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SUMMARY MODELLING REPORT:

Picton WRP and Stonequarry Creek – Evaluating flow and water quality

November 2020

Document history

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1 Introduction

1.1 Background

Sydney Water engaged Ecological Australia and Alluvium Consulting, to undertake flow and water quality modelling for Stonequarry Creek in the broader Nepean River catchment. This work is part of ongoing examination of the Picton Water Recycling Plant (WRP) over different time frames, particularly understanding current and future management of effluent discharge and reuse options. The initial model was developed by Ecological Australia and Alluvium Consulting have taken that model, refined and updated the calibrations and run a series of scenarios.

1.2 Purpose of this report

This report outlines the

- Data inputs used to build the model
- Calibration and validation
- Effluent management scenarios and
- Model outputs and implications

The purpose of the report is to provide confidence in the appropriate use of modelling outputs as a tool to inform management strategies and the environmental approval process for changes to the Picton WRP Environmental Protection Licence (EPL10555).

1.3 Modelling questions

Models can be established for a range of reasons, and these should be based on clear modelling questions to be resolved. In the case of this Source modelling, ultimately it is being used to answer the following questions:

- **How does flow and water quality vary over time across different climatic conditions** in Stonequarry Creek and the Nepean River immediately downstream of Maldon Weir? This provides an understanding of the baseline conditions within a modelling framework.
- **How does discharge from the WRP impact baseline flow and water quality**? This provides metrics to characterise changes in flow and water quality, using the modelling outputs, and considering future inflow and discharge configurations.
- **Can alternative management actions mitigate changes to flow and water quality** such as changes in recycled water use for farm irrigation, different discharge locations or discharge regimes?

The Source modelling framework (developed by eWater) has been used as the key integration tool to answer the above questions in order to bring together timeseries inputs, discharge rules and landscape processes into a single evaluation product to assist in the decision making process.

2 Available data

2.1 Data inputs

Various data inputs are needed for the model build process (Table 2-1).

Appendix A provides details of the key data that is available for the modelling. These inputs are critical to building the model. A brief description of key data used in the model build is provided in section 3.

Table 2-1 Data sources for building a catchment model

1. **Spatial** (including associated metadata and attributes)
   - 1.1 Aerial photography
   - 1.2 Digital Elevation Model (DEM) or contours preferably at 1m resolution
   - 1.3 Catchment delineation
   - 1.4 Impervious area mapping
   - 1.5 Stormwater drainage network
   - 1.6 Sewage network and overflow locations
   - 1.7 Waterways
   - 1.8 Current and future land uses
   - 1.9 Soils
   - 1.10 Vegetation cover
   - 1.11 Locations for time series observations (Rainfall, Evap, Temp, Overflows, Streamflow, Treatment Plants, Water Quality, Other)
2. **Observations**
   - 2.1 Rainfall
   - 2.2 Evaporation/Solar exposure
   - 2.3 Maximum temperature
   - 2.4 Streamflow gauging
   - 2.5 Sewer network modelling / observations
   - 2.6 WRP inflows, treatment flows, dam levels, discharges, reuse etc
   - 2.7 Water quality monitoring (WRP and waterways)
   - 2.8 Extractions from waterways or storages
3. **Reports/Papers**
   - 3.1 Soil classification reports
   - 3.2 Any other relevant studies within the region (Water quality, catchment information, etc)
   - 3.3 Previous modelling (sewer network, river water quality etc)
   - 3.4 Stream flow gauging and rating reports

3 Catchment model development

3.1 Background to Source

The Source platform is not a model on its own, but a group of models that can be configured in different combinations to answer specific modelling questions. Within Source, the user has a choice of river system or catchment configuration. In fact, these two approaches can theoretically be used interchangeably; however, in most cases, one or the other is typically applied for specific projects. Within this project, we applied the catchment configuration to derive an hourly time series of flows for the Stonequarry Creek catchment.

Source has three basic components, generation, delivery and transport, and each of these can be configured independently for specific catchment land uses, topographies or processes.

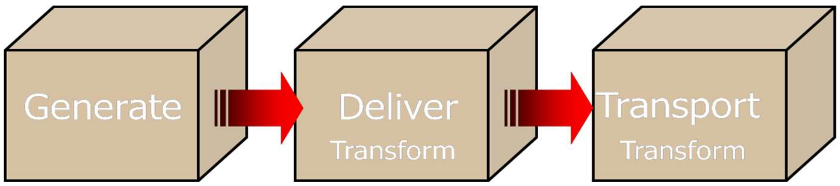


Figure 3-1 Source model components

Under each of the components, there are several models to choose from that are delivered with Source "off the shelf" which can be used by modellers straight away. Where Source has significant capability though is the ability to write additional models, either as equations or as full "plugins" that can increase the ability of the platform to model specific issues. We have used the equations or “functions” component of Source extensively in this model to represent the complex flow interactions resulting from different irrigation scenarios and the precautionary and emergency discharge protocols used at the Picton WRP.

The primary driver of Source is rainfall-runoff, so the configuration, calibration and validation of rainfall-runoff is vital for a robust model. The generated runoff can then be used to drive a constituent generation model, which can also be selected from a range of different model types. The generated flows and constituent loads are delivered to a system link and that delivery can be configured to account for stream conditions such as riparian vegetation, sedimentation, nutrient enrichment and other transformations. Once in the system link, the transport models can be further used to look at constituent decay, enrichment and transformation.

Source therefore has the potential to be configured to a range of catchment processes, if those processes are largely driven by rainfall and runoff. The Source modelling platform can be configured to answer questions about catchment pollutant generation, transport and delivery – using a range of models. The flows and loads to waterways can therefore be simulated using the various models within Source and the ability to add further functions to simulate aspects of a given system.

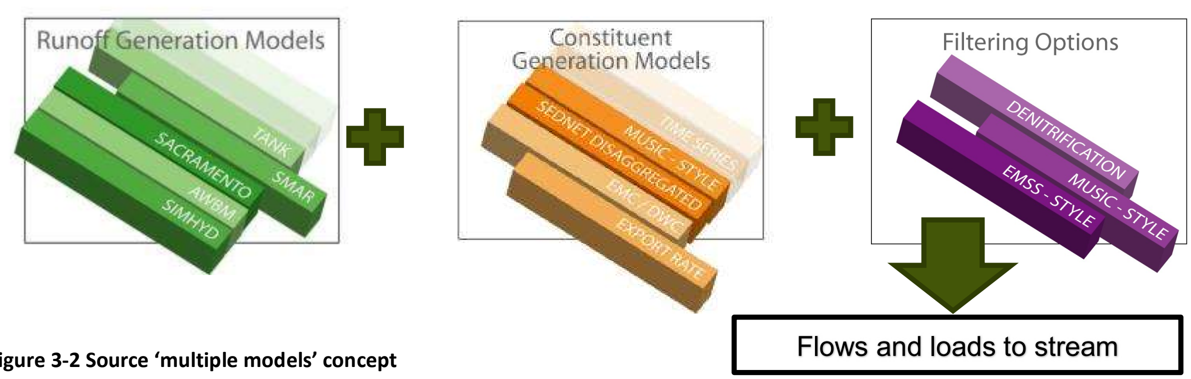


Figure 3-2 Source ‘multiple models’ concept

For the Stonequarry Source model, we used the GR4J and Simhyd sub-daily rainfall-runoff models to describe the conversion of rainfall into runoff. To illustrate the conceptual models used, the Simhyd model is represented in Figure 3-3, with interception of rainfall, evapotranspiration, runoff from impervious surfaces, movement of water through soil (including contributions to groundwater, interflow with water returning to the stream and storage of water as soil moisture with further potential for evapotranspiration).

