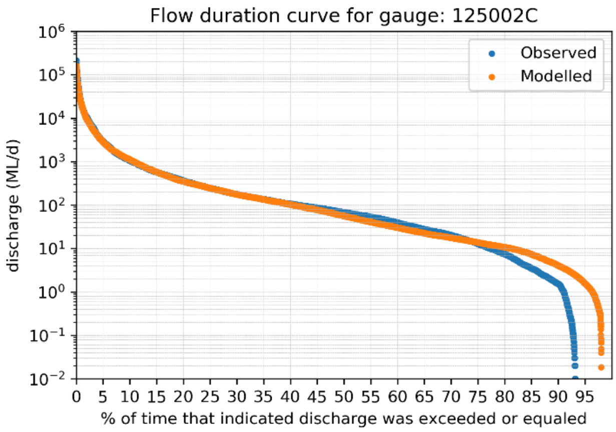

APSIM: Monthly correlation. Gauge: 125013A
Modelled Discharge (ML/month)
Observed discharge (ML/month)

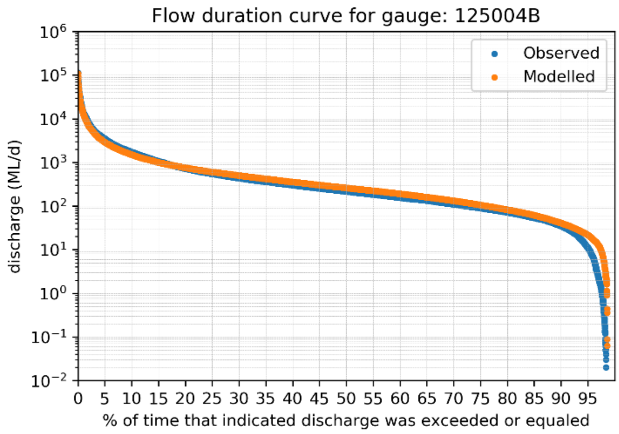

APSIM: Cumulative Flow. Gauge:125013A
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)
1e7

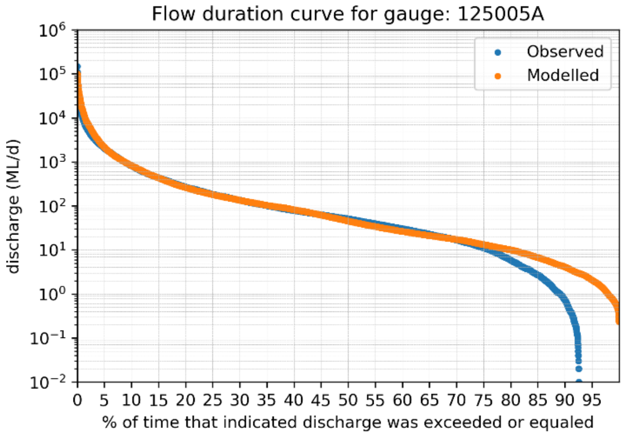

APSIM: Daily correlation. Gauge: 125016A
Modelled Discharge (ML/d)
Observed discharge (ML/d)

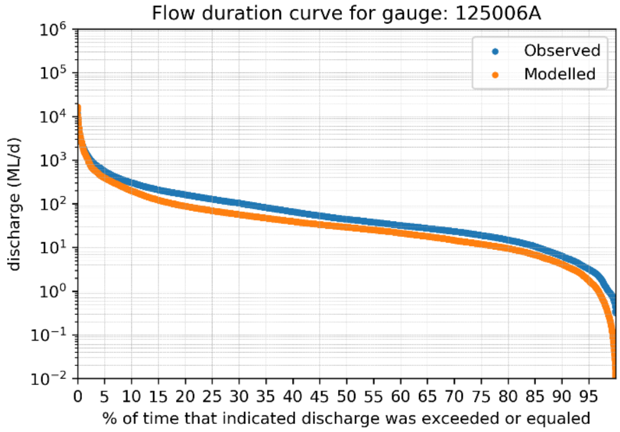

APSIM: Monthly correlation. Gauge: 125016A
Modelled Discharge (ML/month)
Observed discharge (ML/month)

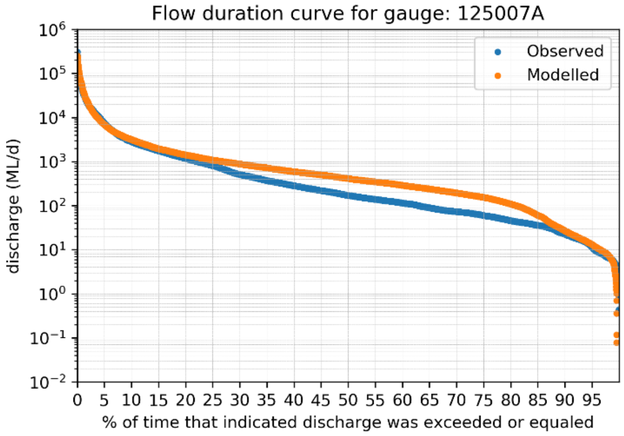

APSIM: Cumulative Flow. Gauge:125016A
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)
1e7

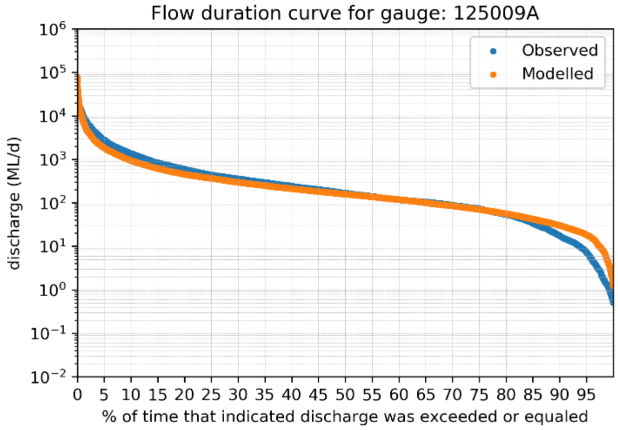

Flow duration curve for gauge: 125002C
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

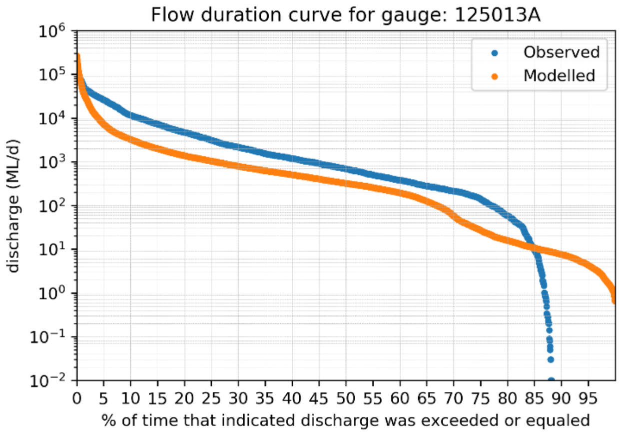

Flow duration curve for gauge: 125004B
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

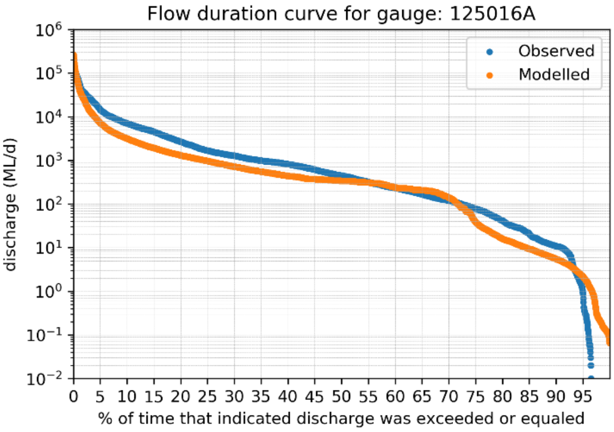

Flow duration curve for gauge: 125005A
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled


Flow duration curve for gauge: 125006A
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled


Flow duration curve for gauge: 125007A
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

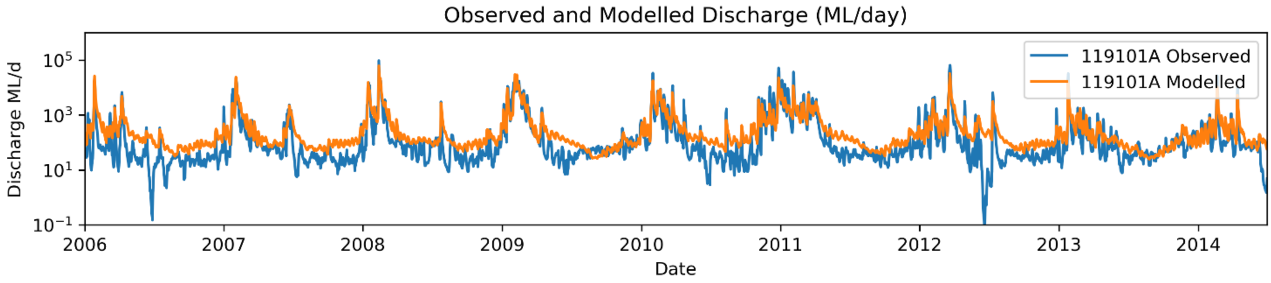

Flow duration curve for gauge: 125009A
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

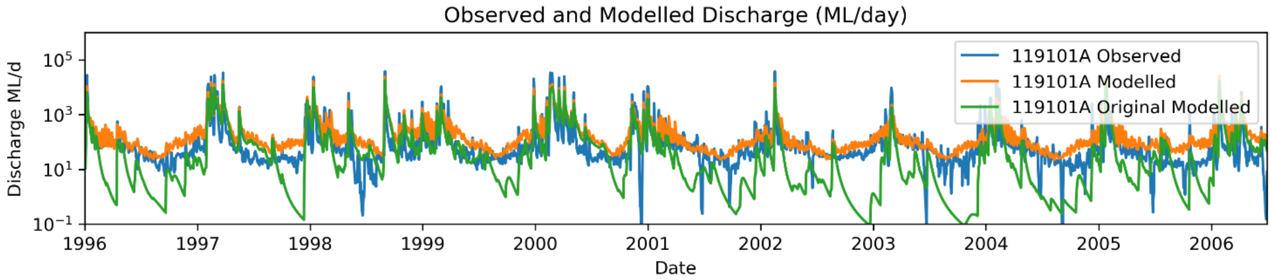

Flow duration curve for gauge: 125013A
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

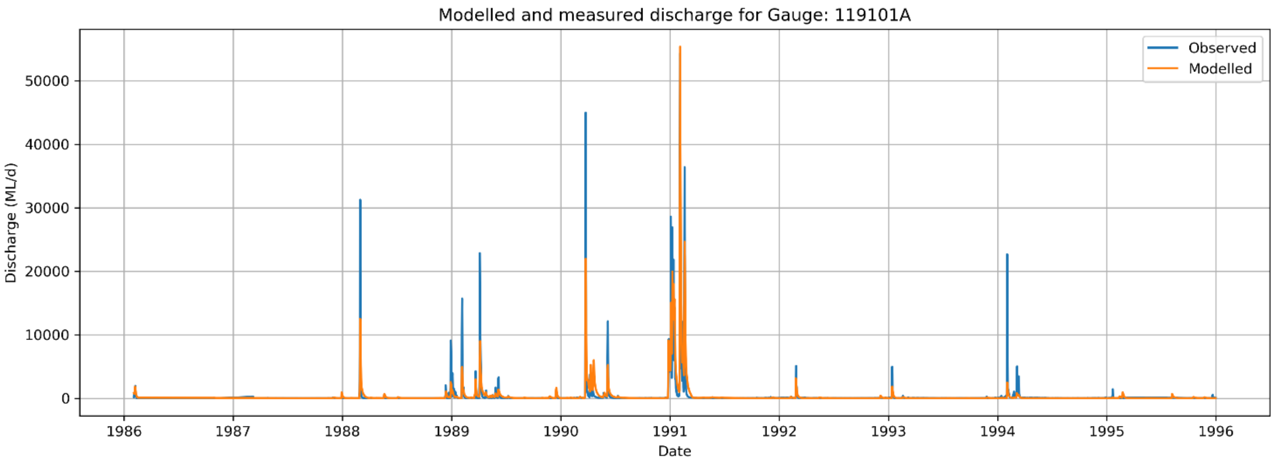

Flow duration curve for gauge: 125016A
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