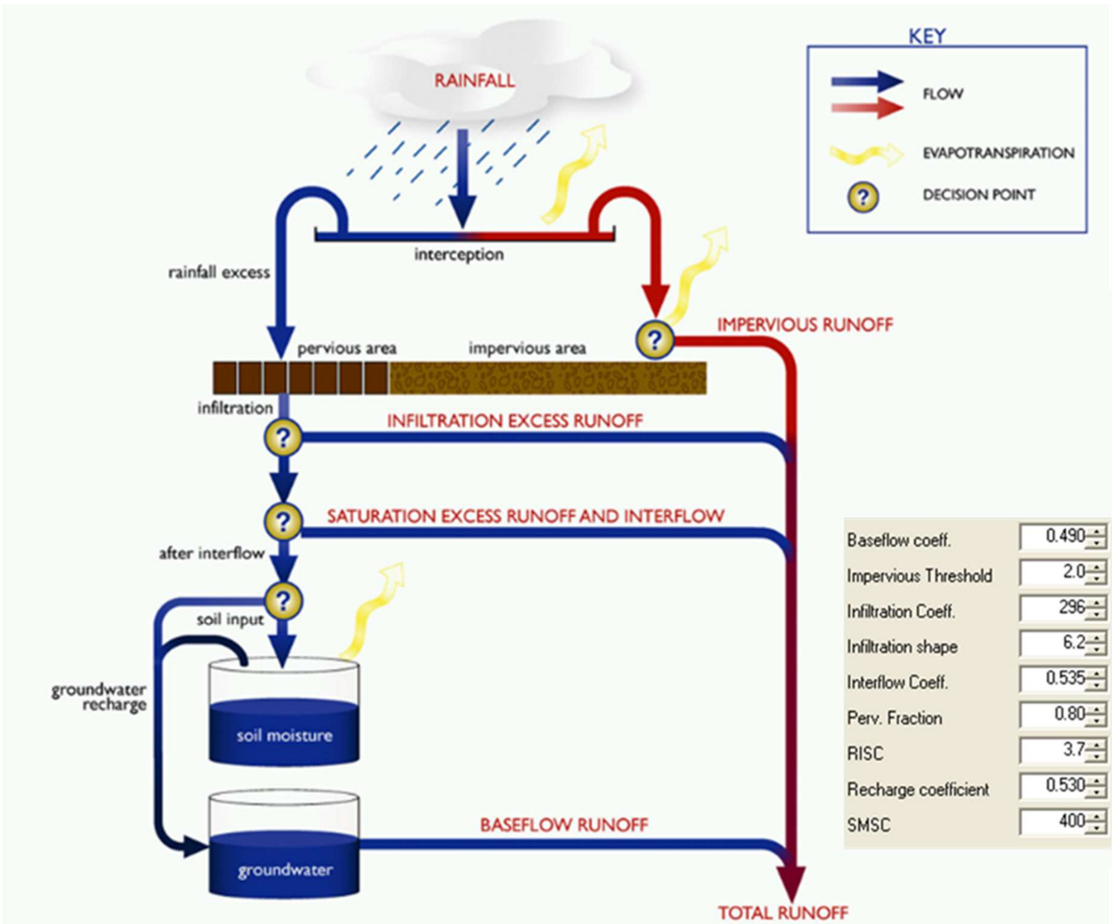


Figure 3-3 Simhyd rainfall runoff model

3.2 Stonequarry model build process

The underlying data used to construct a catchment model within Source are:

- A digital elevation model (DEM) for sub-catchment delineation
- A land use map for defining functional units
- Climate data (hourly rainfall and evaporation data)
- Streamflow gauge data for hydrology calibration and Nepean River flows
- Water quality data for calibrating water quality modelling and as input for the Nepean River
- Discharge and extraction points

The model construction process (using the data described above) with details of various components is outlined in Appendix B.

3.3 Catchment and node-link delineation

The DEM was used to delineate the Stonequarry Creek catchment into 48 sub-catchments, with an average catchment area of 203.53 ha (minimum catchment area of 3.31 ha and maximum of 893.48 ha). The resultant catchment model is shown in Figure 3-4. Appendix A has further details.

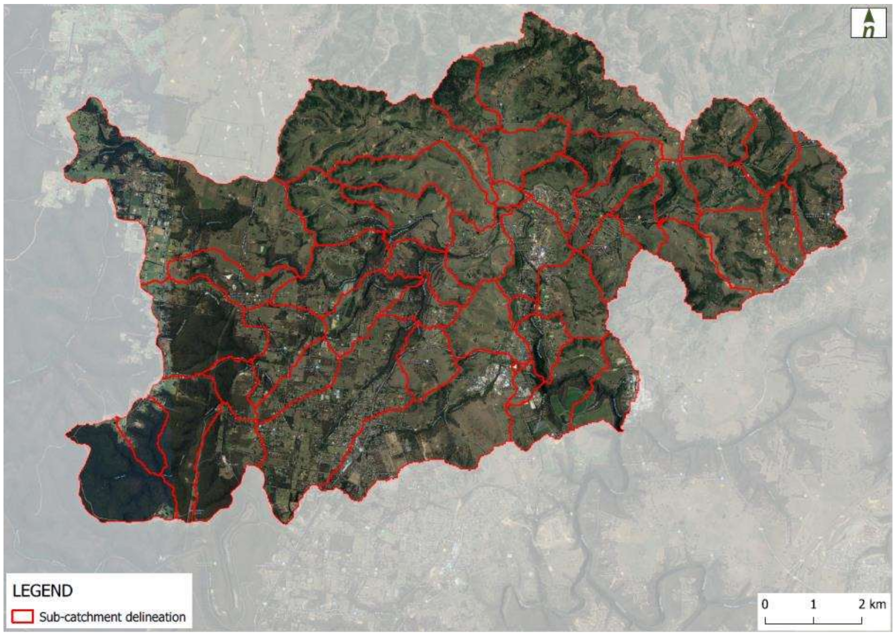


Figure 3-4 Model sub catchments

Nodes and links are used to route water from the catchments, connect point sources and storages through the system and into the Nepean River. The node and link layout is shown in Figure 3-5.

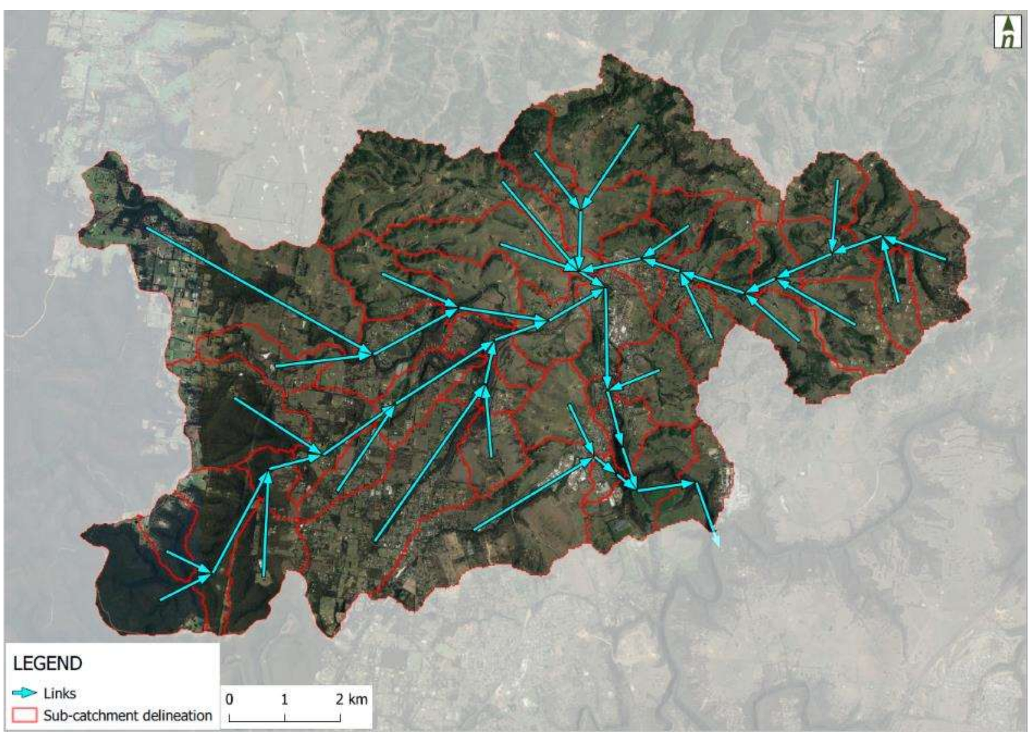


Figure 3-5 Link network within the sub-catchments

3.4 Functional units

Land use data was available for 2017 to represent current land use (Appendix A) covering the entire Stonequarry Creek catchment. The land uses were categorised into 12 functional units (shown spatially Figure 3-6), and allocated within 4 groups that can be simulated with similar rainfall-runoff parameters:

- Forest
- Urban, Commercial, Infrastructure/Utilities, Industrial and Mining
- Open Space, Environmental Living and Horticulture
- Grazing, Peri Urban

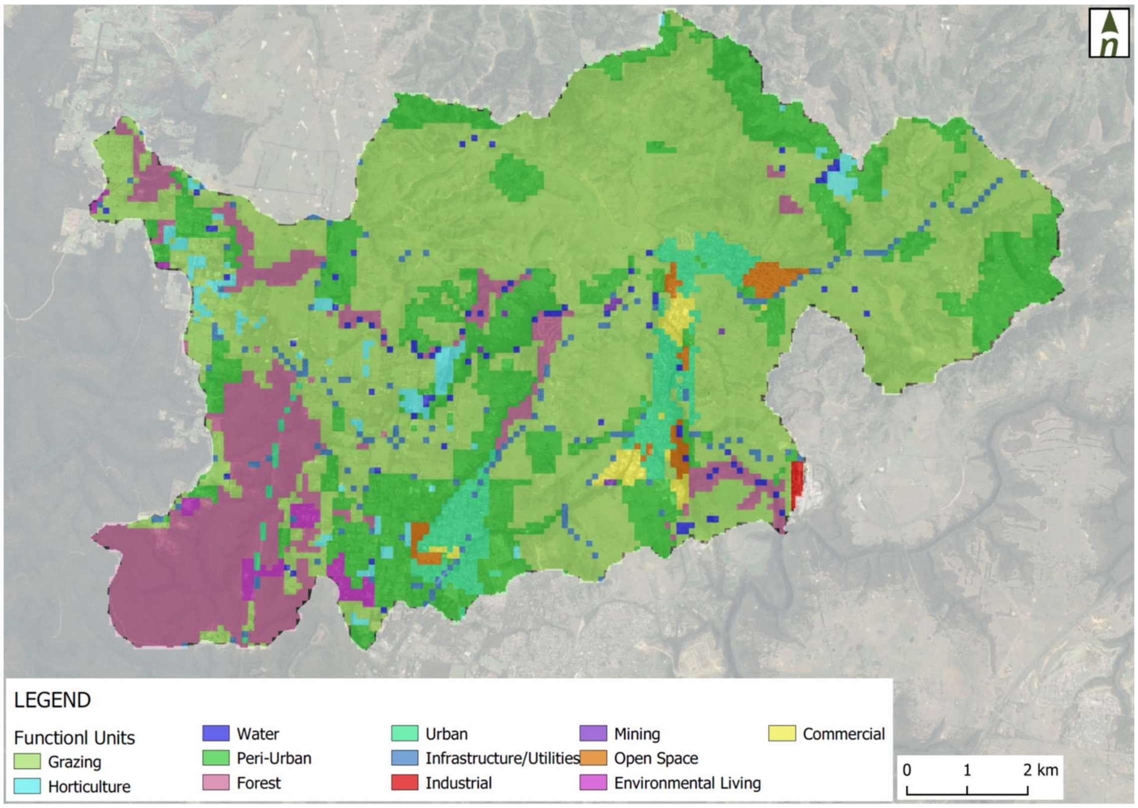


Figure 3-6 Land Use for Source model

3.5 Climate data

The Source model requires continuous and concurrent climate input data time series. Two input files for rainfall were generated for hourly rainfall, at sites 568295 and 568053, and applied to sub-catchments in regions based on proximity and topography. Regressions with other gauges were developed and used to infill missing periods of data to create continuous, concurrent time series over the period 1 January 1990 to 1 January 2019.

Hourly evaporation data was developed by factoring the daily solar exposure data at Picton Council Depot (068052). It was then disaggregated into an hourly time step using hourly temperature data (capped at a minimum of 5 degrees Celsius to avoid negative or unrealistic values).

Appendix A has further details of the spatial distribution of the available climate data.

3.6 Streamflow data

Streamflow data was used to calibrate and validate the rainfall runoff modelling of the Stonequarry Creek catchment and as an input for the Nepean River simulation. Data is available for 3 streamflow gauges:

- 212053 Stonequarry at Picton township (Webster Street near rail viaduct), (approximately 3 km upstream of the WRP discharge point), with data from Water NSW available for the period from December 1990 to January 2019 at a sub-daily timescale (generally 10 to 15 minute intervals).
- 2122006 Stonequarry Creek at Picton WRP, approximately 60 m downstream of the Picton WRP discharge point) from June 1997 to December 2018 at 15 minute intervals.
- 212208 Nepean River, measuring flow over Maldon Weir, upstream of the confluence with Stonequarry Creek.

The locations of relevant streamflow gauges are shown in Figure 3-7. Appendix B has further details with comparison of gauge data.

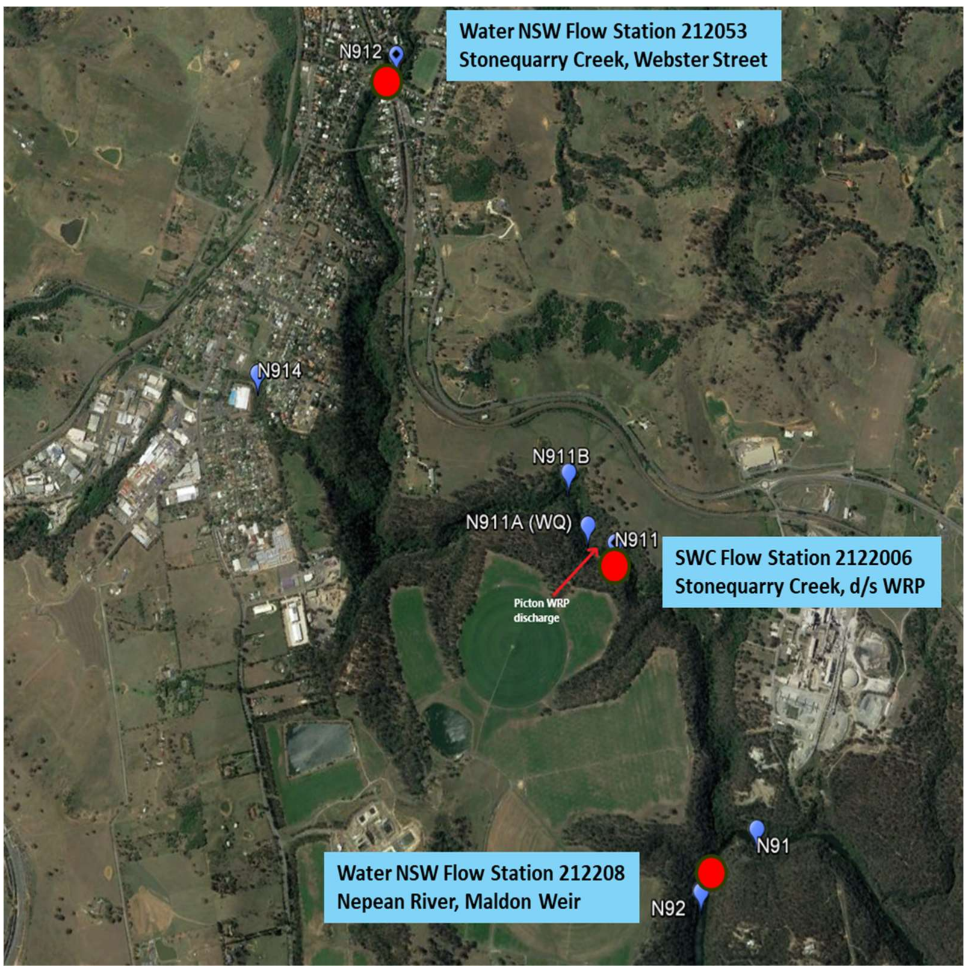


Figure 3-7 Streamflow gauge locations

While it was initially anticipated that the model would be calibrated to the gauges at two locations on Stonequarry Creek it was decided that gauge 2122006 Stonequarry Creek at Picton WRP, (approximately 60 m downstream of the Picton WRP discharge point) would be used for calibration. The sub-hourly data was converted to hourly to produce a record from June 1997 to December 2018.

3.7 Water quality data

Observed water quality data is available at the locations outlined below and shown spatially in Figure 3-8:

- N912: Stonequarry Creek at Picton
- N914: Redbank Creek upstream of Stonequarry Creek
- N911B: Stonequarry Creek upstream of Picton WRP discharge
- N911: Stonequarry Creek downstream of Picton WRP discharge
- N92: Nepean River at Wilton Park (Maldon Weir)
- N91: Nepean River downstream of Stonequarry Creek
- Inflow to Picton WRP
- Discharge from Western Dam to Stonequarry Creek
- Extraction from Eastern Dam for Irrigation

Measurements are available from 2006 onwards at the Picton WRP and from 2012 onwards on the waterways.

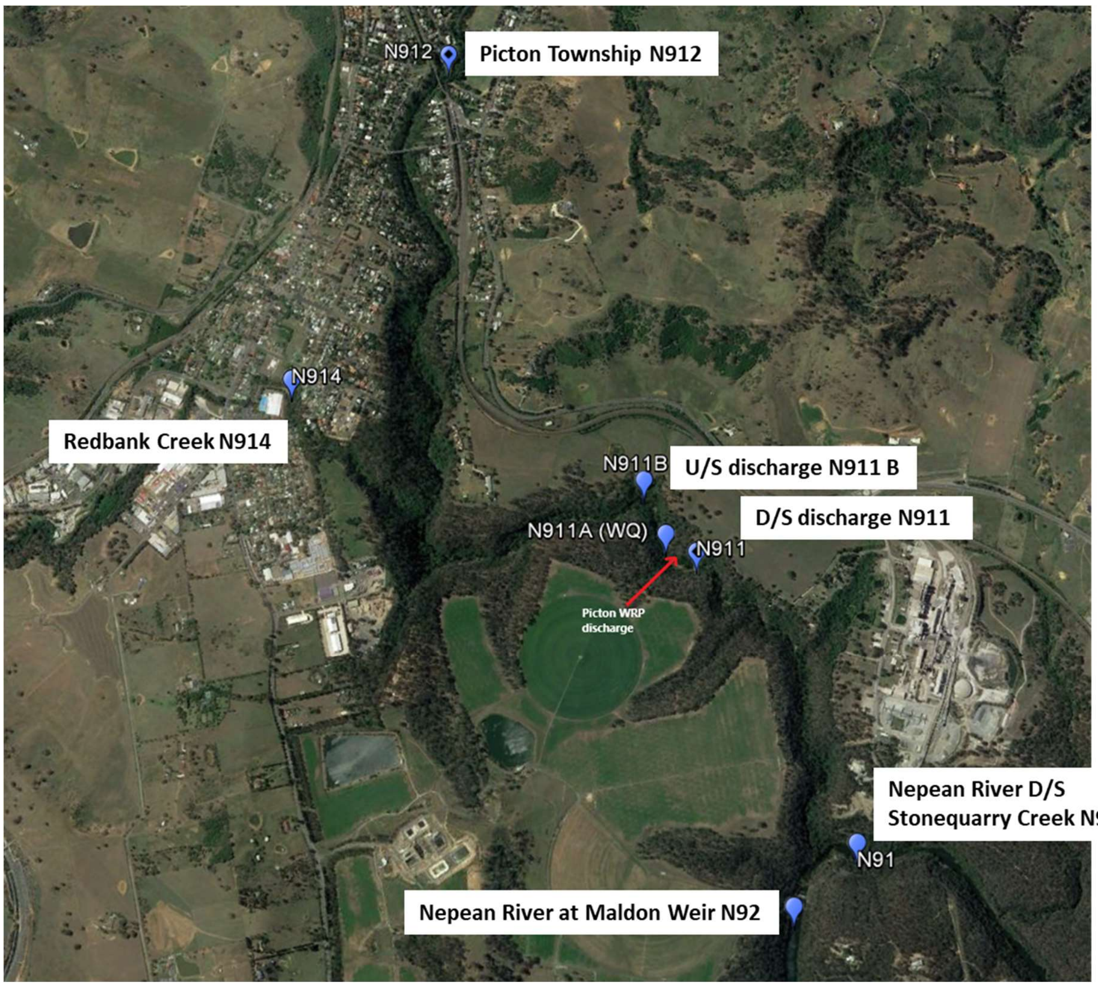


Figure 3-8 Water quality monitoring locations

4 Modelling calibration and validation

Based on the data available (Section 2 and Appendix A), a Source model was developed for the Stonequarry catchment at a one hour timestep (Section 3). This section discusses the calibration and validation of the model for flow and Total Nitrogen.