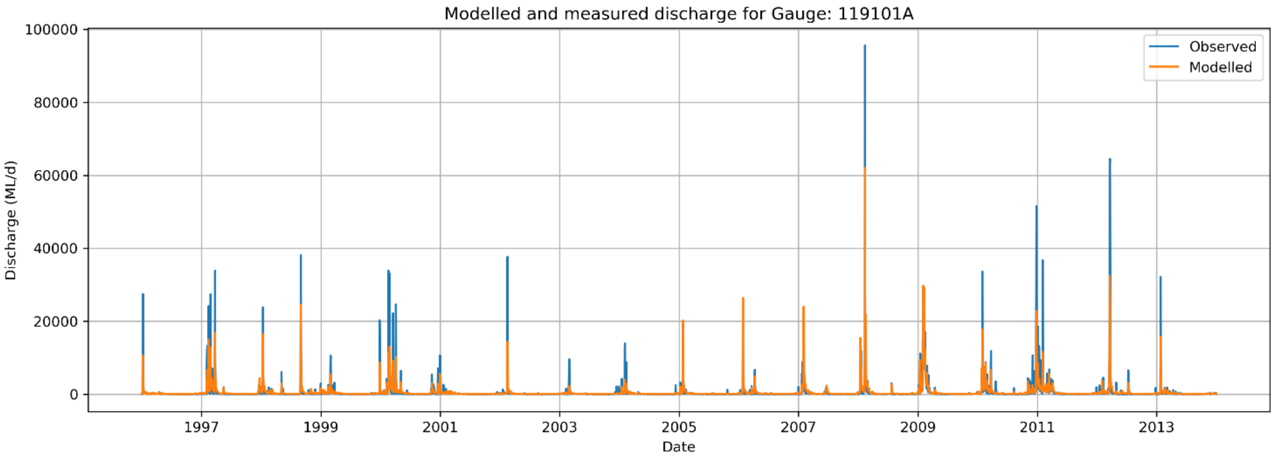
13.2 Barratta catchment

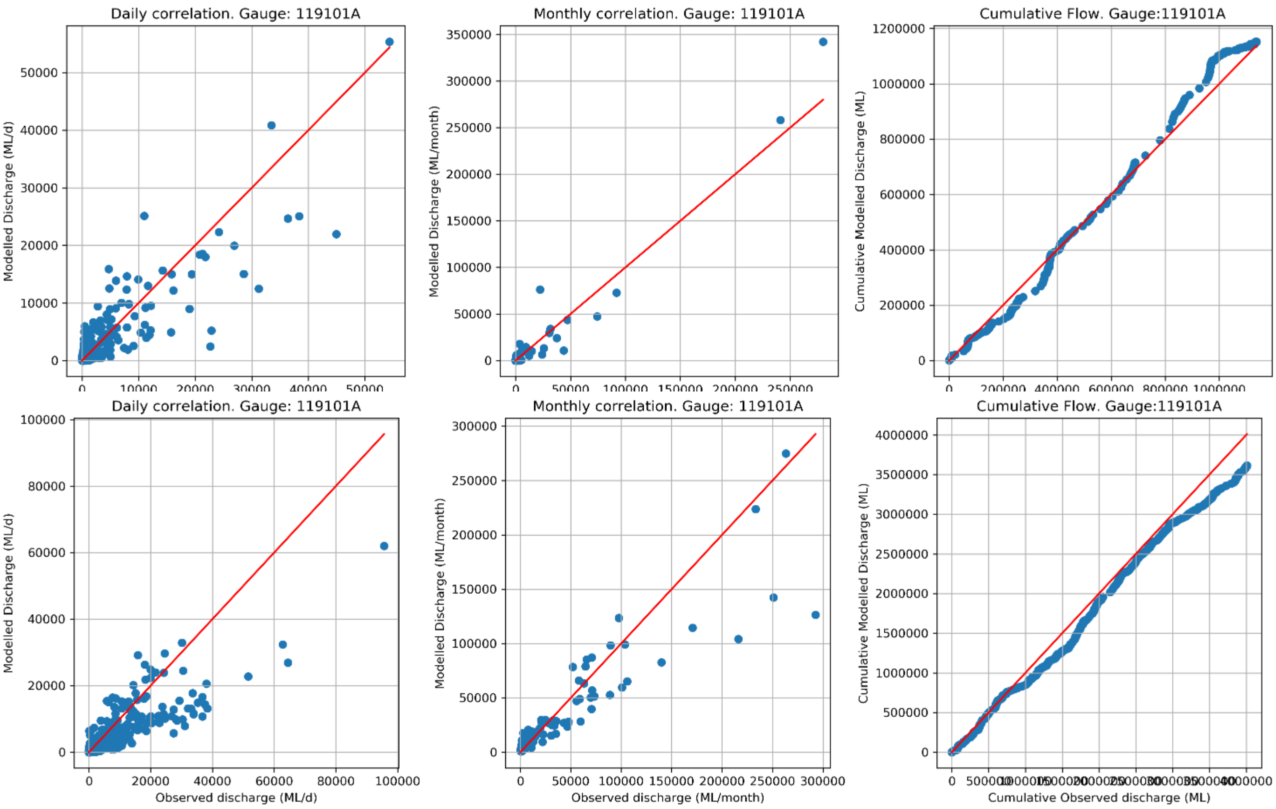
13.2.1 Hydrology performance plots

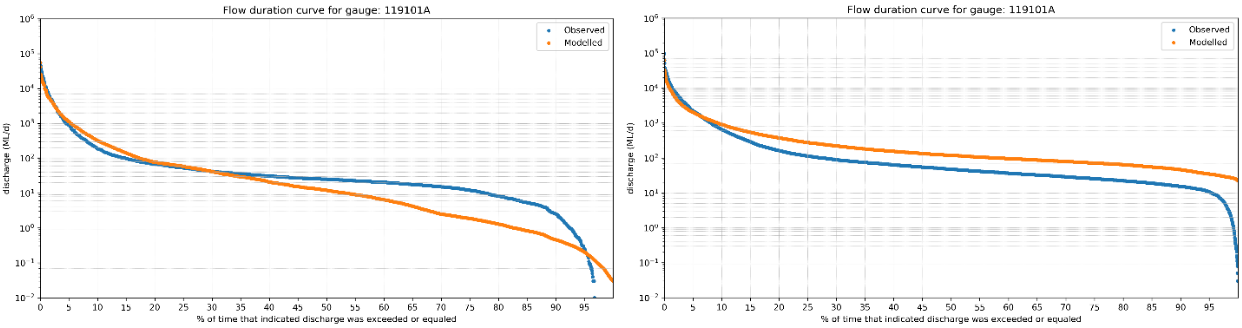






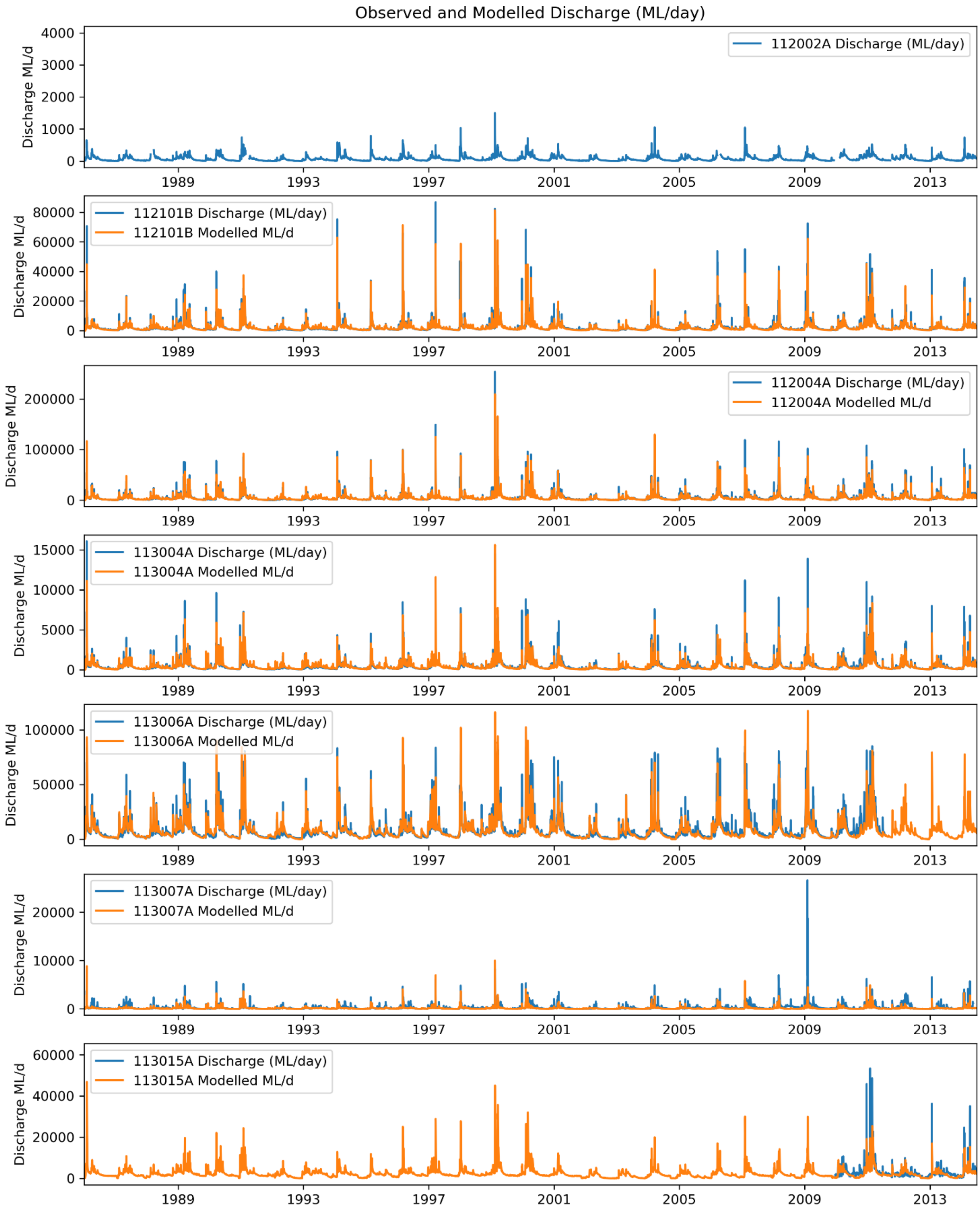


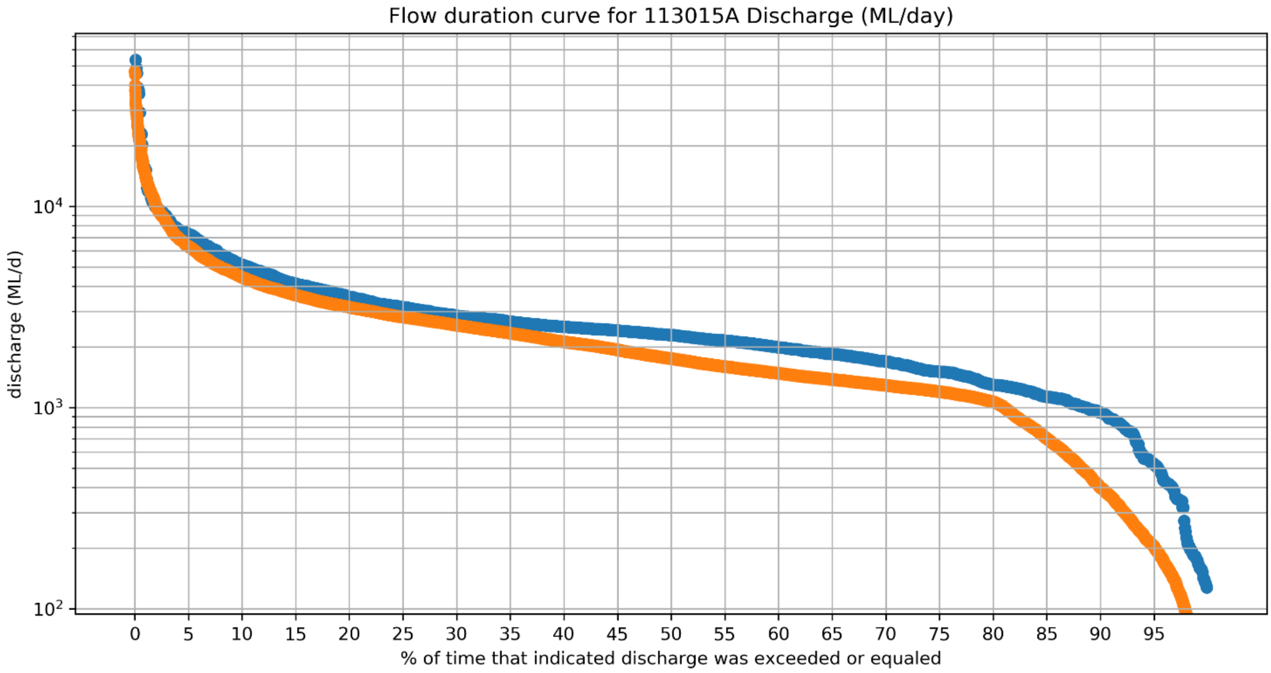

Daily correlation. Gauge: 119101A
Monthly correlation. Gauge: 119101A
Cumulative Flow. Gauge:119101A
Modelled Discharge (ML/d)
Modelled Discharge (ML/month)
Cumulative Modelled Discharge (ML)
Daily correlation. Gauge: 119101A
Monthly correlation. Gauge: 119101A
Cumulative Flow. Gauge:119101A
Modelled Discharge (ML/d)
Modelled Discharge (ML/month)
Cumulative Modelled Discharge (ML)
Observed discharge (ML/d)
Observed discharge (ML/month)
Cumulative Observed discharge (ML)

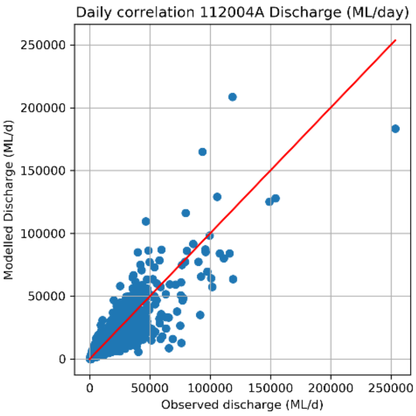

Flow duration curve for gauge: 119101A
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled
Flow duration curve for gauge: 119101A
Observed
Modelled
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

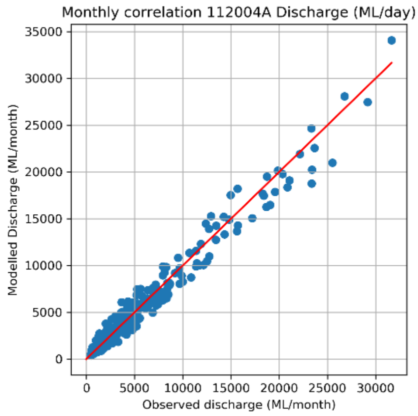
13.3 Tully-Johnstone catchment

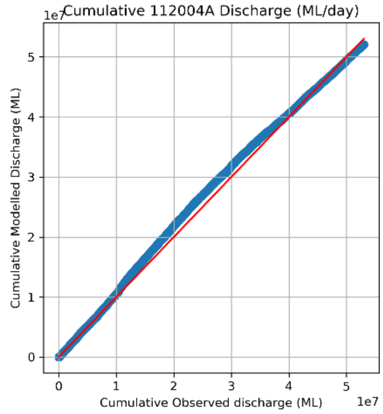
13.3.1 Hydrology performance plots

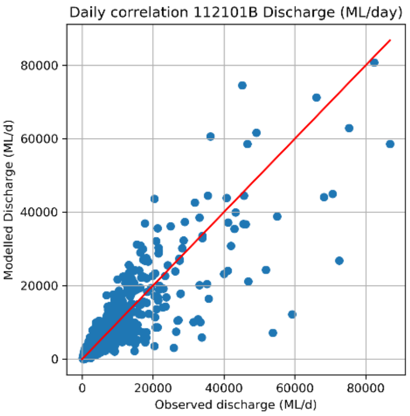


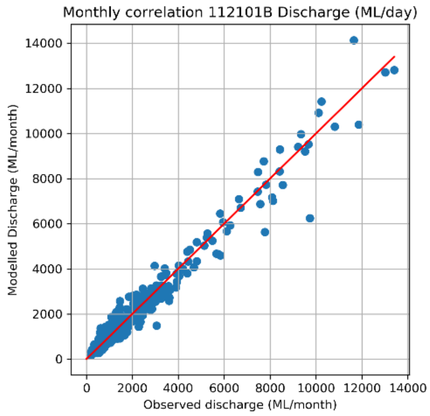

Flow duration curve for 113015A Discharge (ML/day)
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

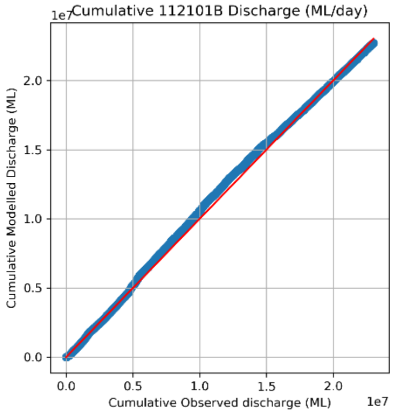

Daily correlation 112004A Discharge (ML/day)
Modelled Discharge (ML/d)
Observed discharge (ML/d)

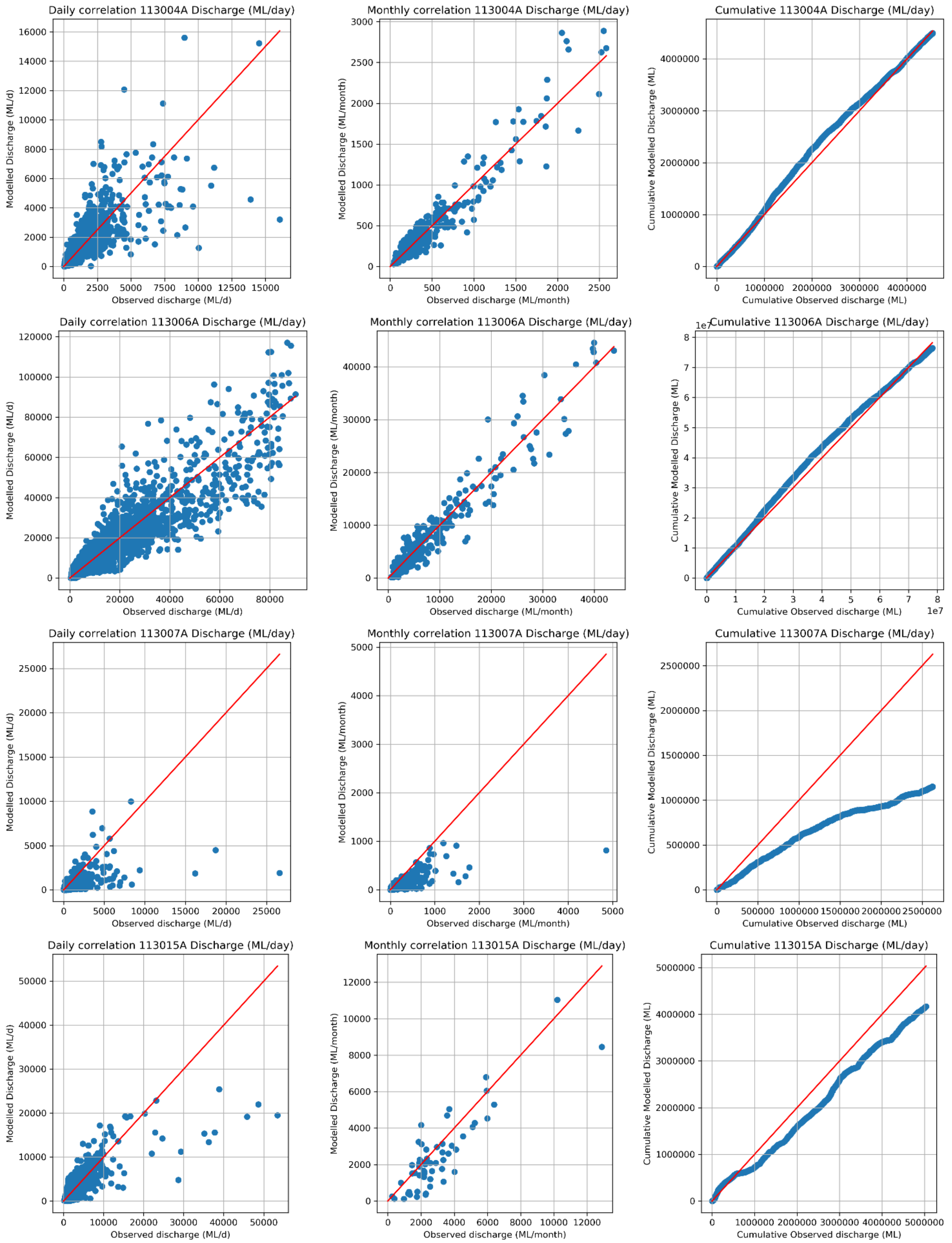

Monthly correlation 112004A Discharge (ML/day)
Modelled Discharge (ML/month)
Observed discharge (ML/month)