The overall results in this section show that the model is applicable for use to examine different Picton WRP configurations and examining their effect on the surround catchment environment.

Further detail on the model validation is provided in Appendix C.

4.1 Catchment Flows

Catchment flows were calibrated to the Stonequarry Creek at Picton WRP gauge (2122006) between January 2014 and December 2018 with validation between 1997 and 2013. The other available flow gauge, Stonequarry Creek at Picton (2112053) was used only for validation as the gauge is a flood flow gauge and its representation of lower flows was not deemed appropriate for calibration, as discussed in Section 7.3.

Calibration

The hydrograph results in Figure 4-1 show that the model is capturing the flow patterns within the catchment. It also demonstrates the variability of rainfall and uncertainty in the gauge results whereby some months the model is underpredicting and some months it is over predicting. The flow duration curves within Figure 4-2 show exceedance curves for concurrent modelled and observed data. The model flows above 3.5 ML/d are represented appropriately with flows below 3.5 ML/d being potentially slightly over estimated. Given the uncertainty in flow gauging this representation is considered appropriate.

Summary statistics are also presented in Table 4-1 for the calibration at Gauge 2122006. The results show that based on the Moriasi (2007) criteria the Nash Sutcliffe Efficiency (NSE) can be rated as very good at the hourly, daily and monthly scales, while the model bias could be considered to be high with a tendency to underestimate flow by around 12% at all timescales. While these results indicate that the model may be under performing, statistics do not always convey the full story. Examining this in conjunction with the time series shows that the model is producing model results fit for use for this project.

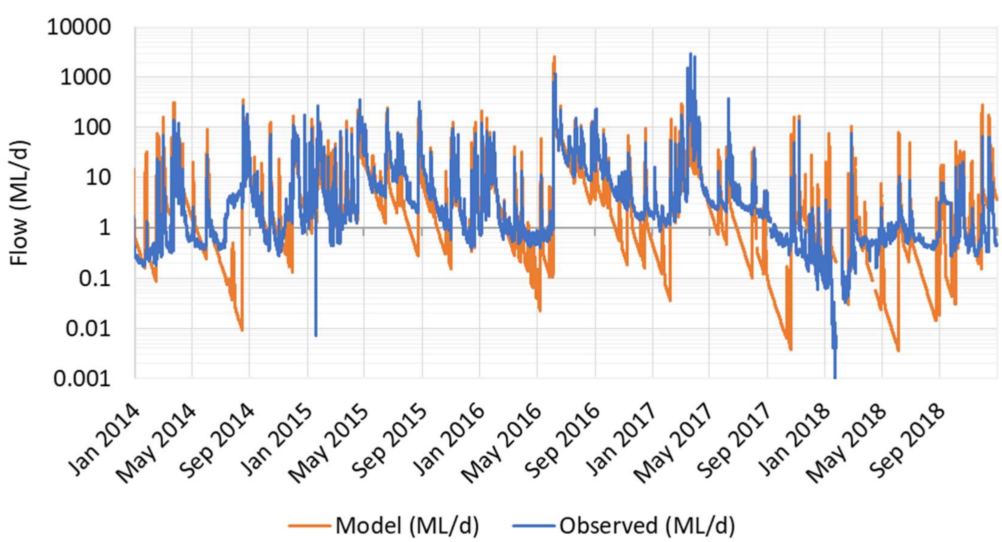


Figure 4-1 Gauge 2122006 calibration hydrograph – hourly

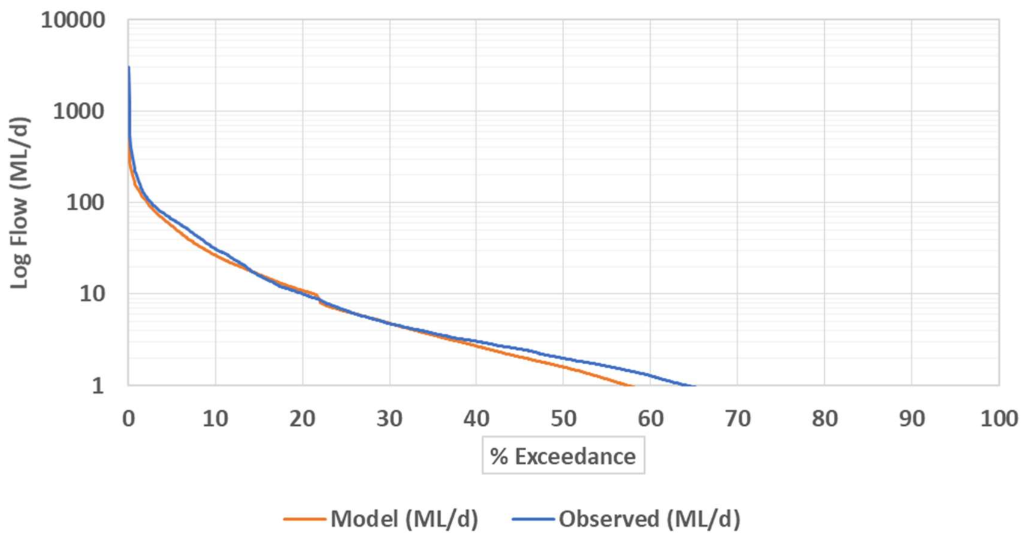


Figure 4-2 Gauge 2122006 calibration flow duration curve – hourly

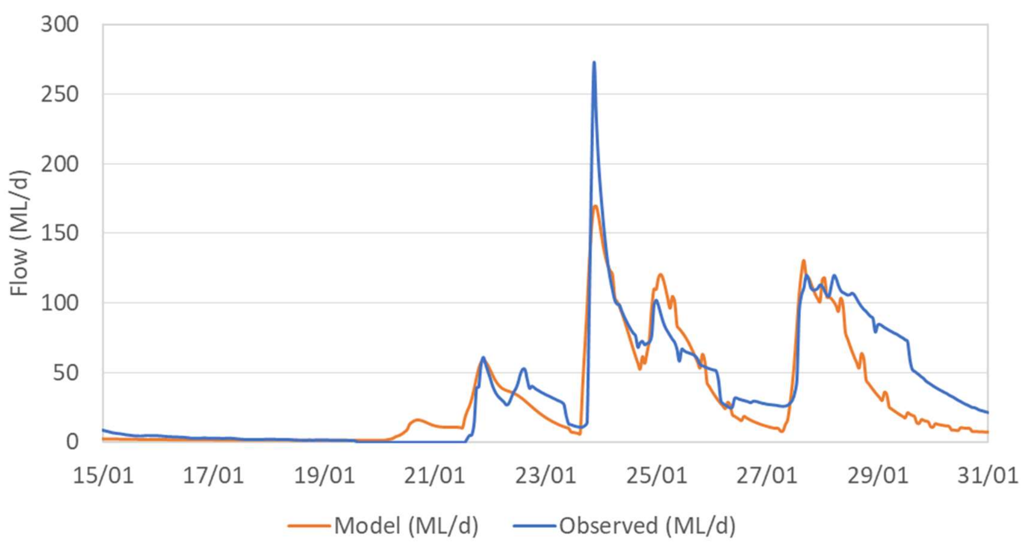


Figure 4-3 Gauge 2122006 January 23rd 2015 (mid-range) calibration event comparison – hourly

Table 4-1 Gauge 2122006 calibration statistics

Statistic	Hourly	Daily	Monthly
NSE	0.691	0.725	0.735
Mean Observed Flow	11.59 ML/d	11.54 ML/d	340.08 ML/m
Mean Modelled Flow	10.22 ML/d	10.20 ML/d	300.67 ML/m
Bias	-11.85%	-11.59%	-11.59%

Validation

Gauge 2122006

The hydrograph results in Figure 4-4 show that the model is representing the flow magnitudes well during the validation period. This is further demonstrated in the flow duration curves within Figure 4-5 that show exceedance curves for concurrent modelled and observed data. The results of which show that the model flows are relatively consistent with the observed data over the validation period though with some over-estimation of medium flows.

Summary statistics are also presented in for the validation at gauge 2122006 for information purposes. We use these to ensure that there is still positive Nash Sutcliffe Efficiencies over the validation time period and that the flow magnitudes are reasonable but given some of the uncertainties regarding different parts of the flow regime, the results will not provide exact representations of observed flows. When developing these models, we are aiming to ensure the calibration results are achieving the Moriasi criteria and that the validation period demonstrates that the model response is satisfactorily reproducing the observed flow response. Based on the results obtained, the model appears to meet this requirement.

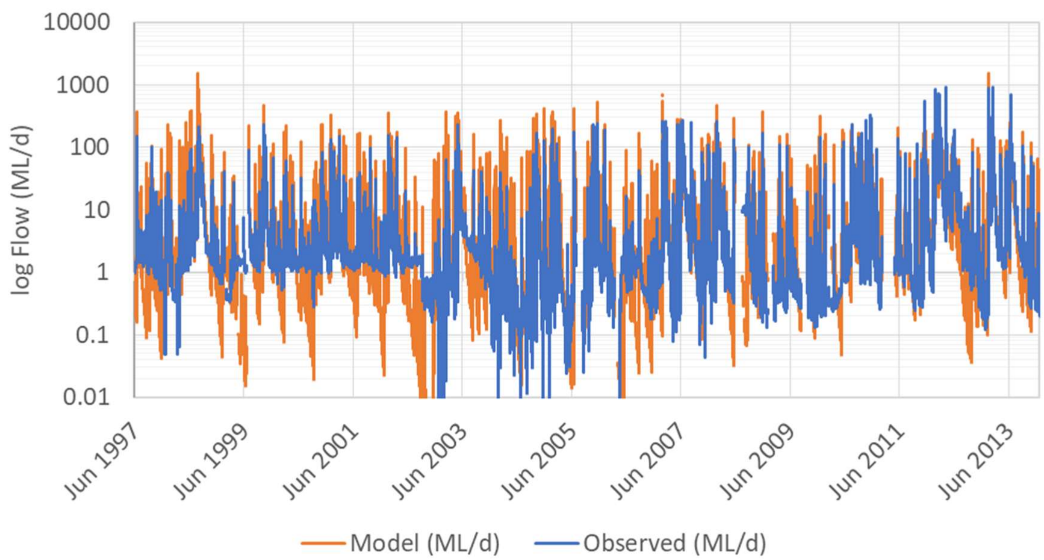


Figure 4-4 Gauge 2122006 validation hydrograph – hourly

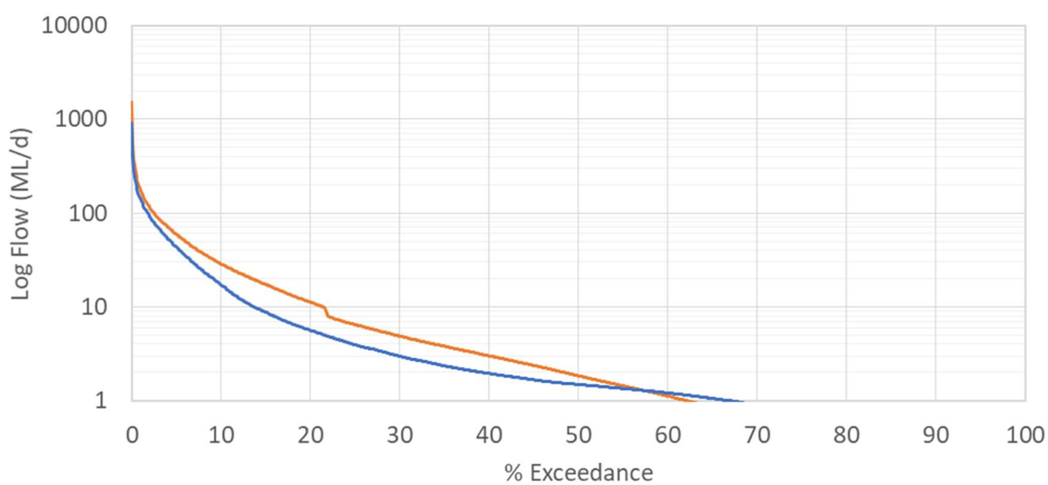


Figure 4-5 Gauge 2122006 validation flow duration curve – hourly

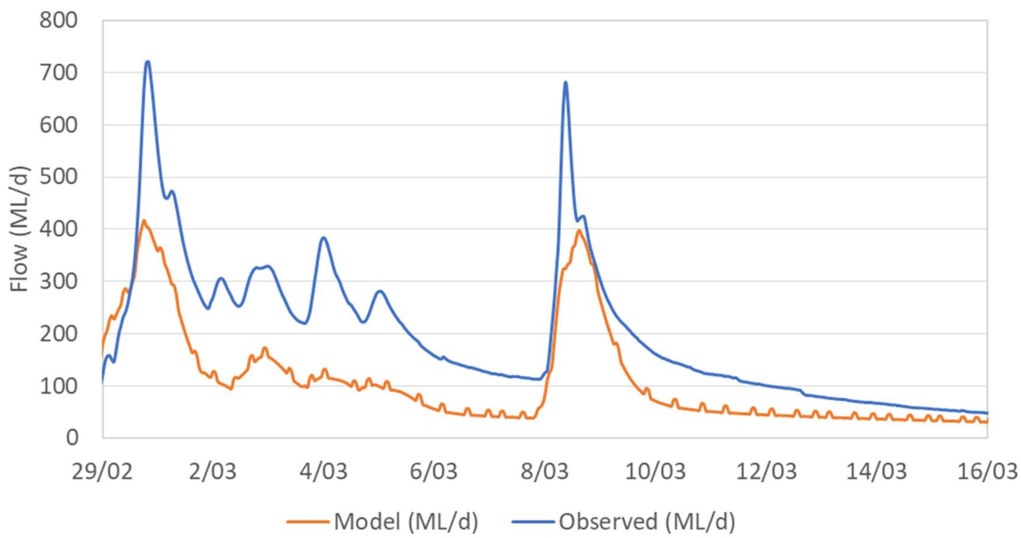


Figure 4-6 Gauge 2122006 March 8th 2012 (mid-range) validation event comparison – hourly

Gauge 212053

The hydrograph results in Figure 4-7 show that the model is capturing the lower to mid-level flows appropriately but not capturing the high flows. This is not unexpected as the model was calibrated to flow periods at the downstream gauge that represent the lower to mid-range flows. This is further demonstrated in the flow duration curves within Figure 4-8 that show exceedance curves for concurrent modelled and observed data. The results of which show that the flows are matching well between the modelled and observed flows, except the very high flows.

Given that our focus has been on ensuring the model is calibrated well for the low to medium flows, the model appears to be reproducing these flows well at both gauge 2122005 and 212053 and is therefore fit for purpose for answering the key modelling questions.