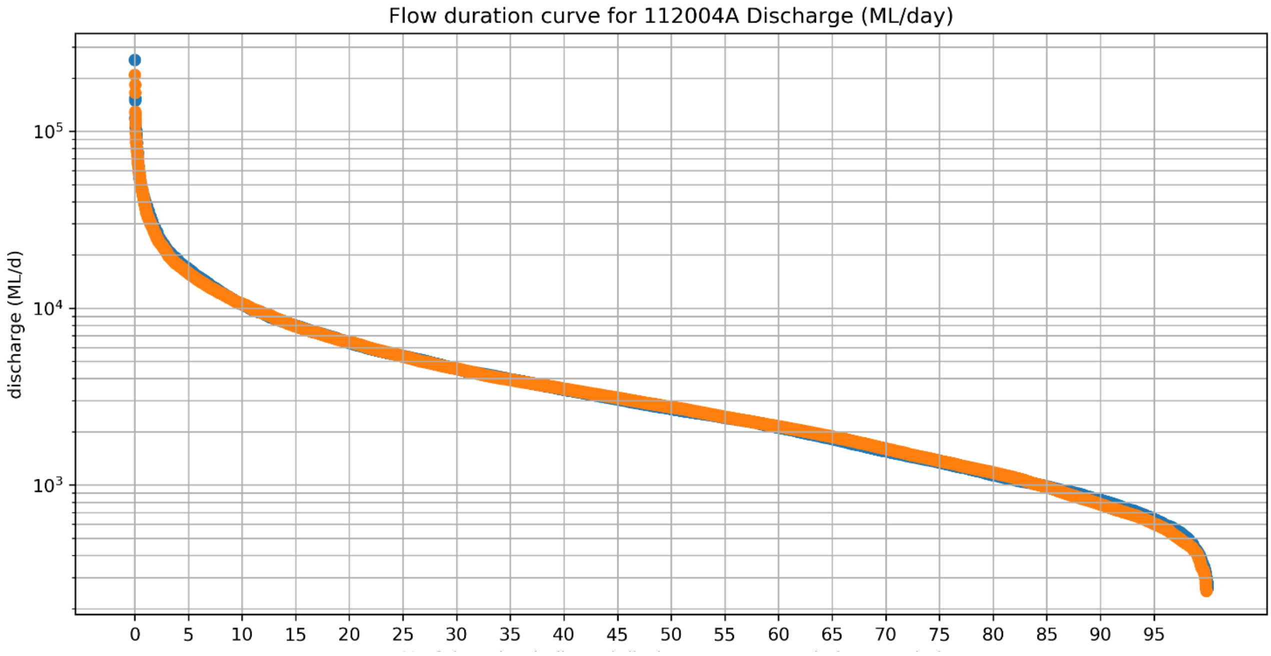

Cumulative 112004A Discharge (ML/day)
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)

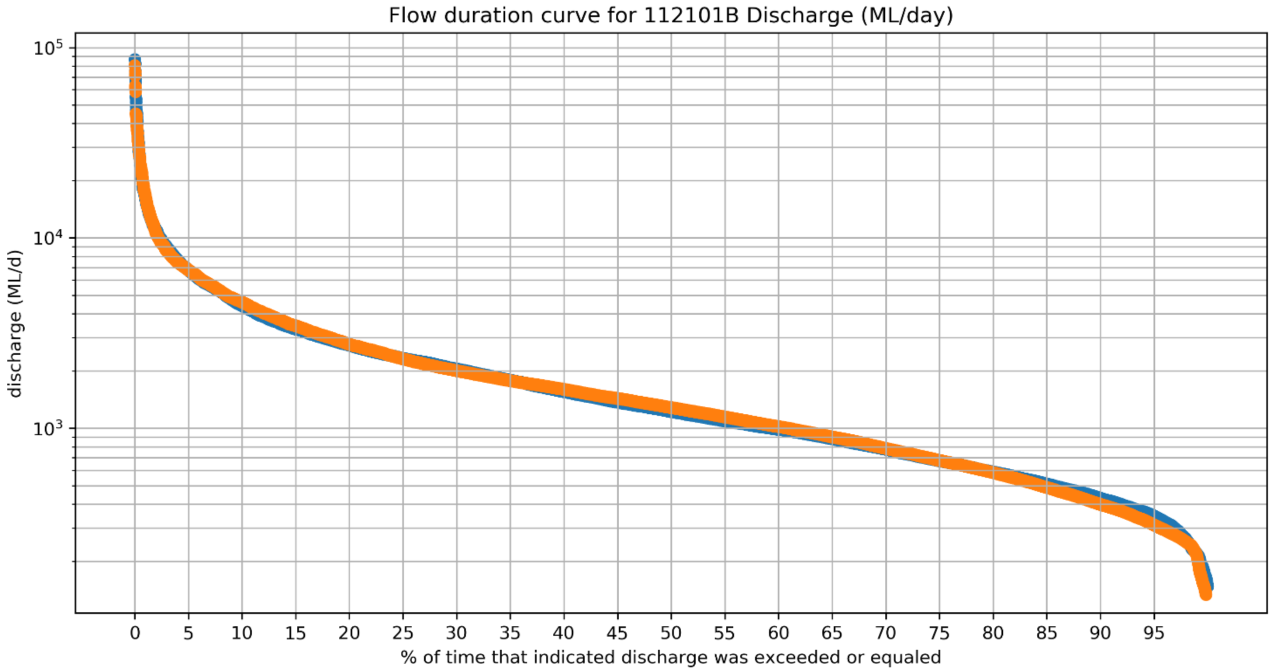

Daily correlation 112101B Discharge (ML/day)
Modelled Discharge (ML/d)
Observed discharge (ML/d)

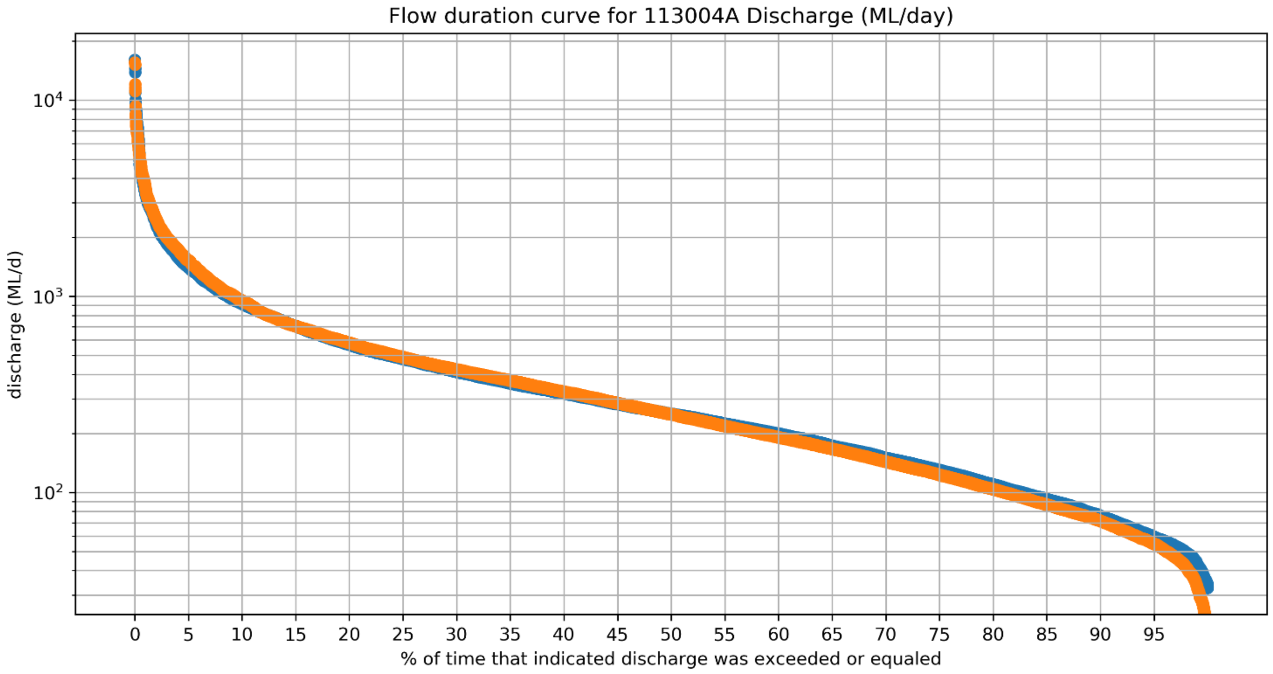

Monthly correlation 112101B Discharge (ML/day)
Modelled Discharge (ML/month)
Observed discharge (ML/month)


Cumulative 112101B Discharge (ML/day)
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)

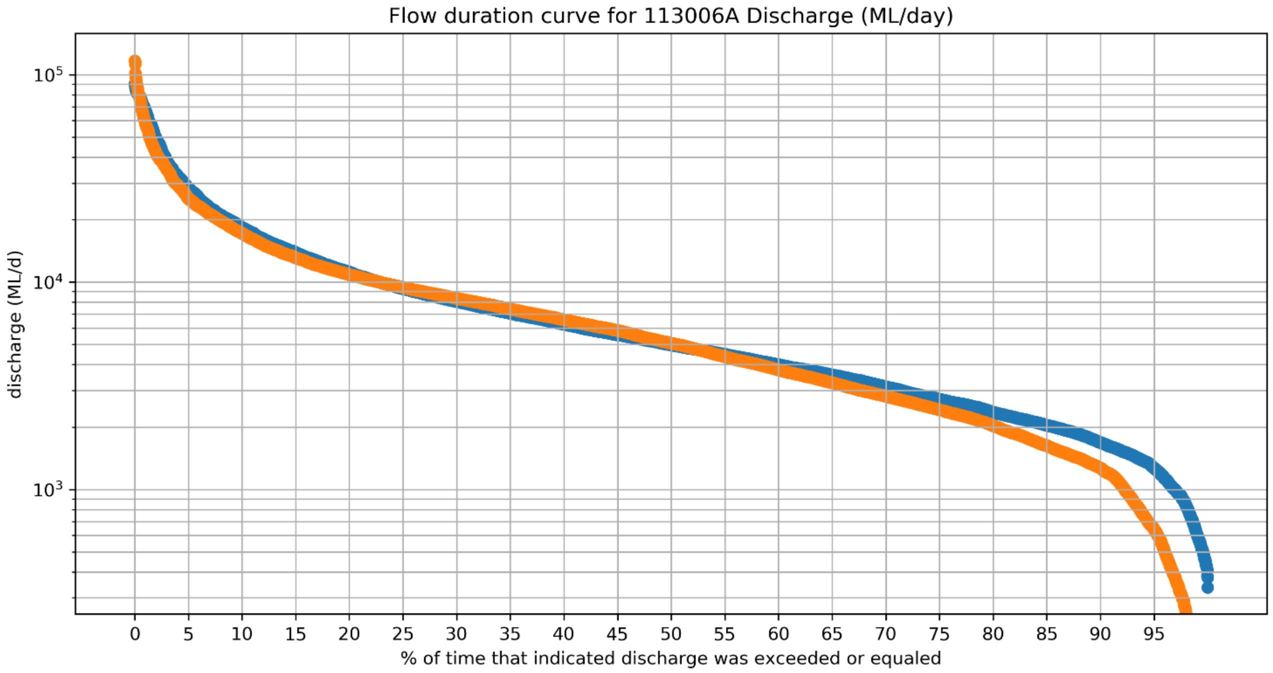

Daily correlation 113004A Discharge (ML/day)
Modelled Discharge (ML/d)
Observed discharge (ML/d)
Monthly correlation 113004A Discharge (ML/day)
Modelled Discharge (ML/month)
Observed discharge (ML/month)
Cumulative 113004A Discharge (ML/day)
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)
Daily correlation 113006A Discharge (ML/day)
Modelled Discharge (ML/d)
Observed discharge (ML/d)
Monthly correlation 113006A Discharge (ML/day)
Modelled Discharge (ML/month)
Observed discharge (ML/month)
Cumulative 113006A Discharge (ML/day)
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)
1e7
Daily correlation 113007A Discharge (ML/day)
Modelled Discharge (ML/d)
Observed discharge (ML/d)
Monthly correlation 113007A Discharge (ML/day)
Modelled Discharge (ML/month)
Observed discharge (ML/month)
Cumulative 113007A Discharge (ML/day)
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)
Daily correlation 113015A Discharge (ML/day)
Modelled Discharge (ML/d)
Observed discharge (ML/d)
Monthly correlation 113015A Discharge (ML/day)
Modelled Discharge (ML/month)
Observed discharge (ML/month)
Cumulative 113015A Discharge (ML/day)
Cumulative Modelled Discharge (ML)
Cumulative Observed discharge (ML)


Flow duration curve for 112004A Discharge (ML/day)
discharge (ML/d)
10^5
10^4
10^3
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95

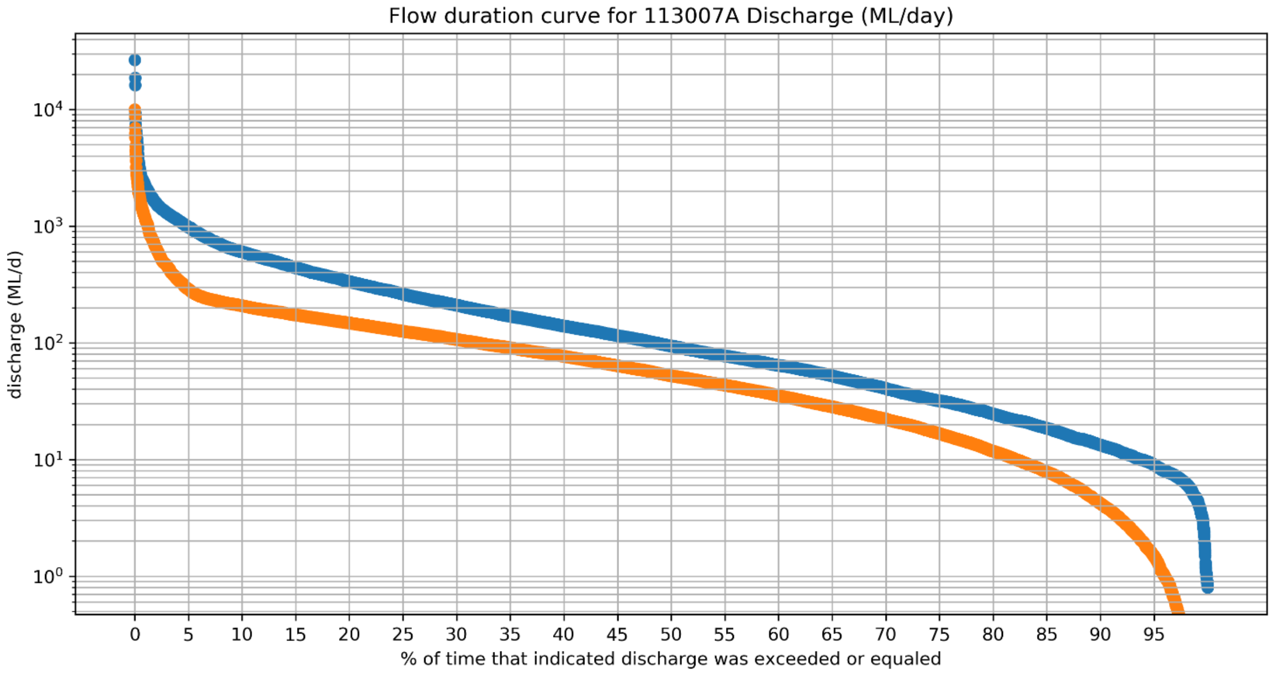

Flow duration curve for 112101B Discharge (ML/day)
discharge (ML/d)
10^5
10^4
10^3
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
% of time that indicated discharge was exceeded or equaled



Flow duration curve for 113004A Discharge (ML/day)
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

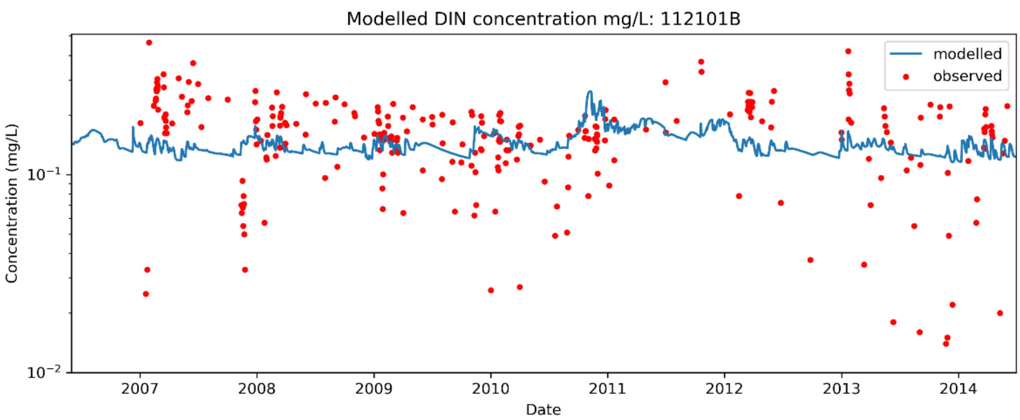


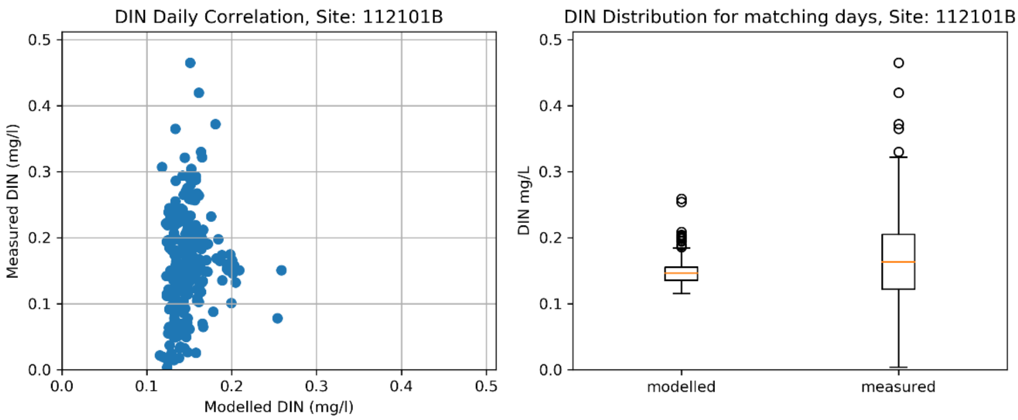
Flow duration curve for 113006A Discharge (ML/day)
discharge (ML/d)
% of time that indicated discharge was exceeded or equaled

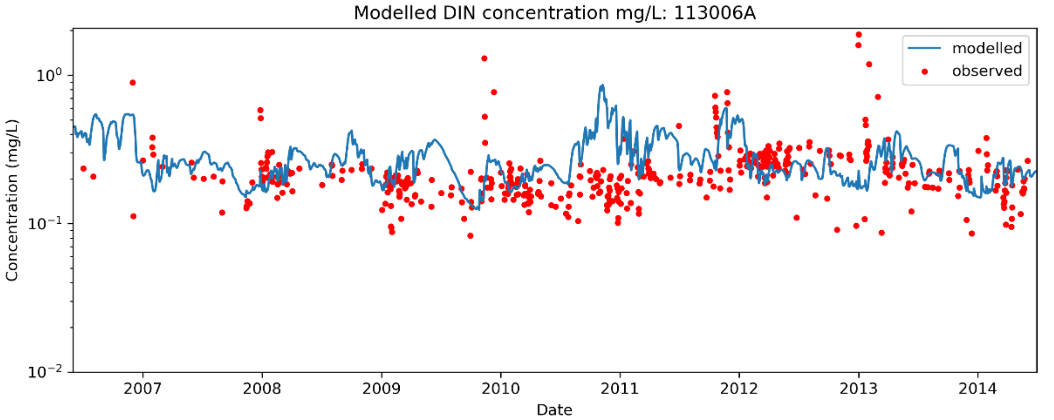


13.4 Water quality performance

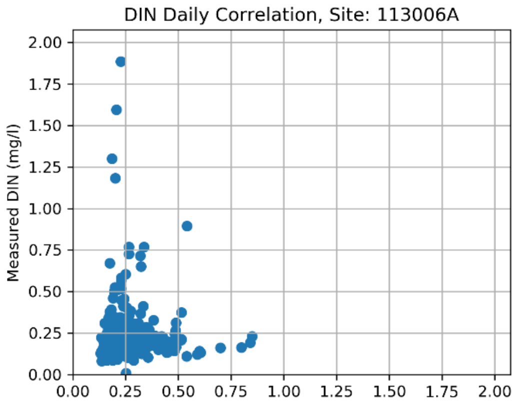
13.4.1 DIN performance plots



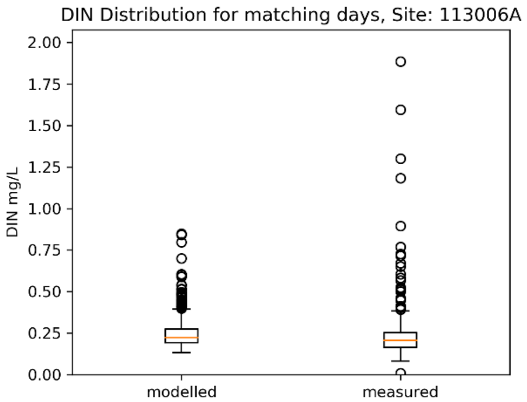




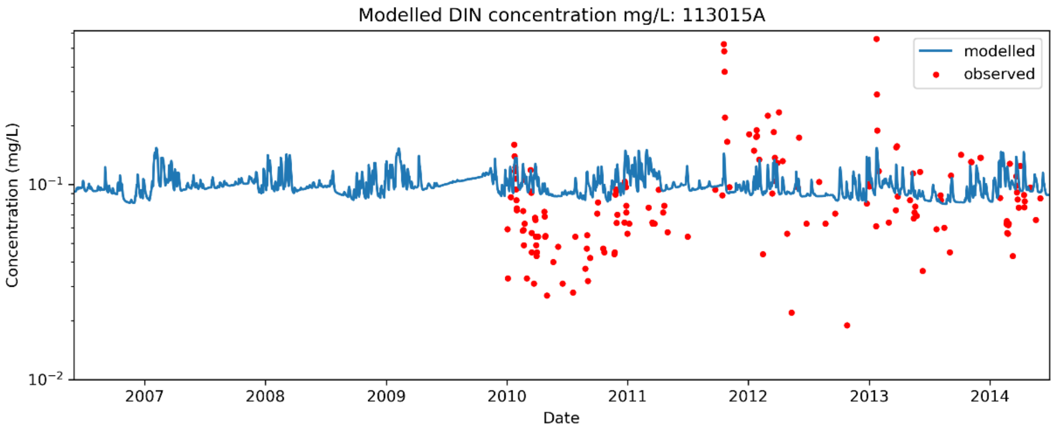
Modelled DIN concentration mg/L: 113006A
modelled
observed
Concentration (mg/L)
10^0
10^{-1}
10^{-2}
2007
2008
2009
2010
2011
2012
2013
2014
Date



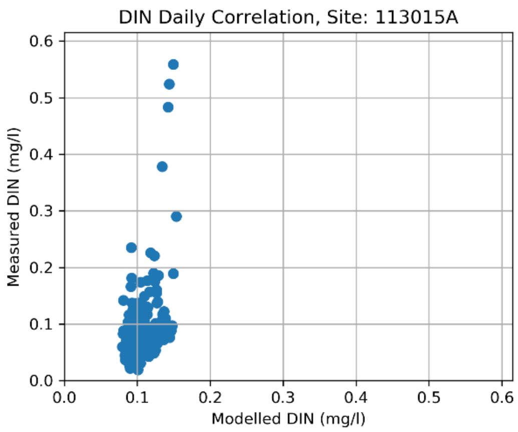
DIN Daily Correlation, Site: 113006A
Measured DIN (mg/l)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00



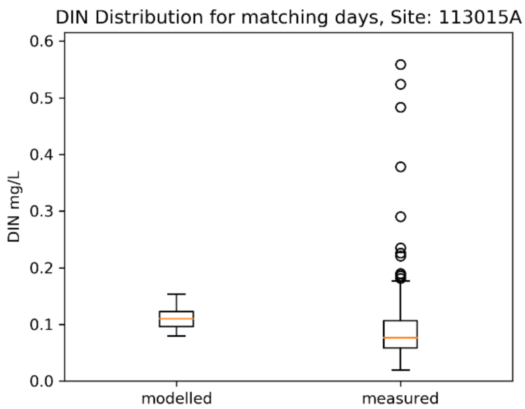
DIN Distribution for matching days, Site: 113006A
DIN mg/L
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
modelled
measured



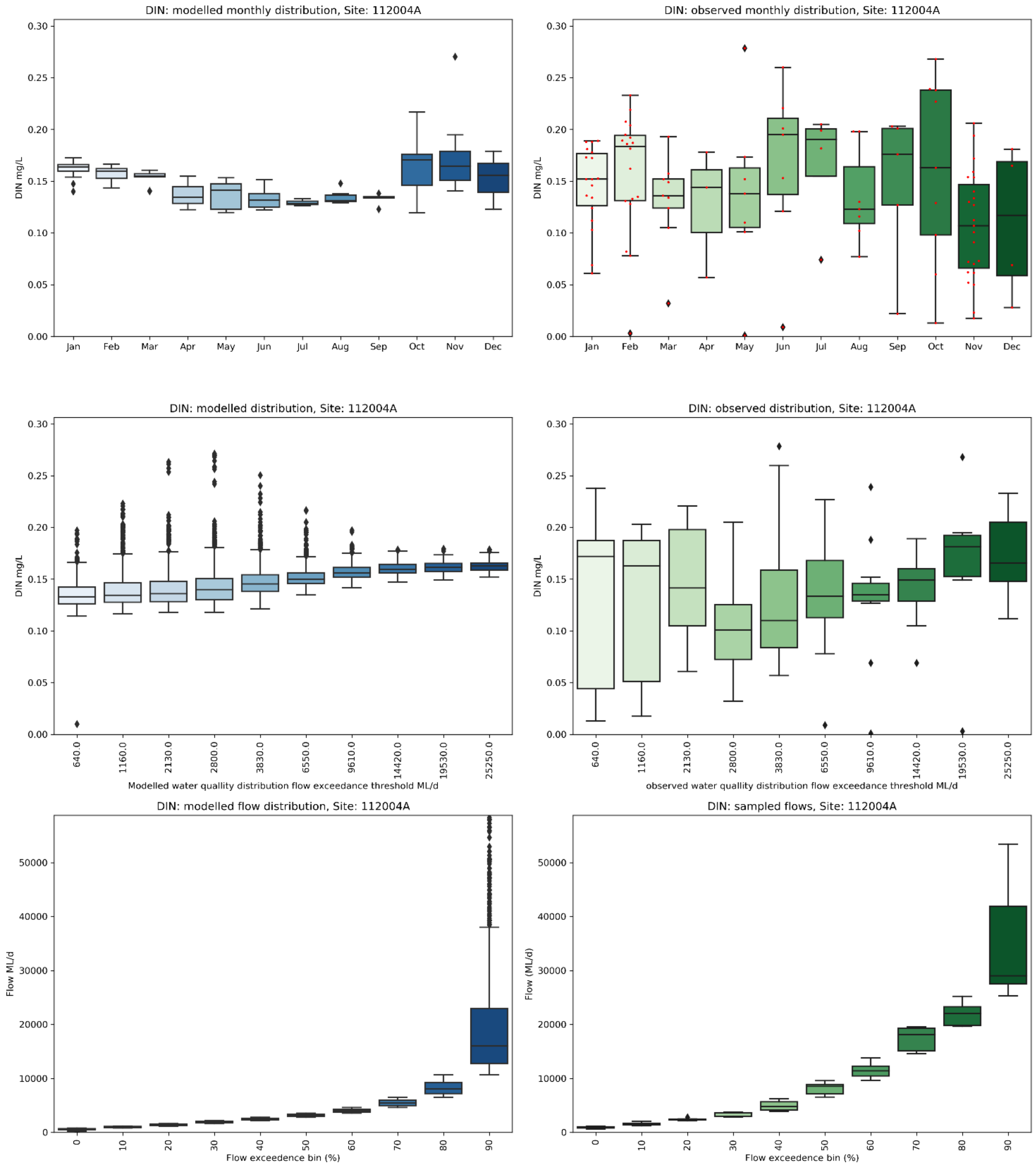
Modelled DIN concentration mg/L: 113015A
modelled
observed
Concentration (mg/L)
10^{-1}
10^{-2}
2007
2008
2009
2010
2011
2012
2013
2014
Date

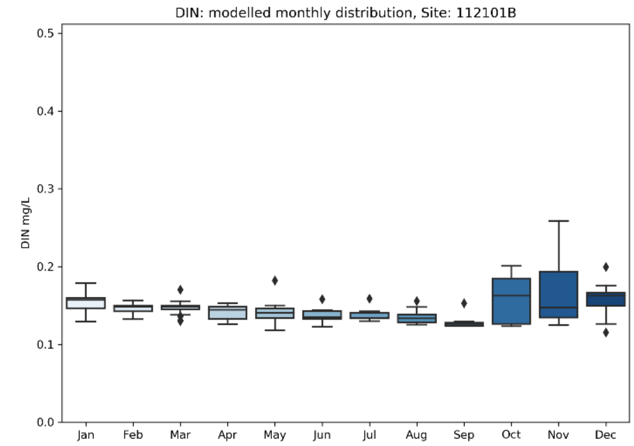


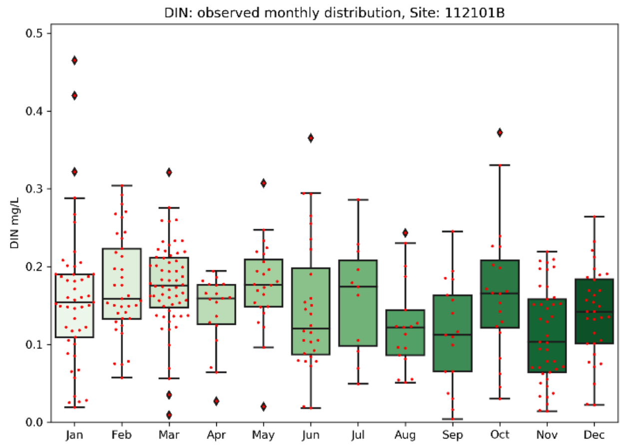
DIN Daily Correlation, Site: 113015A
Measured DIN (mg/l)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Modelled DIN (mg/l)

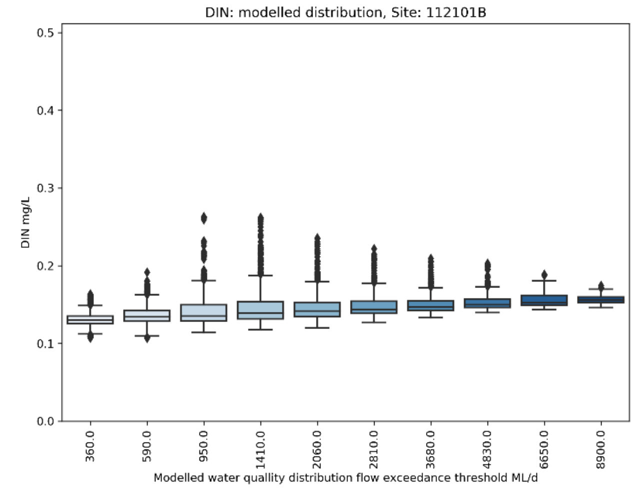


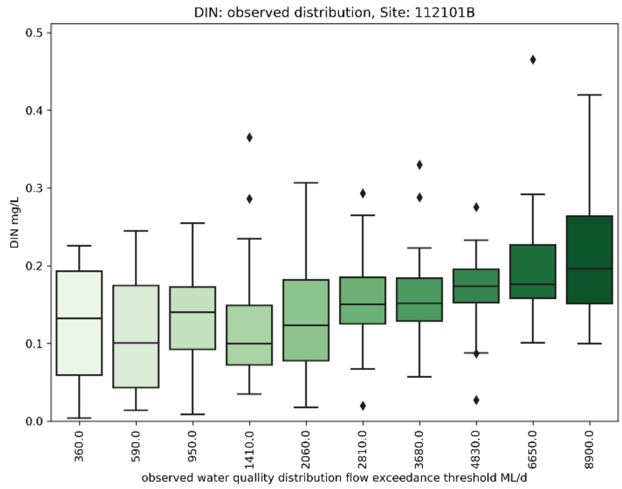
DIN Distribution for matching days, Site: 113015A
DIN mg/L
0.6
0.5
0.4
0.3
0.2
0.1
0.0
modelled
measured