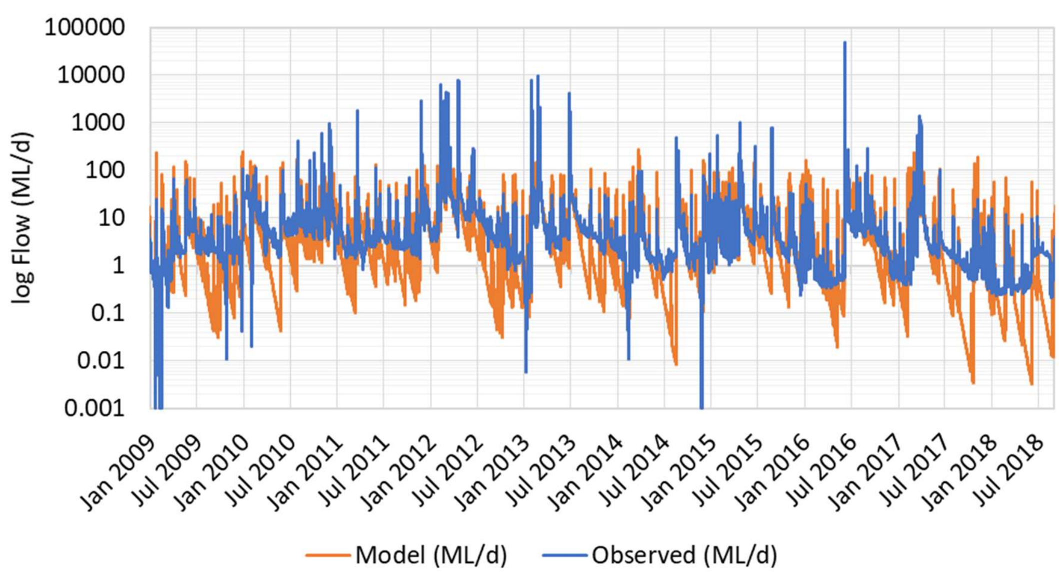


Figure 4-7 *Gauge 212053 validation hydrograph – hourly*

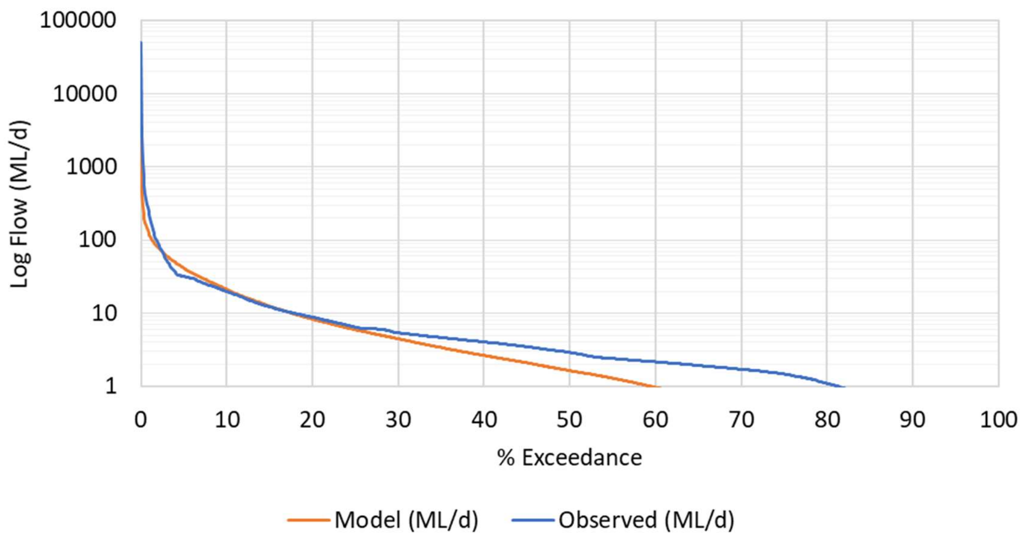


Figure 4-8 *Gauge 212053 validation flow duration curve – hourly*

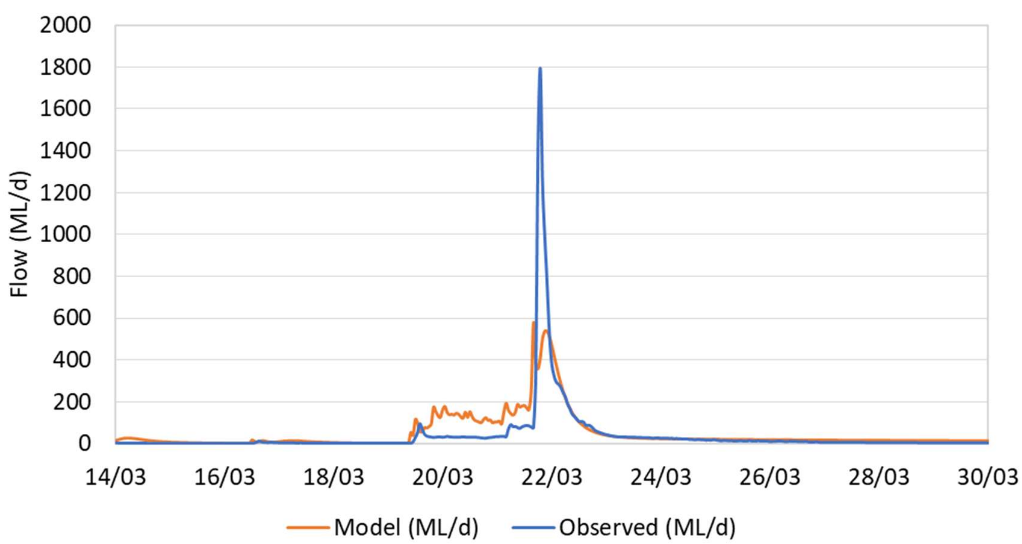


Figure 4-9 *Gauge 212053 March 22nd 2011 (mid-range) validation event comparison – hourly*

4.2 Picton Water Recycling Plant Flows and Dam Levels

The model representation of the Picton Water Recycling Plant (WRP) and its associated infrastructure (Eastern and Western Dams, irrigation application and discharge to Stonequarry Creek) used observed flow and level information for:

- Picton WRP flows to the Western Dam from the Equalisation Basin (flow through the filters)
- Western Dam to Eastern Dam water transfer
- Eastern Dam water extraction for irrigation
- Discharge to Stonequarry Creek from the Western Dam
- Eastern Dam storage level and Western Dam storage level

The calibrated model matched dry weather flow through the filters. Accurate wet weather flow gauging is not available (but a new gauge on the bypass line to the Eastern Dam is planned in scheduled works).

4.3 Total Nitrogen

Total nitrogen was calibrated at seven observations points within the model. Due to the limited availability of total nitrogen observations (and water quality parameters in general), it was not possible to undertake a split calibration and validation approach as was undertaken for flow. The locations used for calibration were:

- Picton Township (N912)
- Redbank Creek (N914)
- Upstream of Picton WRP (N911B)
- Downstream of Picton WRP (N911)
- Nepean River downstream of Stonequarry Creek (N91)
- Picton WRP Discharge to Stonequarry
- Picton WRP Irrigation from Eastern Dam

Figure 4-10 shows the percentage bias in Total Nitrogen at each of the observation points in the mode domain. The colour gradings refer to the Moriasi (2007) categorisation of model fit for Total Nitrogen (Very Good <±25%, Good <±40%, Satisfactory <±70% and Unsatisfactory >±70%). All locations are rated as very good or satisfactory.

The sites on Stonequarry Creek that are underestimating the results is due to the timing of observations compared to the modelled results. Though examining the time series and box plot results for these locations show that the model is capturing the variability appropriately.

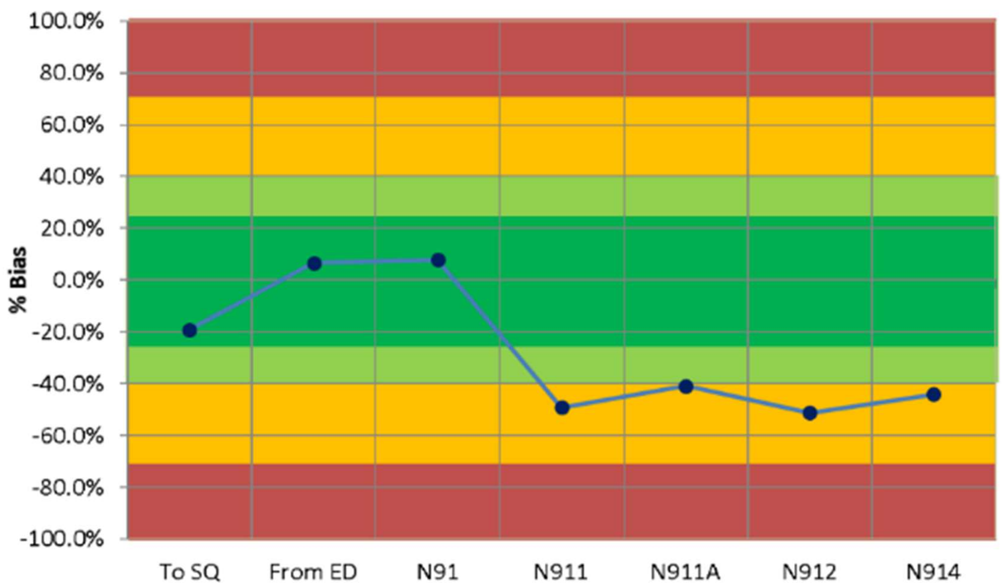


Figure 4-10 Total Nitrogen percentage bias

Figure 4-11 outlines box plot results for Total Nitrogen at each of the locations. Box plots are examined in pairs at each site comparing observed (left) and modelled (right) concentrations. The box plots show:

- Maximum (upper dot),
- Closest value, without exceeding the 75th percentile + 1.5 the inter quartile range (upper whisker)
- 75^{th} percentile (upper limit of box)

- 50th percentile ("middle" of box)
- 25th percentile (lower limit of box
- Closest value, without being less than 25th percentile - 1.5 the inter quartile range (lower whisker)
- Minimum (lower dot)

It can be seen from the box plots that the modelled represents the observed Total Nitrogen concentrations appropriately.

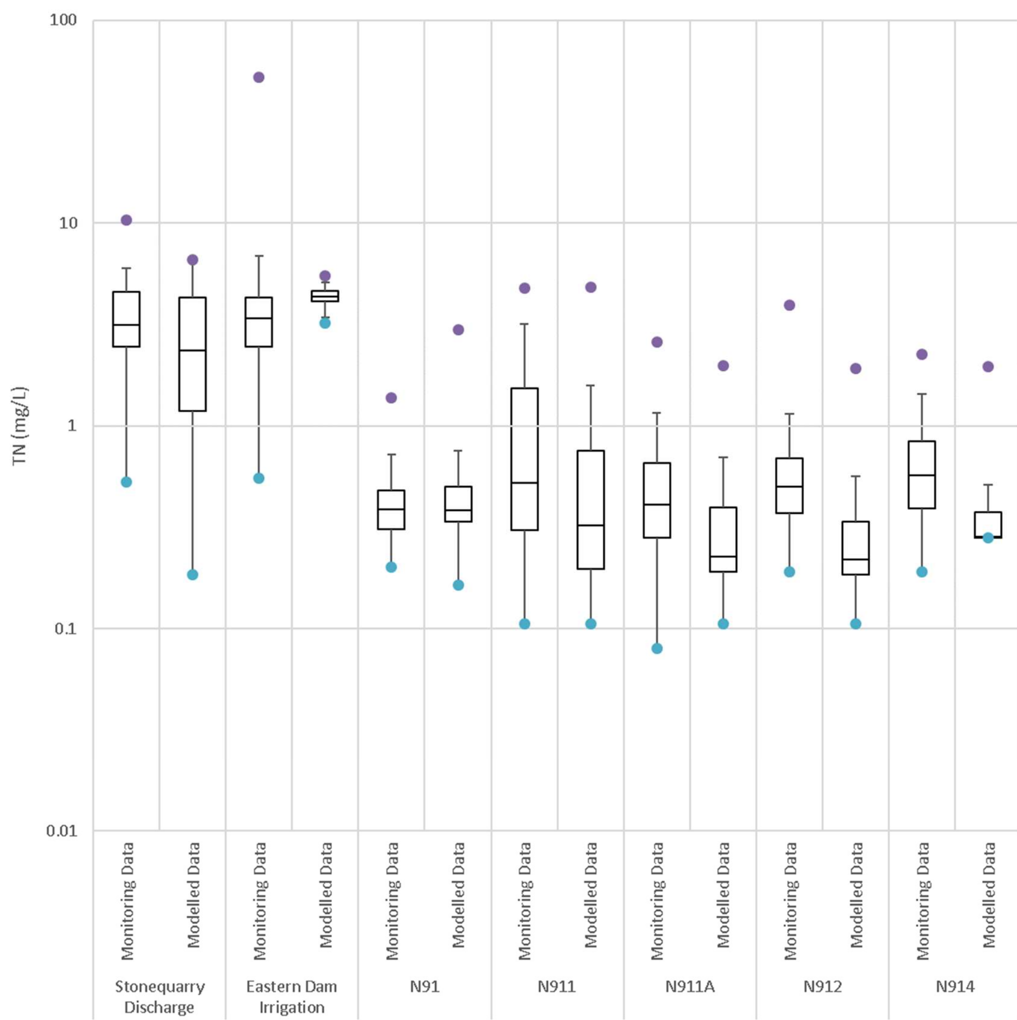


Figure 4-11 Total Nitrogen Box Plot

Figure 4-12 shows scatter plots representing the mean, median and 95th percentile of modelled versus observed concentrations. Each dot on the graph represents one of the seven comparison locations. It can be observed that the sites surround the one to one line on the graphs.