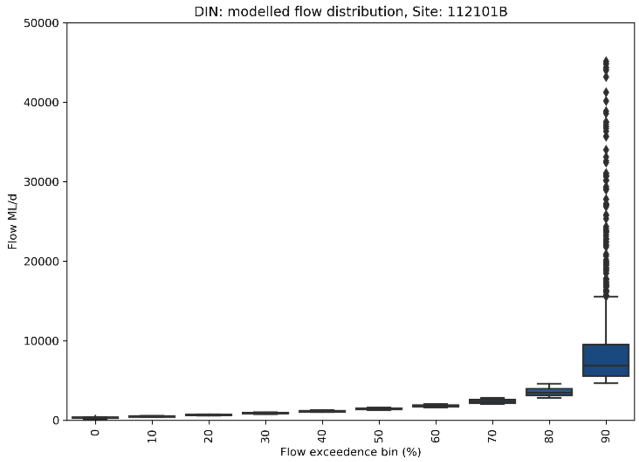

DIN: modelled monthly distribution, Site: 112004A
DIN: observed monthly distribution, Site: 112004A
DIN mg/L
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
DIN: modelled distribution, Site: 112004A
DIN: observed distribution, Site: 112004A
640.0
1160.0
2130.0
2800.0
3830.0
6550.0
9610.0
14420.0
19530.0
25250.0
Modelled water quallity distribution flow exceedance threshold ML/d
observed water quallity distribution flow exceedance threshold ML/d
DIN: modelled flow distribution, Site: 112004A
DIN: sampled flows, Site: 112004A
Flow ML/d
Flow (ML/d)
Flow exceedence bin (%)

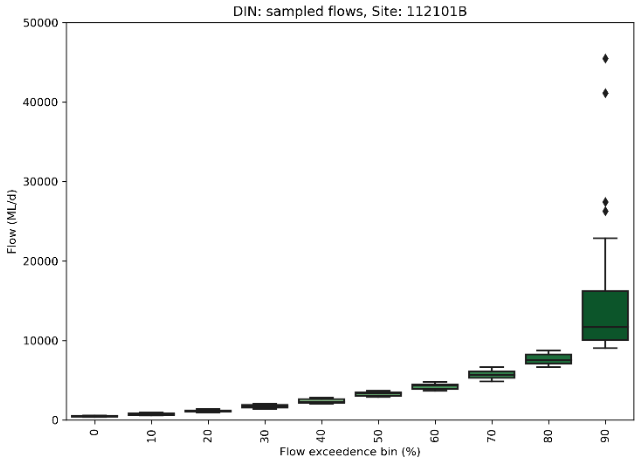

DIN: modelled monthly distribution, Site: 112101B
DIN mg/L
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

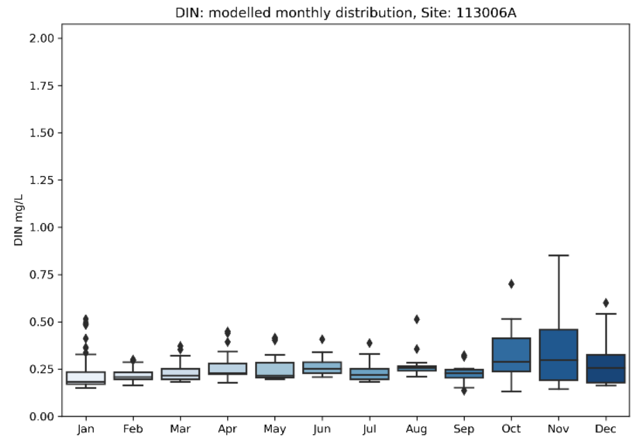

DIN: observed monthly distribution, Site: 112101B
DIN mg/L
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

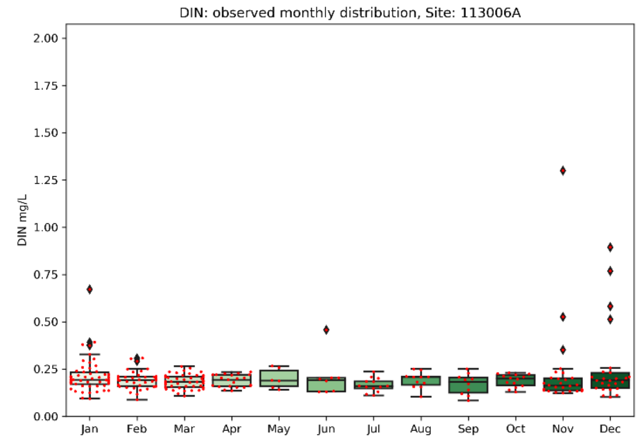

DIN: modelled distribution, Site: 112101B
DIN mg/L
Modelled water quallity distribution flow exceedance threshold ML/d

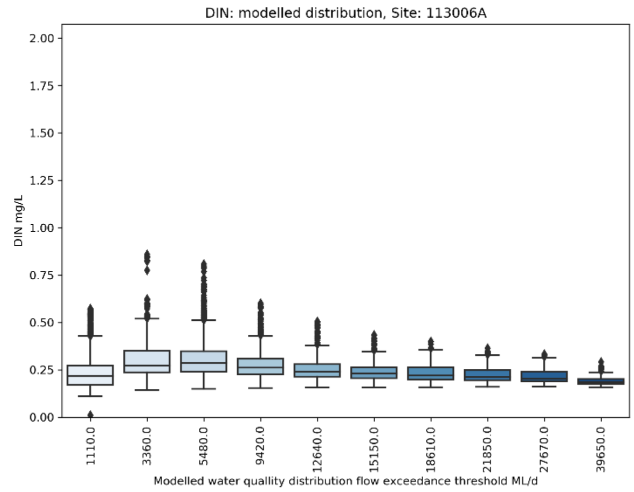

DIN: observed distribution, Site: 112101B
DIN mg/L
observed water quallity distribution flow exceedance threshold ML/d

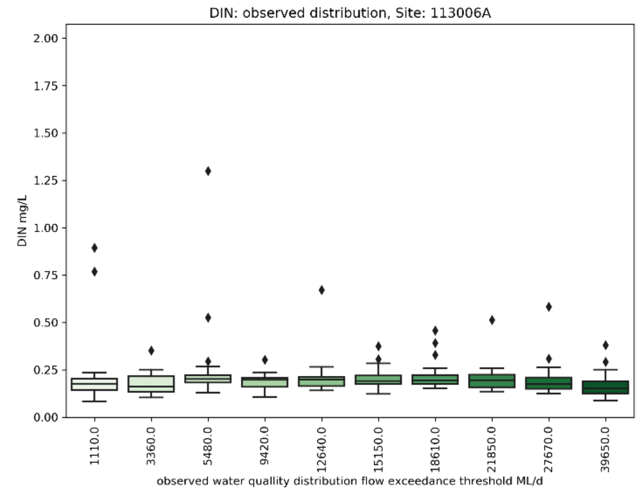

DIN: modelled flow distribution, Site: 112101B
Flow ML/d
Flow exceedence bin (%)

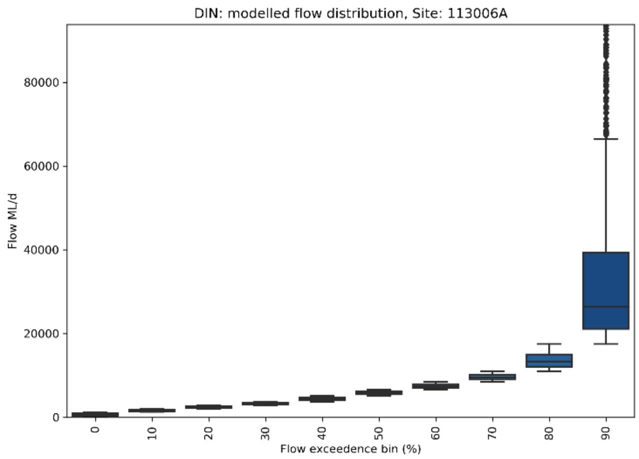

DIN: sampled flows, Site: 112101B
Flow (ML/d)
Flow exceedence bin (%)

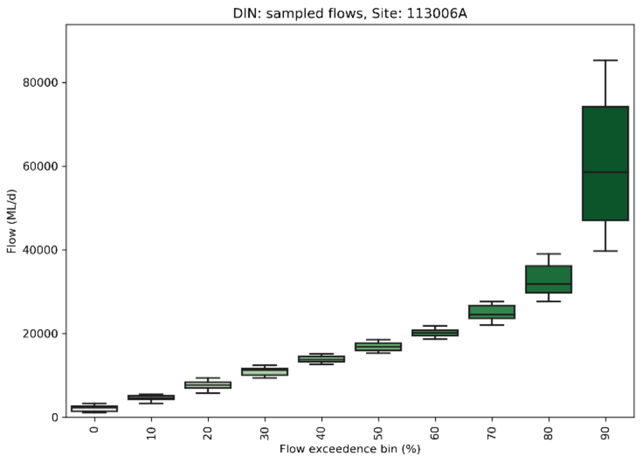

DIN: modelled monthly distribution, Site: 113006A
DIN mg/L
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

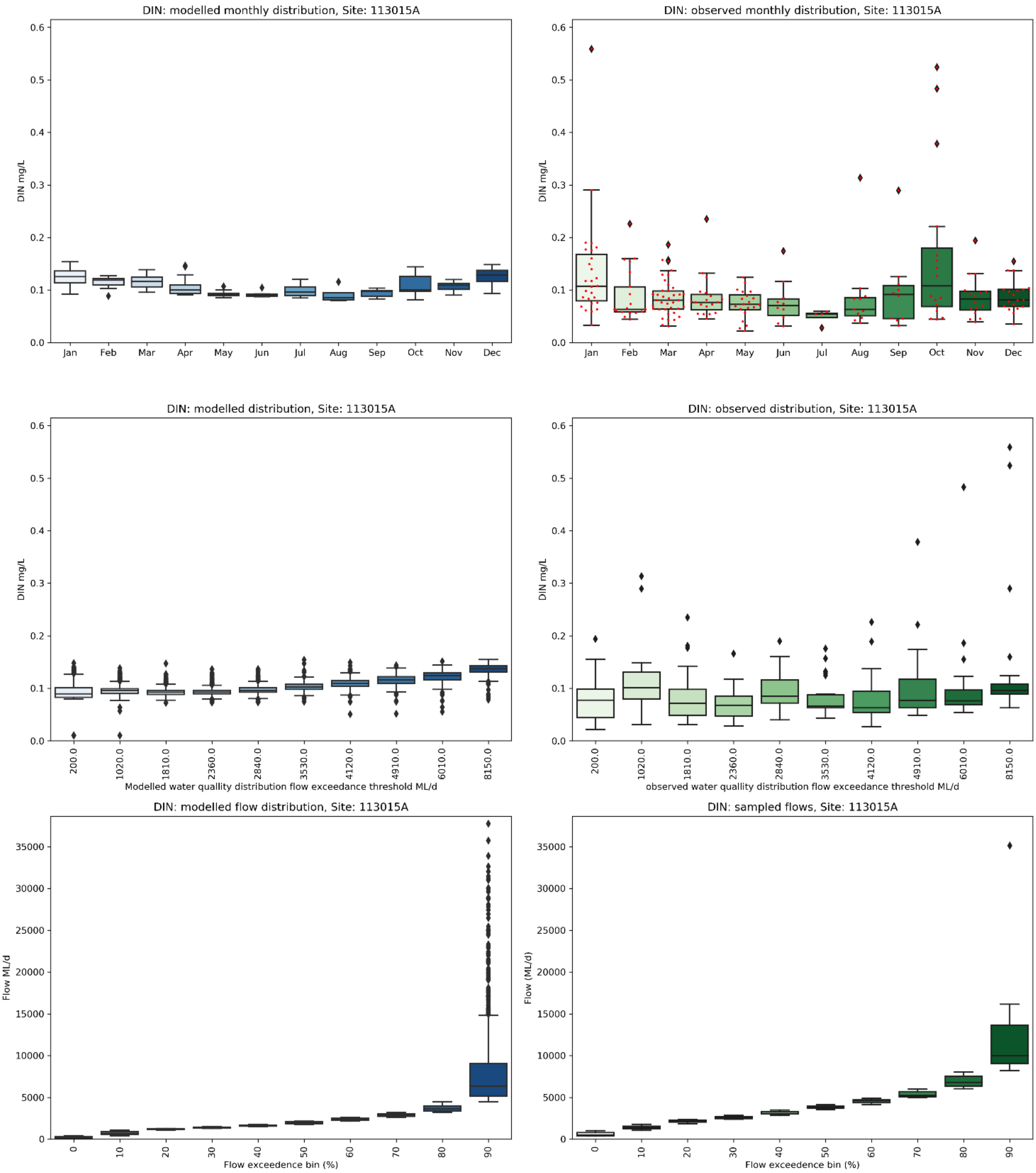

DIN: observed monthly distribution, Site: 113006A
DIN mg/L
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


DIN: modelled distribution, Site: 113006A
DIN mg/L
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1110.0
3360.0
5480.0
9420.0
12640.0
15150.0
18610.0
21850.0
27670.0
39650.0
Modelled water quallity distribution flow exceedance threshold ML/d

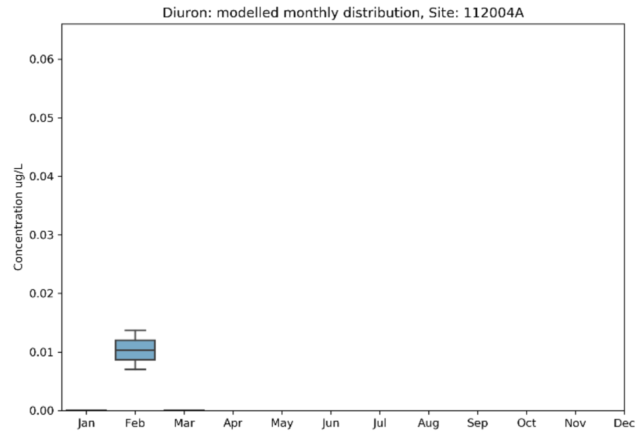

DIN: observed distribution, Site: 113006A
DIN mg/L
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1110.0
3360.0
5480.0
9420.0
12640.0
15150.0
18610.0
21850.0
27670.0
39650.0
observed water quallity distribution flow exceedance threshold ML/d

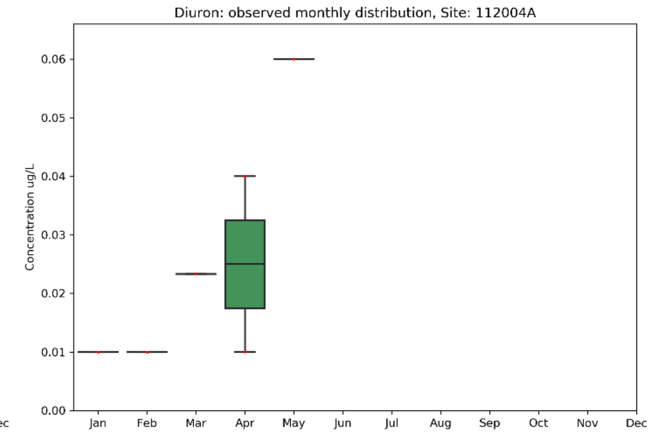

DIN: modelled flow distribution, Site: 113006A
Flow ML/d
80000
60000
40000
20000
0
0
10
20
30
40
50
60
70
80
90
Flow exceedence bin (%)

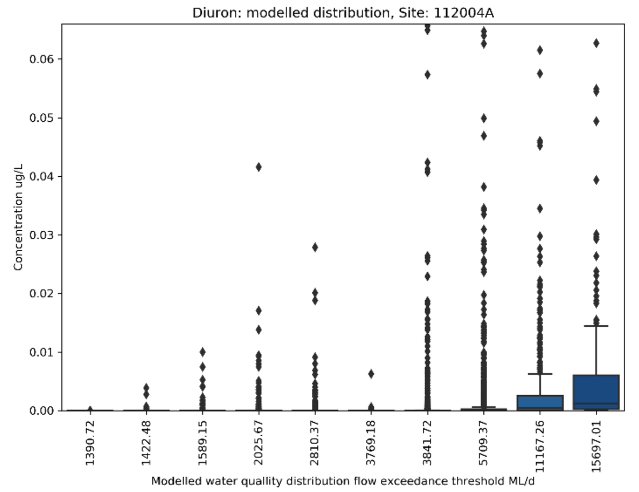

DIN: sampled flows, Site: 113006A
Flow (ML/d)
80000
60000
40000
20000
0
0
10
20
30
40
50
60
70
80
90
Flow exceedence bin (%)