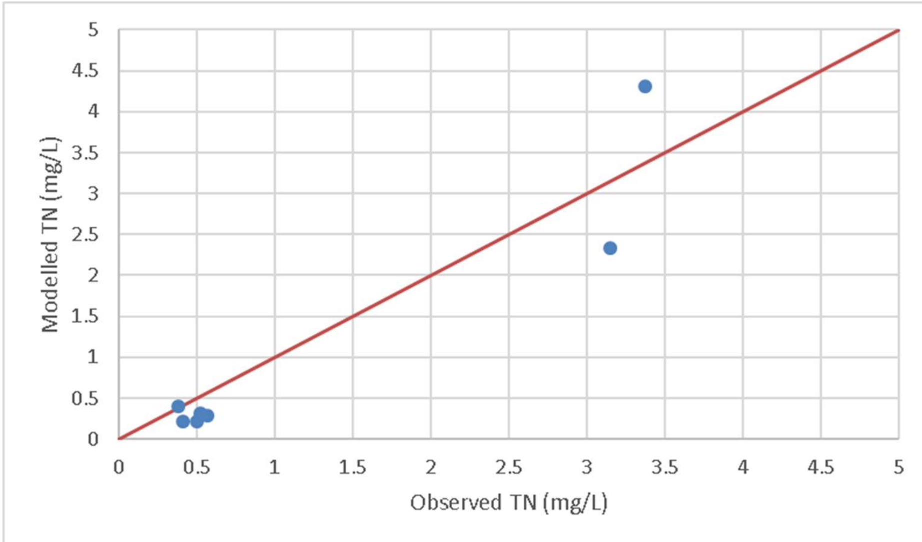


Figure 4-12 Total Nitrogen scatter plot - median concentrations

Further details are provided in Appendix D, with TN results at various water quality sites, and other parameters.

4.4 Calibration and Validation Conclusions

The key conclusions from the model calibration and validation are:

- Picton WRP to Stonequarry Creek captures the range of variability within the observed data of the recent period but is higher than the observations earlier in time. This indicates that concentration or load of Total Nitrogen entering the Western Dam or how the Western Dam processes Total Nitrogen has changed over time.
- Picton WRP irrigation (from Eastern Dam) models less variability that in the observed data indicating that the decay applied to the storages does not capture the entire variability within the dam and that there are other processes occurring.
- N914 captures the range of variability of the observed data.
- N912 captures the majority of variability in the observed data, however a couple of values are outside the modelled variability. These higher observations may not be representative of typical catchment flows.
- N911 captures the range of variability appropriately as shows clearly the effect of discharges from Picton WRP.
- N911B, despite being in such close proximity to N911, shows a very different profile as it is not affected by the Picton WRP discharges. It shows that the catchment conditions are represented appropriately.
- N91 results show that the Nepean River and Stonequarry concentrations are being captured appropriately. However, the observations are all at the lower end of the modelled results, with events spiking above the observed variability. This could be due to attenuation of Total Nitrogen concentrations at the downstream end of Stonequarry Creek, or more likely, the observations are captured on dry weather flow days.

4.5 Limitations and recommendations for further work

The model and scenarios developed above provide a useful tool to study various configurations for the Picton WRP in the context of Stonequarry Creek and the Nepean River. While no model can be expected to exactly reproduce observed flows and concentrations, the model has been calibrated based on the best available data, recognising limitations in both the observed data and the model.

Throughout the model development process a number of areas for future model refinement were identified. These are:

1. **WRP inflows:** The model assumes water entering Picton WRP during wet weather events contains lower Total Nitrogen and Total Phosphorus concentrations than during dry weather. The wet weather concentration and wet weather removal efficiency values that have been assumed for this project could be revised if improved information (e.g. monitoring data) becomes available. The inflows in wet weather have been optimised using data for the 2015- 2017 period. The inflow calibration could be improved once sufficient accurate inflow gauging is available (new magflow gauge since late 2019).
2. **Land use and model parameters:** The parameterisation of catchment water quality generation models contains differences in concentrations between land use types, but these are based on literature values and the experience of the modellers with similar catchments in NSW (e.g. South Creek) and other catchments across Australia. While these parameters provide an appropriate representation of the overall catchment load within Stonequarry Creek, should land use change be examined in the future using this model, it is recommended that refinement in the parameterisation of land use hydrology and pollutant export is undertaken, especially with regards to the likely increases in urbanisation.
3. **Creek flow gauge improvements:** As for the Picton WRP gauge, the Stonequarry Creek flow gauge at Picton has unreliable flow gauging for lower flows and is more representative of flood flows (*pers. comm. WaterNSW)*. It therefore would be beneficial to better understand these limitations and support upgrades of the gauge should that be possible. Opportunities to enhance low flow gauging have been identified by Sydney Water's Hydrometrics team.
4. **Creek flow gauging:** There are limits to the accuracy of the creek flow gauging (both Maldon Weir and Stonequarry Creek flows at Picton WRP). Although some improvements to the gauge have been made, there would be value in further accuracy in the critical low flow and cease to flow periods. The catchment calibration should therefore be revised once a period of additional data (e.g. after 1-2 years) has been obtained.
5. **Nepean River simulation:** the model uses a limited period of data from Maldon Weir as an input to the model, with limited water quality data. An input time series will be available in 2021 from the new Hawkesbury Nepean which includes simulation of the upstream catchment (and may provide a better input for this model). The e-flows hydrology and water quality (since mid 2010) should be reflected in this data input.
6. **WRP flow and water quality:** It would be beneficial if Picton WRP had a greater range of monitoring of flow and water quality through the site to be able to better quantify flow and quality changes through different stages of the treatment process to improve the simulation of the WRP, including:
    - Wet weather bypass flows pre and post treatment
    - Dry weather outflows
    - Any extractions or transfers not currently monitored from either Eastern or Western Dam
7. **Refine extreme event simulation:** better simulation and calibration to accurate gauging of high inflows to the WRP, and movement of water through the WRP and transfers between dams should allow for modelled spills from the dams in extreme events to be minimised.

8. **Reuse on offsite farms:** irrigation on nearby farms has been assumed to have a lower usage rate than at the Picton farm, and is likely to use more manual irrigation infrastructure. Once irrigation has commenced on nearby farms the expected usage rates should be revised if needed and the characteristics of the infrastructure for the reuse scheme reflected in the model.

5 Scenarios and model results

5.1 Current and future inflows

The calibration scenario has the current configuration of infrastructure and uses 2.7 ML/d for the dry weather flow in the Picton WRP. This corresponds to inflows in recent years for the period 2014 – 2018 which is the period that also has regular water quality data available in the receiving waterways. The scenario has been adopted as the Baseline Scenario 1.

Future scenarios (for the short to medium term) consider 4 ML/d inflow – and these are the focus for this report and for the Review of Environmental Factors and Licence Variation Application.

Further scenarios have considered 5.5 ML/d inflow (inflow predicted in 2046) to support further planning.

5.2 Infrastructure requirements for compliance

A scenario was developed to consider the infrastructure required to be compliant with the current precautionary discharge regime in the Environmental Protection Licence (EPL 10555), with 4 ML/d inflow to the WRP. To prevent discharge when streamflow is only above 8 ML/d and with discharge limited to 25% of creek flow, in line with the EPL precautionary discharge rules, (across the 28 year time series with climatic extremes represented from 1991 - 2018), it would require:

- Offsite dam storage of approximately 1,900 ML (5 – 10 times the current farm dam storage).
- Large pump (30 ML/d capacity) to transfer water to an offsite storage (double the capacity of the pumps used for irrigation of 119 ha on the existing Picton Farm, and 5-10 times the capacity of the proposed large transfer pumps for the scheme that has been designed)
- Additional offsite irrigation area (180 ha) in addition to the current irrigation area – 1.5 times the irrigated area on the Picton Farm now.

To accommodate inflows to the WRP of 4 ML/d, greater flexibility is required for discharge, with a change to the precautionary discharge regime that limits discharge to Stonequarry Creek. Alternatively recycled water could be released at a new discharge location (Nepean River).