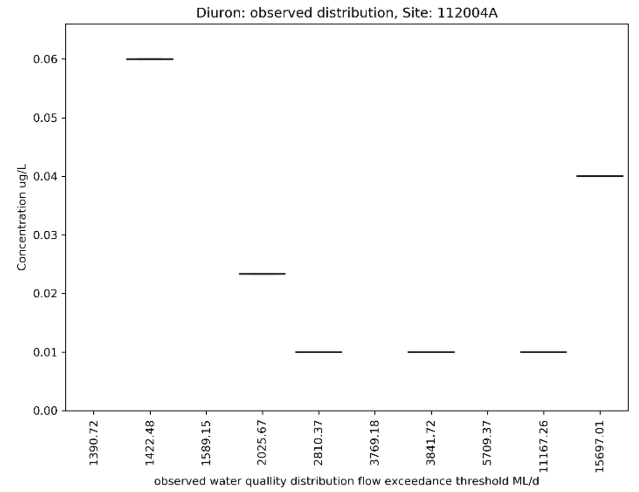

DIN: modelled monthly distribution, Site: 113015A
DIN mg/L
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
DIN: observed monthly distribution, Site: 113015A
DIN mg/L
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
DIN: modelled distribution, Site: 113015A
DIN mg/L
200.0 1020.0 1810.0 2360.0 2840.0 3530.0 4120.0 4910.0 6010.0 8150.0
Modelled water quallity distribution flow exceedance threshold ML/d
DIN: observed distribution, Site: 113015A
DIN mg/L
200.0 1020.0 1810.0 2360.0 2840.0 3530.0 4120.0 4910.0 6010.0 8150.0
observed water quallity distribution flow exceedance threshold ML/d
DIN: modelled flow distribution, Site: 113015A
Flow ML/d
Flow exceedence bin (%)
DIN: sampled flows, Site: 113015A
Flow (ML/d)
Flow exceedence bin (%)

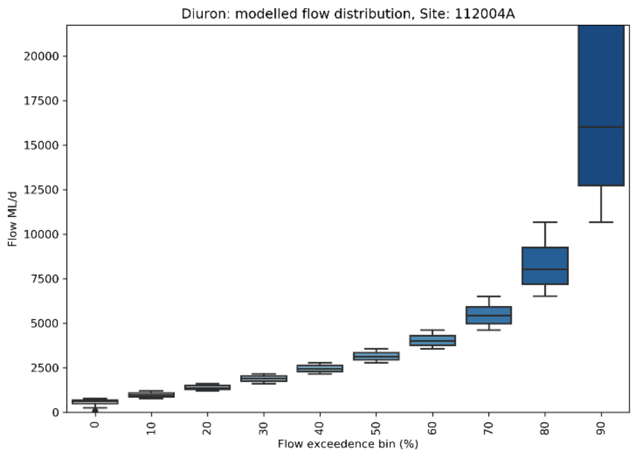
13.4.2 Diuron performance plots

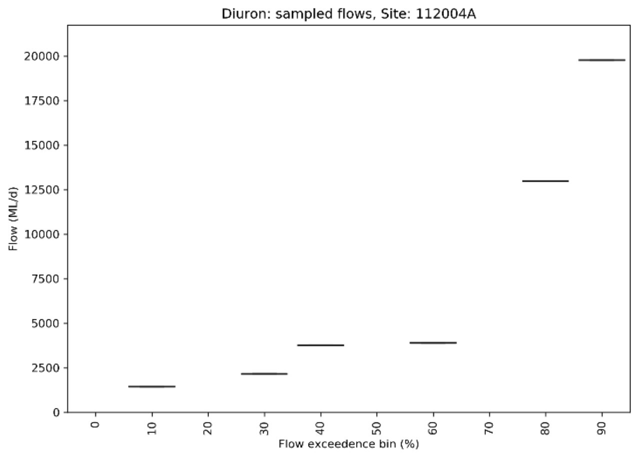


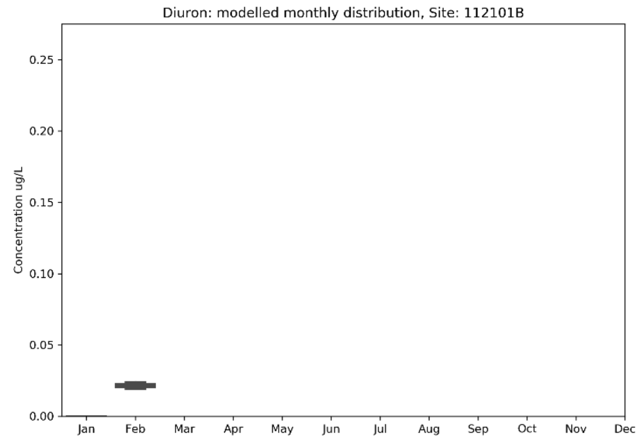


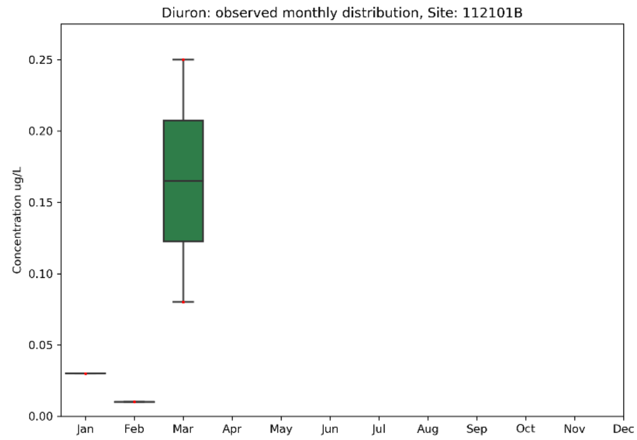


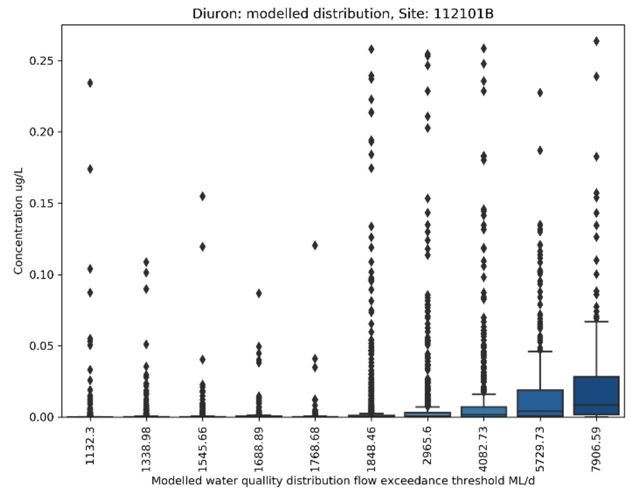


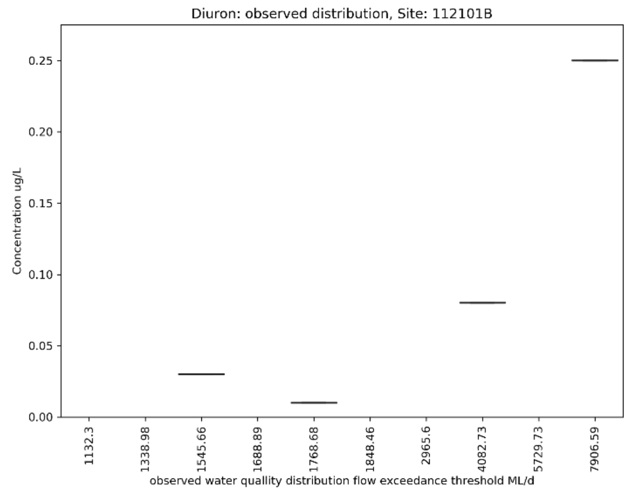


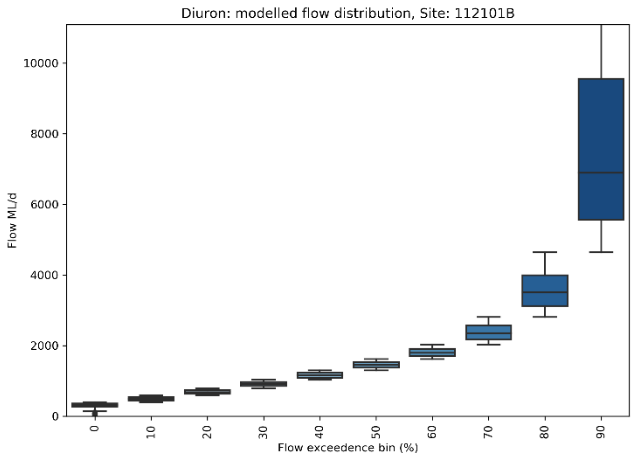


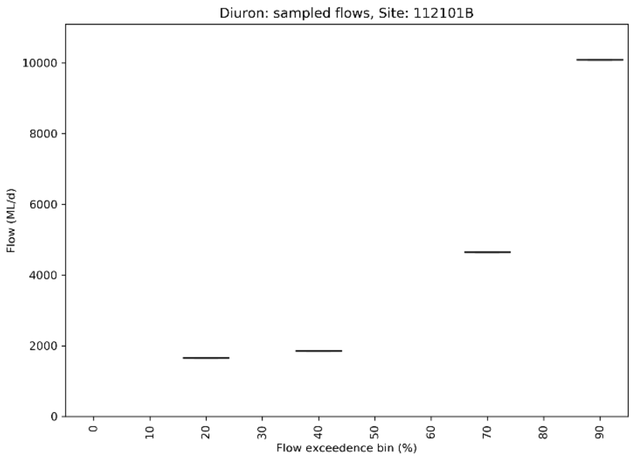

Diuron: modelled monthly distribution, Site: 112101B
Concentration ug/L
0.00
0.05
0.10
0.15
0.20
0.25
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

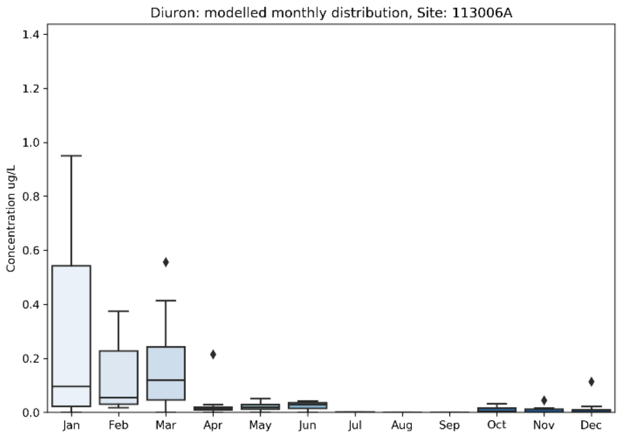

Diuron: observed monthly distribution, Site: 112101B
Concentration ug/L
0.00
0.05
0.10
0.15
0.20
0.25
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

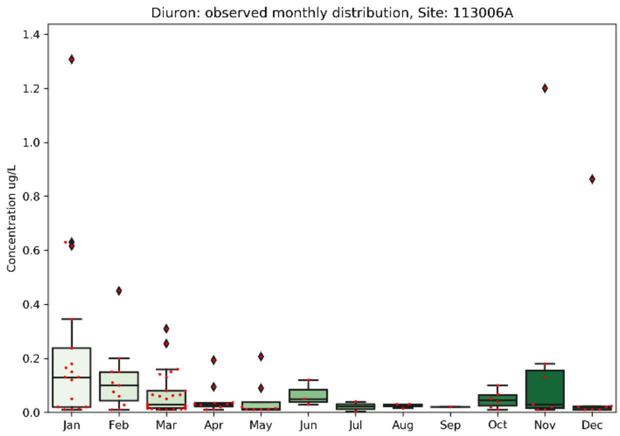

Diuron: modelled distribution, Site: 112101B
Concentration ug/L
0.00
0.05
0.10
0.15
0.20
0.25
1132.3 1338.98 1545.66 1688.89 1768.68 1848.46 2965.6 4082.73 5729.73 7906.59
Modelled water quallity distribution flow exceedance threshold ML/d

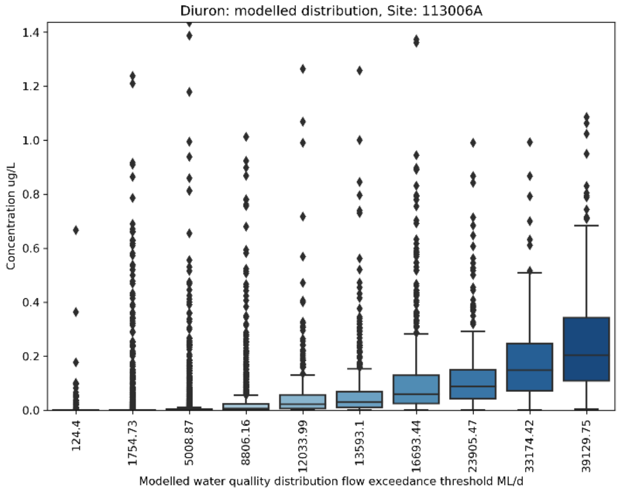

Diuron: observed distribution, Site: 112101B
Concentration ug/L
0.00
0.05
0.10
0.15
0.20
0.25
1132.3 1338.98 1545.66 1688.89 1768.68 1848.46 2965.6 4082.73 5729.73 7906.59
observed water quallity distribution flow exceedance threshold ML/d

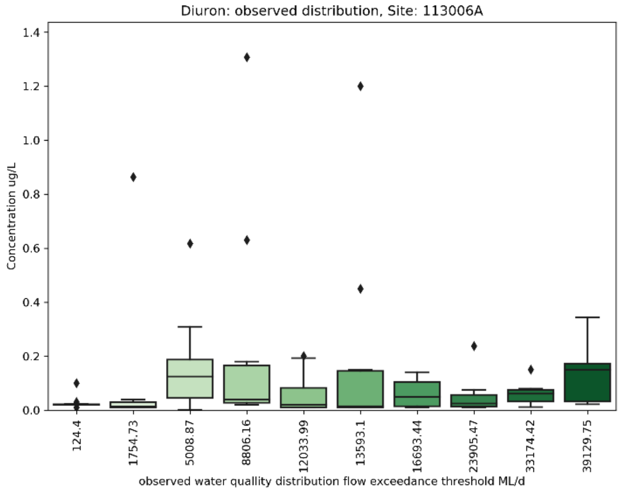

Diuron: modelled flow distribution, Site: 112101B
Flow ML/d
0
2000
4000
6000
8000
10000
0 10 20 30 40 50 60 70 80 90
Flow exceedence bin (%)

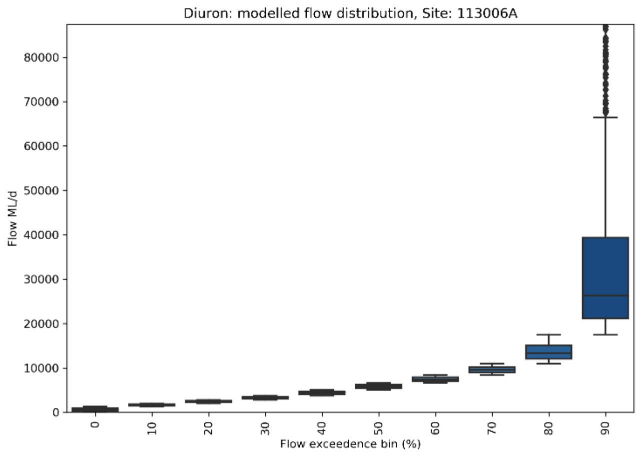

Diuron: sampled flows, Site: 112101B
Flow (ML/d)
0
2000
4000
6000
8000
10000
0 10 20 30 40 50 60 70 80 90
Flow exceedence bin (%)

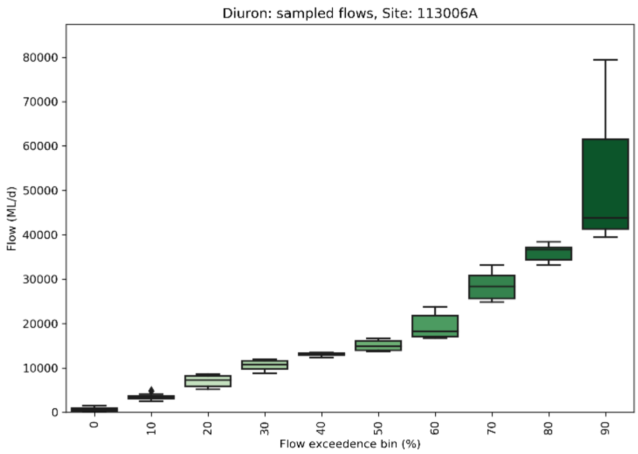

Diuron: modelled monthly distribution, Site: 113006A
Concentration ug/L
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

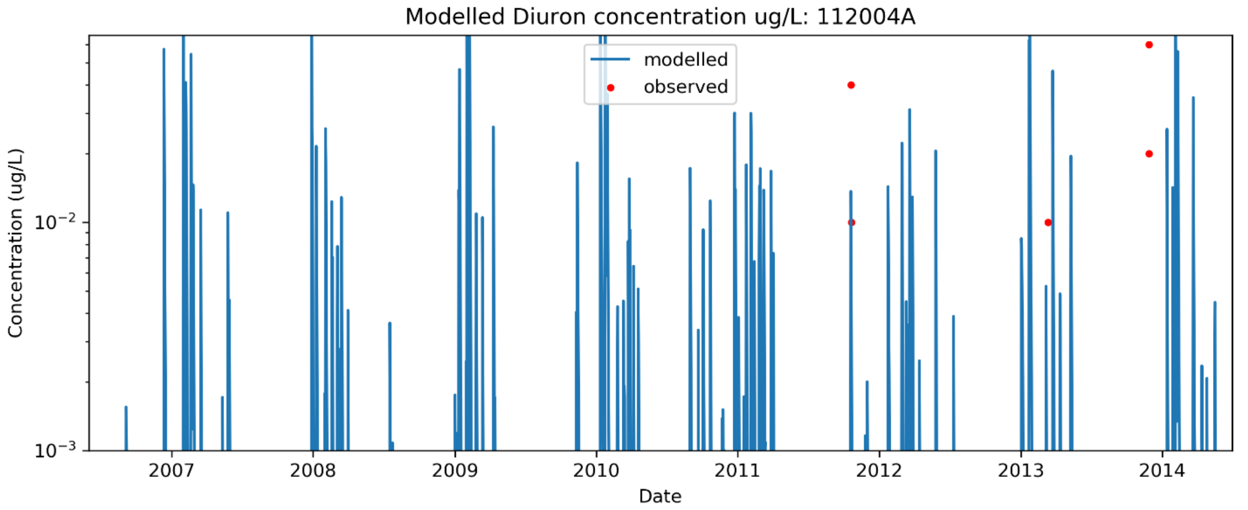

Diuron: observed monthly distribution, Site: 113006A
Concentration ug/L
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

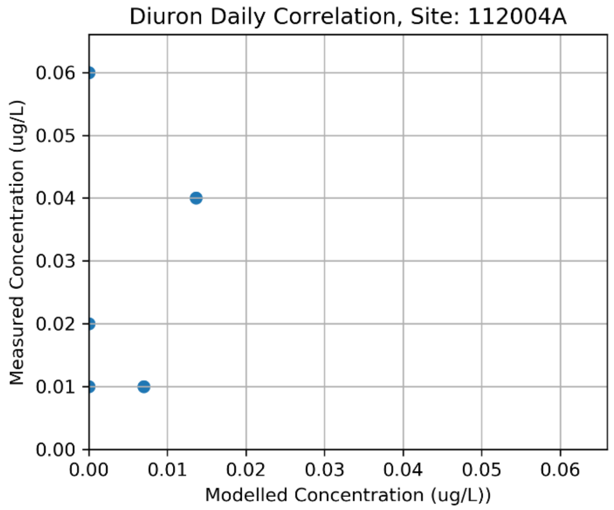

Diuron: modelled distribution, Site: 113006A
Concentration ug/L
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
124.4
1754.73
5008.87
8806.16
12033.99
13593.1
16693.44
23905.47
33174.42
39129.75
Modelled water quallity distribution flow exceedance threshold ML/d

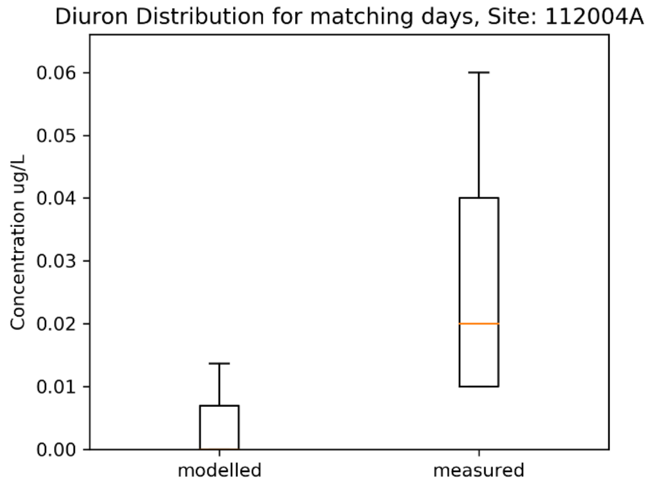

Diuron: observed distribution, Site: 113006A
Concentration ug/L
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
124.4
1754.73
5008.87
8806.16
12033.99
13593.1
16693.44
23905.47
33174.42
39129.75
observed water quallity distribution flow exceedance threshold ML/d

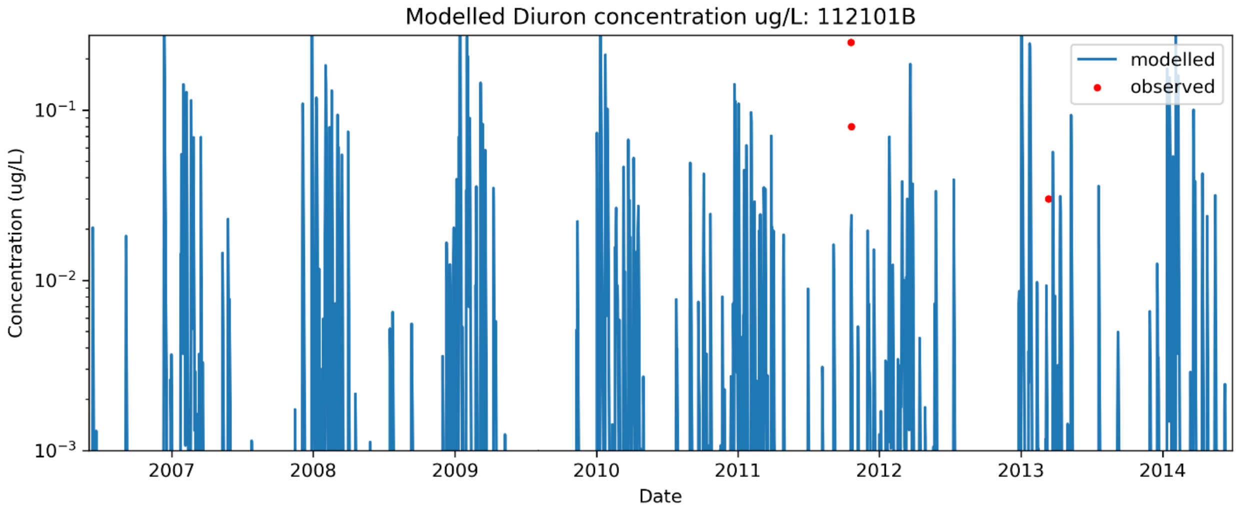

Diuron: modelled flow distribution, Site: 113006A
Flow ML/d
0
10000
20000
30000
40000
50000
60000
70000
80000
0
10
20
30
40
50
60
70
80
90
Flow exceedence bin (%)


Diuron: sampled flows, Site: 113006A
Flow (ML/d)
0
10000
20000
30000
40000
50000
60000
70000
80000
0
10
20
30
40
50
60
70
80
90
Flow exceedence bin (%)

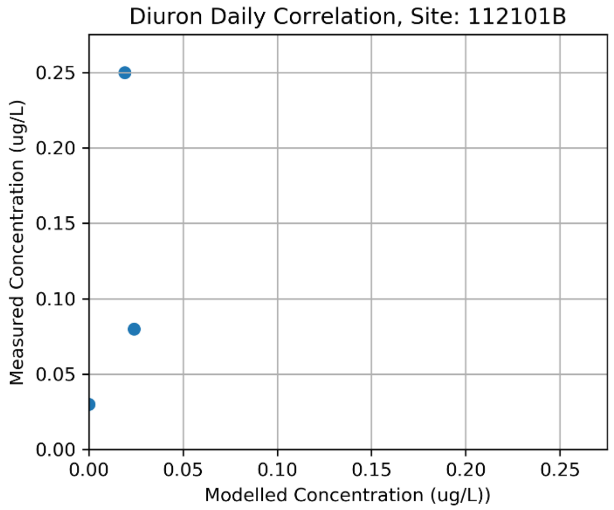

Modelled Diuron concentration ug/L: 112004A
modelled
observed
Concentration (ug/L)
10^{-2}
10^{-3}
2007
2008
2009
2010
2011
2012
2013
2014
Date


Diuron Daily Correlation, Site: 112004A
Measured Concentration (ug/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Modelled Concentration (ug/L))

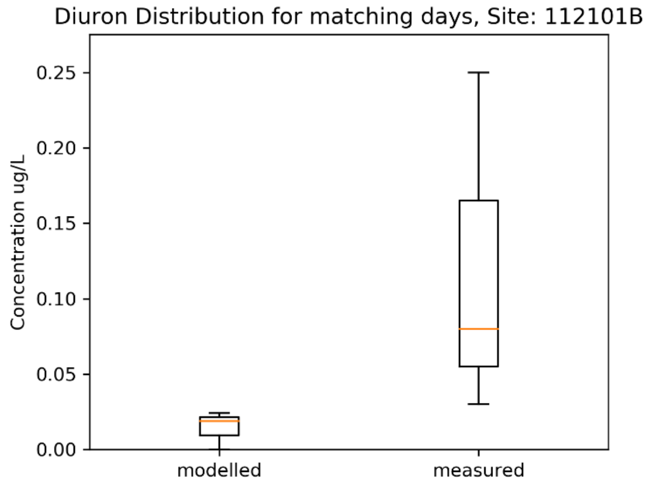

Diuron Distribution for matching days, Site: 112004A
Concentration ug/L
0.06
0.05
0.04
0.03
0.02
0.01
0.00
modelled
measured



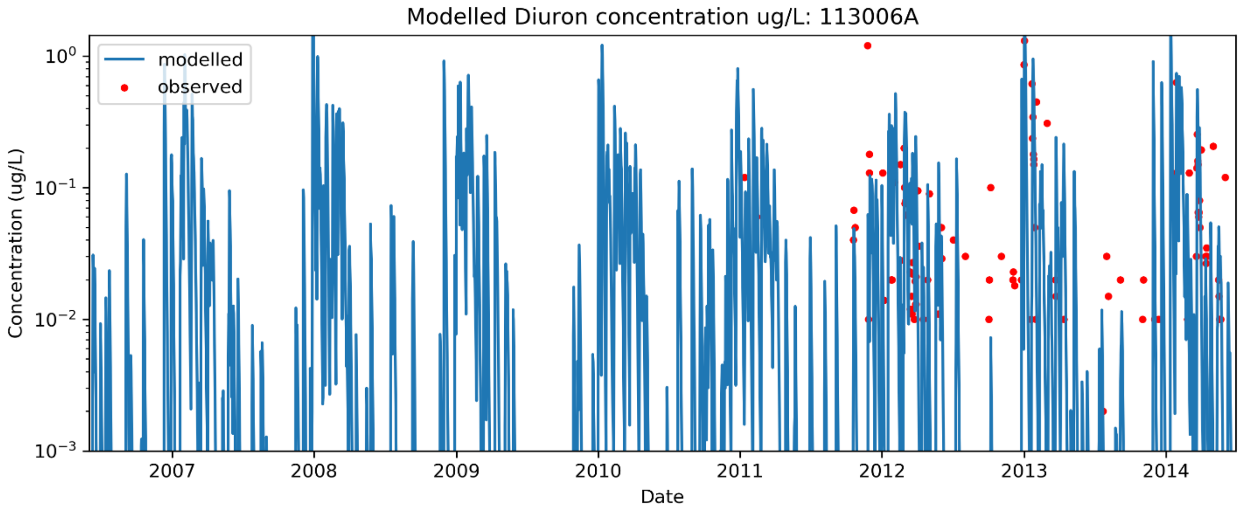
Modelled Diuron concentration ug/L: 112101B
Concentration (ug/L)
10^{-1}
10^{-2}
10^{-3}
2007
2008
2009
2010
2011
2012
2013
2014
Date
modelled
observed

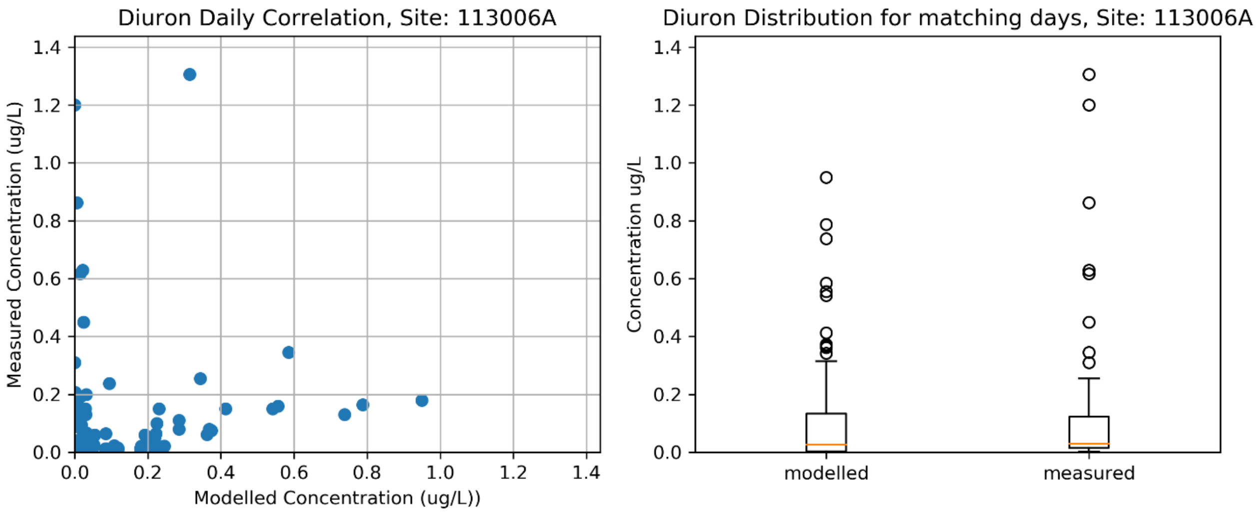


Diuron Daily Correlation, Site: 112101B
Measured Concentration (ug/L)
Modelled Concentration (ug/L))
0.00
0.05
0.10
0.15
0.20
0.25

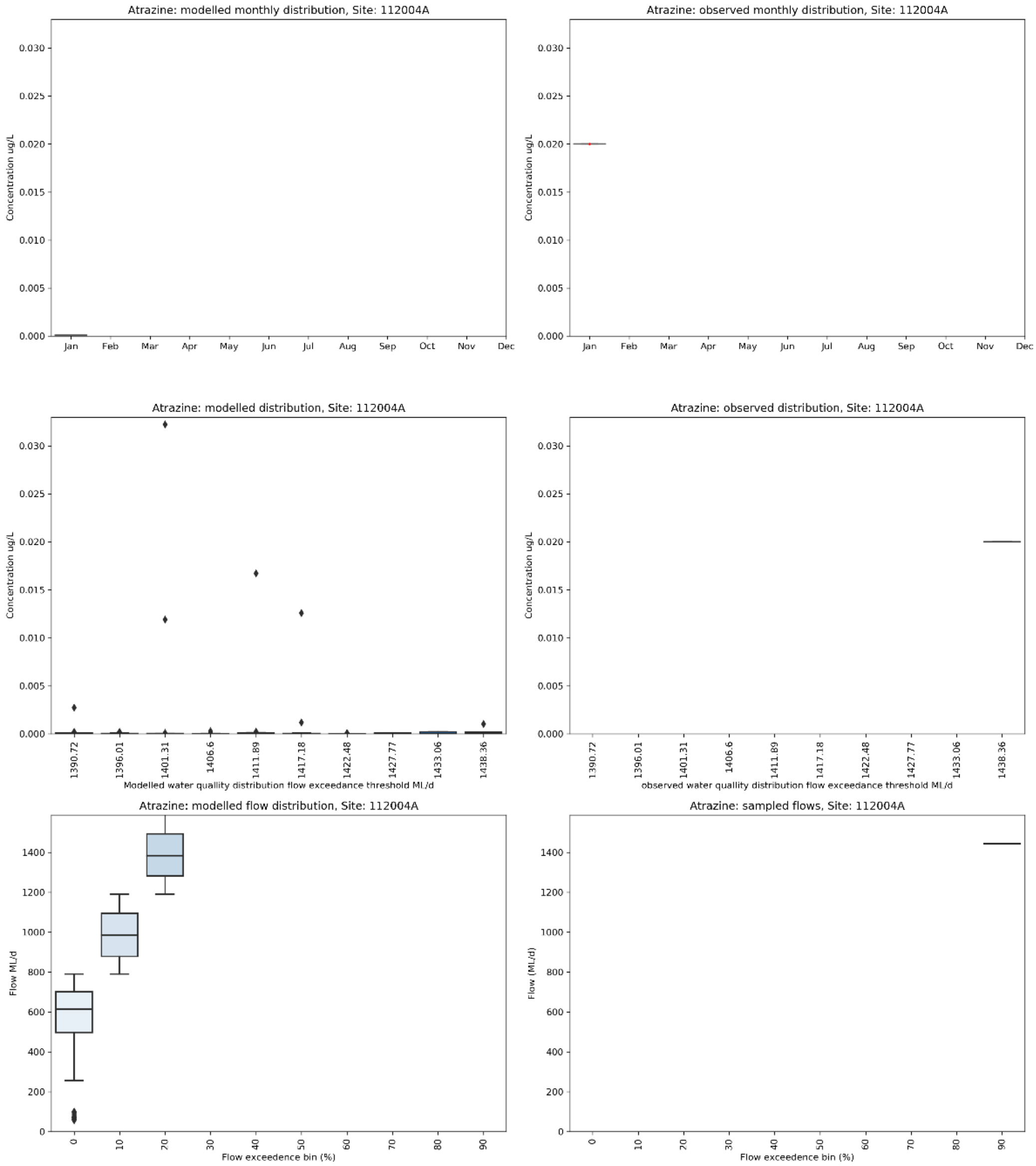


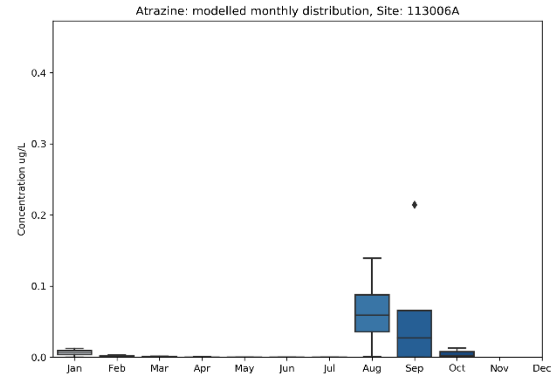
Diuron Distribution for matching days, Site: 112101B
Concentration ug/L
0.00
0.05
0.10
0.15
0.20
0.25
modelled
measured

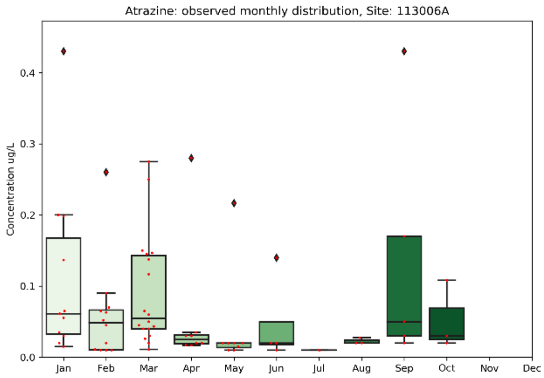

Modelled Diuron concentration ug/L: 113006A
modelled
observed
Concentration (ug/L)
10^0
10^{-1}
10^{-2}
10^{-3}
2007
2008
2009
2010
2011
2012
2013
2014
Date

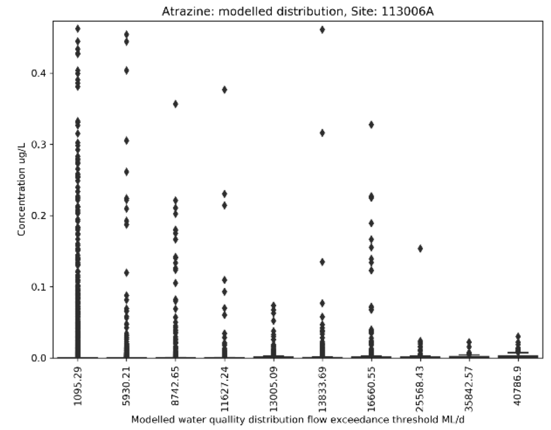

Diuron Daily Correlation, Site: 113006A
Measured Concentration (ug/L)
Modelled Concentration (ug/L))
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Diuron Distribution for matching days, Site: 113006A
Concentration ug/L
modelled
measured

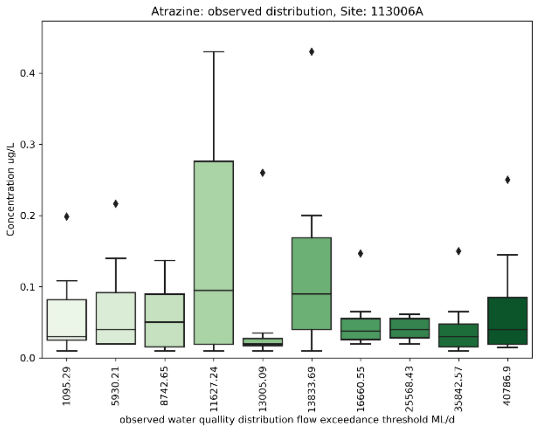
13.4.3 Atrazine performance plots

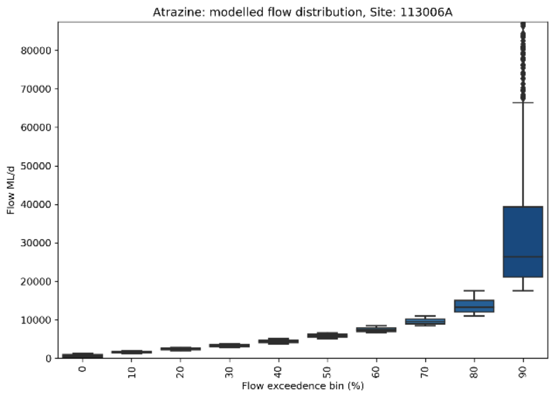


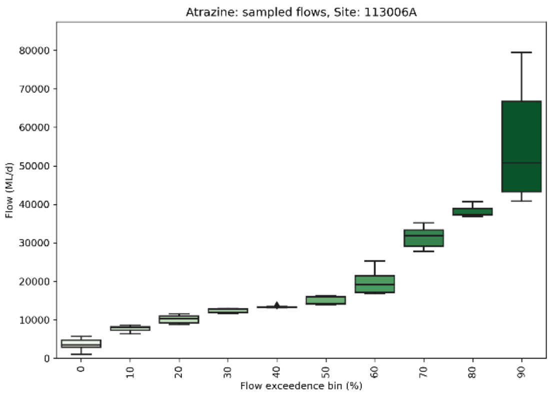

Atrazine: modelled monthly distribution, Site: 113006A
Concentration ug/L
0.0
0.1
0.2
0.3
0.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

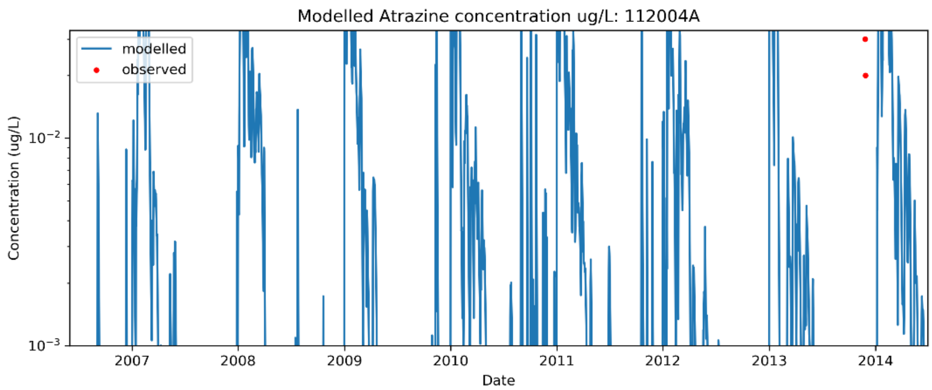

Atrazine: observed monthly distribution, Site: 113006A
Concentration ug/L
0.0
0.1
0.2
0.3
0.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

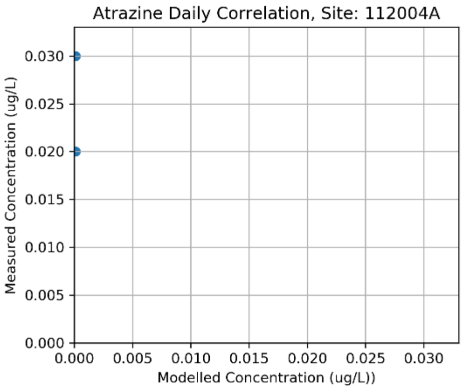

Atrazine: modelled distribution, Site: 113006A
Concentration ug/L
0.0
0.1
0.2
0.3
0.4
1095.29
5930.21
8742.65
11627.24
13005.09
13833.69
16660.55
25568.43
35842.57
40786.9
Modelled water quallity distribution flow exceedance threshold ML/d

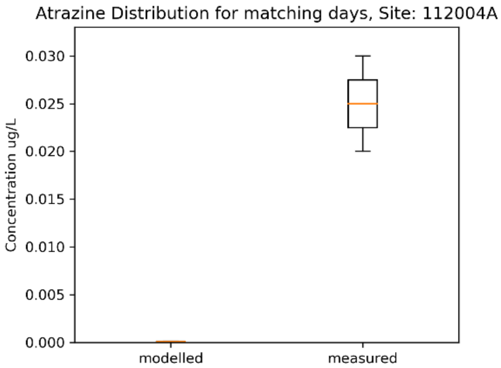

Atrazine: observed distribution, Site: 113006A
Concentration ug/L
0.0
0.1
0.2
0.3
0.4
1095.29
5930.21
8742.65
11627.24
13005.09
13833.69
16660.55
25568.43
35842.57
40786.9
observed water quallity distribution flow exceedance threshold ML/d

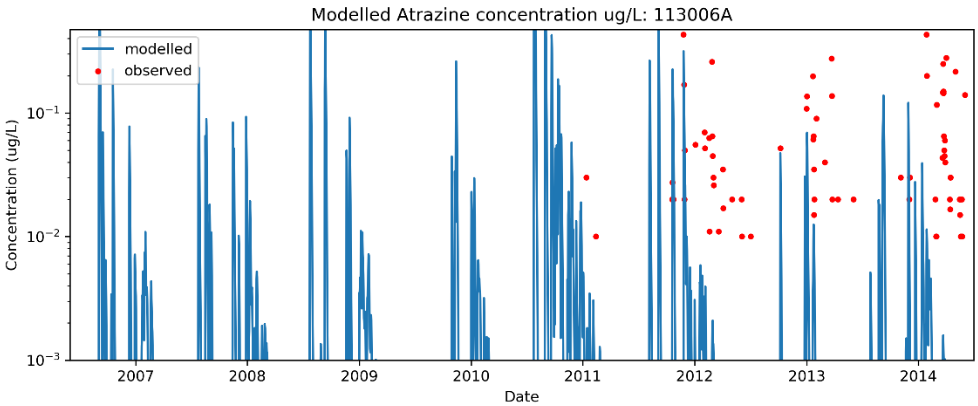

Atrazine: modelled flow distribution, Site: 113006A
Flow ML/d
0
10000
20000
30000
40000
50000
60000
70000
80000
0
10
20
30
40
50
60
70
80
90
Flow exceedence bin (%)

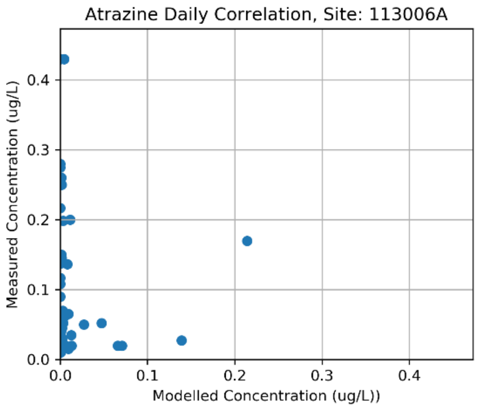

Atrazine: sampled flows, Site: 113006A
Flow (ML/d)
0
10000
20000
30000
40000
50000
60000
70000
80000
0
10
20
30
40
50
60
70
80
90
Flow exceedence bin (%)

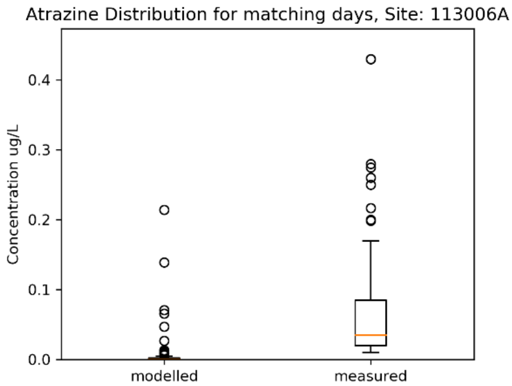

Modelled Atrazine concentration ug/L: 112004A
modelled
observed
Concentration (ug/L)
10^{-2}
10^{-3}
2007
2008
2009
2010
2011
2012
2013
2014
Date


Atrazine Daily Correlation, Site: 112004A
Measured Concentration (ug/L)
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.000
0.005
0.010
0.015
0.020
0.025
0.030
Modelled Concentration (ug/L))


Atrazine Distribution for matching days, Site: 112004A
Concentration ug/L
0.030
0.025
0.020
0.015
0.010
0.005
0.000
modelled
measured


Modelled Atrazine concentration ug/L: 113006A
modelled
observed
Concentration (ug/L)
10^{-1}
10^{-2}
10^{-3}
2007
2008
2009
2010
2011
2012
2013
2014
Date


Atrazine Daily Correlation, Site: 113006A
Measured Concentration (ug/L)
0.4
0.3
0.2
0.1
0.0
0.0
0.1
0.2
0.3
0.4
Modelled Concentration (ug/L))


Atrazine Distribution for matching days, Site: 113006A
Concentration ug/L
0.4
0.3
0.2
0.1
0.0
modelled
measured

14 LIST OF ABBREVIATIONS

APSIM	Agricultural Production Systems sIMulator
BR	Baseflow store runoff (mm/d)
D	Original APSIM drainage time series (mm/d)
DD	Deep drainage (mm/d) that is not seen at the gauge
DIN	Dissolved inorganic nitrogen
DR	Deep drainage delivery ratio (%)—the ratio of drainage delivered to the drainage store to total drainage calculated by APSIM (value between 0 and 1).
DS	Drainage delivered to drainage store
DSE	Drainage store emptying ratio—the percentage of drainage store delivered to the stream in a time step—typically between 0.03 and 0.1, and similar to the LZFK and LZPK values in the Sacramento model
DWC	Dry weather concentrations
EMC	Event mean concentrations
ET	Evapotranspiration
FU	Functional unit – base modelling unit of Source models
GBR	Great Barrier Reef
NSE	Nash Sutcliffe Efficiency
PEST	Parameter ESTimation – optimisation software
RMSE	Root mean square error
SR	Surface store runoff (mm/d)
SS	Surface runoff delivered to the surface store (mm/d) = the time series provided by APSIM
SSE	Surface store emptying ratio—the percentage of the surface store delivered to the stream in a time step—typically close to 1 and similar in value to the UH1 parameter in the Sacramento model

14.1 Sacramento parameters

Parameter name	Parameter description
ADIMP	The additional fraction of the catchment which develops impervious characteristics under soil saturation conditions.
LZFPM	Lower zone free water primary maximum—the maximum capacity from which primary baseflow can be drawn.
LZFSM	Lower zone free water supplemental maximum—the maximum volume from which supplemental baseflow can be drawn.
LZPK	The ratio of water in *LZFPM*, which drains as baseflow each day.
LZSK	The ratio of water in *LZFSM*, which drains as baseflow each day.
LZTWM	Lower zone tension water maximum—the maximum capacity of lower zone tension water. Water from this store can only be removed through evapotranspiration.
PCTIM	The permanently impervious fraction of the basin contiguous with stream channels, which contributes to direct runoff.
PFREE	The minimum proportion of percolation from the upper zone to the lower zone directly available for recharging the lower zone free water stores.
REXP	An exponent determining the rate of change of the percolation rate with changing lower zone water storage.
RSERV	Fraction of lower zone free water unavailable for transpiration.
SARVA	A decimal fraction representing that portion of the basin normally covered by streams, lakes and vegetation that can deplete stream flow by evapotranspiration.
SIDE	The ratio of non-channel baseflow (deep recharge) to channel (visible) baseflow.
SSOUT	The volume of the flow which can be conveyed by porous material in the bed of stream.
UH1	The first component of the unit hydrograph, i.e. the proportion of instantaneous runoff not lagged.
UH2	The second component of the unit hydrograph, i.e. the proportion of instantaneous runoff lagged by one time-step.
UH3	The third component of the unit hydrograph.
UH4	The fourth component of the unit hydrograph.
UH5	The fifth component of the unit hydrograph.
UZFWM	Upper zone free water maximum—this storage is the source of water for interflow and the driving force for transferring water to deeper depths.
UZK	The fraction of water in *UZFWM*, which drains as interflow each day.
UZTWM	Upper zone tension water maximum—the maximum volume of water held by the upper zone between field capacity and the wilting point which can be lost by direct evaporation and evapotranspiration from soil surface. This storage is filled before any water in the upper zone is transferred to other storages.
ZPERC	The proportional increase in Pbase that defines the maximum percolation rate.