The precautionary discharge approach could be retained, with periods of 'excess discharge' permitted, or alternative configurations that discharge less volume each day but over a longer period. Further refinement to the regimes within the 'book-end' scenarios proposed below can be adopted, drawing on further information from water quality testing, ecological values, water balance outcomes and flow gauging. Additional reuse (if feasible) will reduce the periods of time when discharge in low flow conditions is required.

5.3 Scenarios

A number of scenarios were developed and iterated to evaluate different discharge regimes, influent volumes and discharge points. These factors were considered in the selection of the scenarios:

- **additional reuse:** efforts are underway to expand reuse further - but there is uncertainty with a range of aspects, hence scenarios consider 60 ha reuse to reflect the immediate opportunities on the two nearest farms. The key limitations are in successful implementation (hence there is limited value in model simulations of larger reuse areas at this point in time)
    - Scheme implementation (relies on agreements with nearby farmers and funding)
    - Scheme longevity (concerns with longevity particularly for nearest properties)

    - Actual usage / simulated demand (variation on demands/irrigation areas best to refine once nearby farm scheme operation and effectiveness can be described with data, and what is feasible to deliver through collaboration with nearby farms)
- **discharge regimes:** There are a multitude of possible regimes. Work now underway to understand metrics that may be higher priority for protection of local waterway values / local species out of frequency of discharge, discharge as proportion of creek flow, zero flow days etc. Accurate simulation of the refinements to the modelling regime in very low flow conditions is likely to require further refinement to the gauges, and additional monitoring data to understand any changes in the ecosystem in response to changes to the discharge regime.
- **alternative discharge location:** Due to the challenges in Stonequarry Creek in low flow conditions, scenarios are included with an alternative discharge location so that if the dilution provided by the greater flows in the Nepean River provides better overall environmental outcomes than increased discharge to Stonequarry, these scenarios can be assessed.

Ultimately, four representative scenarios were selected:

- **Scenario 1** - Baseline "2014-2019"
    - 2.7 ML/d inflow with current irrigation area,
    - Stonequarry discharge, TN 4 mg/L, TP 0.1 mg/L

- **Scenario 2**_SQ_60 Future
    - 4 ML/d inflow, 60 ha offsite reuse (179 ha total irrigation area)
    - Stonequarry discharge, TN 3 mg/L, TP 0.1 mg/L

- **Scenario 3**_NP_60 Future
    - 4 ML/d inflow, 60 ha offsite reuse (179 ha total irrigation area)
    - Nepean discharge, TN 3 mg/L, TP 0.1 mg/L

- **Scenario 4**_NP_0 Future
    - 4 ML/d inflow, 0 ha offsite reuse (119 total),
    - Nepean discharge, TN 3 mg/L, TP 0.1 mg/L

Scenario 1 represents the current discharge conditions from the Picton WRP with median discharge of 2.7 ML/day to Stonequarry Creek, and a constant TN concentration of 4 mg/L and TP concentration of 0.1 mg/L.

Scenario 2_SQ_60 represents an increase to the median discharge of the Picton WRP to 4 mL/day to Stonequarry Creek, and a constant TN and TP concentration to 3 mg/L and 0.1 mg/L, respectively. The total irrigation area is increased to 179 ha assuming 60 ha of external farming area for reuse.

Scenario 3_NP_60 represents an increase to the median discharge of the Picton WRP to 4 ML/day and a constant TN and TP concentration to 3 mg/L and 0.1 mg/L, respectively. Discharges up to 15 mL/day are released the Nepean River and are determined by the month and the available storage capacity in the Western Dam. The total irrigation area is increased to 179 ha assuming 60 ha of external farming area for reuse.

Scenario 4_NP_0 represents an increase to the median discharge of the Picton WRP to 4 ML/day and a constant TN and TP concentration to 3 mg/L and 0.1 mg/L, respectively. Discharges up to 15 ML/day are released the Nepean River and are determined by the month and the available storage capacity in the Western Dam. No additional area for reuse other than the existing 119ha are simulated.

The key parameters used in the modelling scenarios are summarised below (Table 5-1).

Table 5-1 *Key parameters for modelling scenarios*

Model Scenarios				
Parameter	**Scenario 1 Baseline**	**Scenario 2 SQ_60**	**Scenario 3 NP_60**	**Scenario 4 NP_0**
Wastewater inflow volume (ML/d)	2.7	4	4	4
Discharge location	Stonequarry Creek	Stonequarry Creek	Nepean River	Nepean River
Discharge regimes	Precautionary (linked to creek flow) with excess (linked to dam levels)	Precautionary with excess as for Sc. 1	Excess linked to dam levels	Excess linked to dam levels
Irrigation area (ha)	119	179	179	119
		Includes 60ha on nearby farms	Includes 60ha on nearby farms	
TN conc. WRP discharge (mg/L)	4.0	3.0	3.0	3.0
	Prior to new treatment			
TP conc. WRP discharge (mg/L)	0.1	0.1	0.1	0.1
conservative TP concentration				

5.4 Flows

Within the Stonequarry catchment, flows are generated upstream of the current WRP discharge point through rainfall conversion to runoff from a mix of land uses. The model simulates both the pervious and impervious diffuse runoff and pollutant export from these areas through a dynamic rainfall runoff model that simulates soil moisture, rainfall interception, infiltration and baseflow components. These are dependent therefore on the area and characteristics of each land use and the calibration parameters established by the model.

The results presented in this section are therefore representative of both the catchment conditions and operation of the WRP and associated irrigation infrastructure and data inputs as shown in Figure 5-1. Operation of the WRP and irrigation changes according to each scenario run. Baseline conditions represent the existing case as best as possible and are used to compare the remaining scenarios.

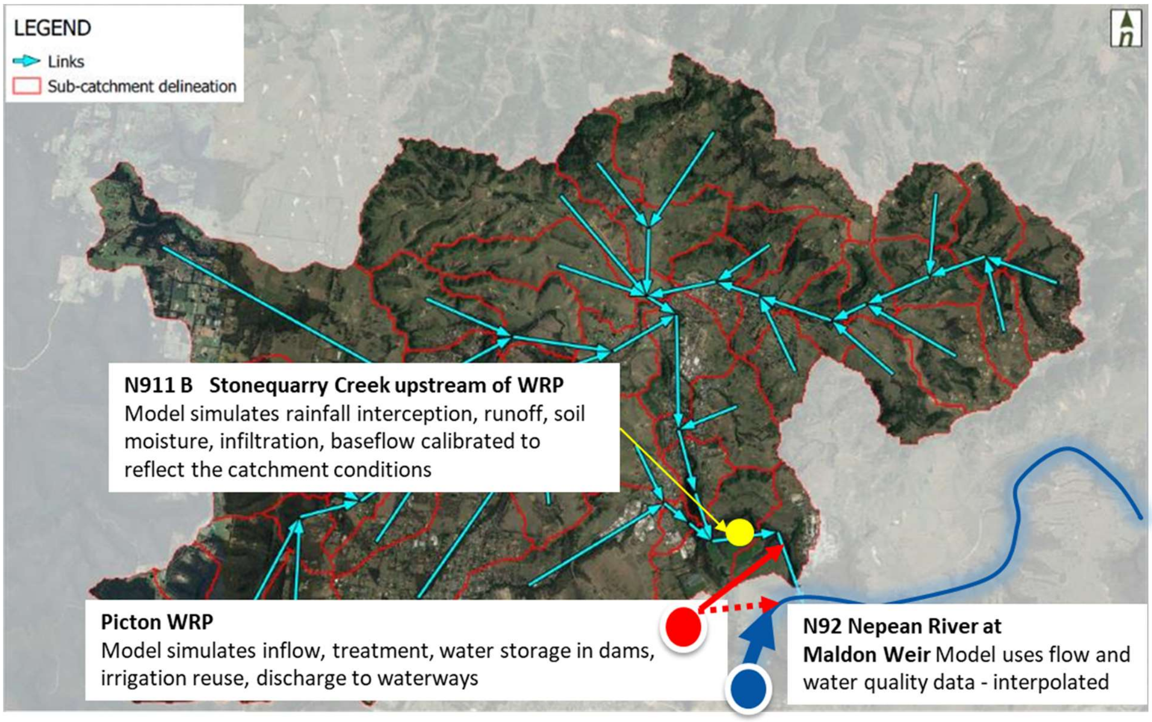


Figure 5-1 Model simulation of Stonequarry Creek catchment conditions, Picton WRP and Nepean River

Flows in the catchment are highly variable both as indicated by the observed data and replicated in the model. The current and proposed operation of the WRP with discharge to Stonequarry Creek will vary according to those flows.

> Flows upstream of the WRP discharge point in Stonequarry Creek are represented by the site 'N911 B' in the model. Stormwater runoff characteristics are reflected in the observed flows, including flows from the urban areas and cleared landscapes are altered from a natural predevelopment hydrology. This results in higher peak flows in storm events, larger volumes of runoff, but reduced baseflows between rainfall events.

Summary result for N911 B are shown below (Table 5-2), in addition to the annual variation in flows which provides some indication of the likely variability in flows year to year (Figure 5-2). A flow duration curve is also shown which provides an understanding of the typical flows in the creek (as modelled).

Table 5-2 Summary of modelled flows – N911B Stonequarry Creek Upstream of WRP discharge

N911B	
Metric	**All scenarios**
Mean Annual Flows (ML/yr)	4,086
Mean Annual Flow Frequency (days/yr)	365

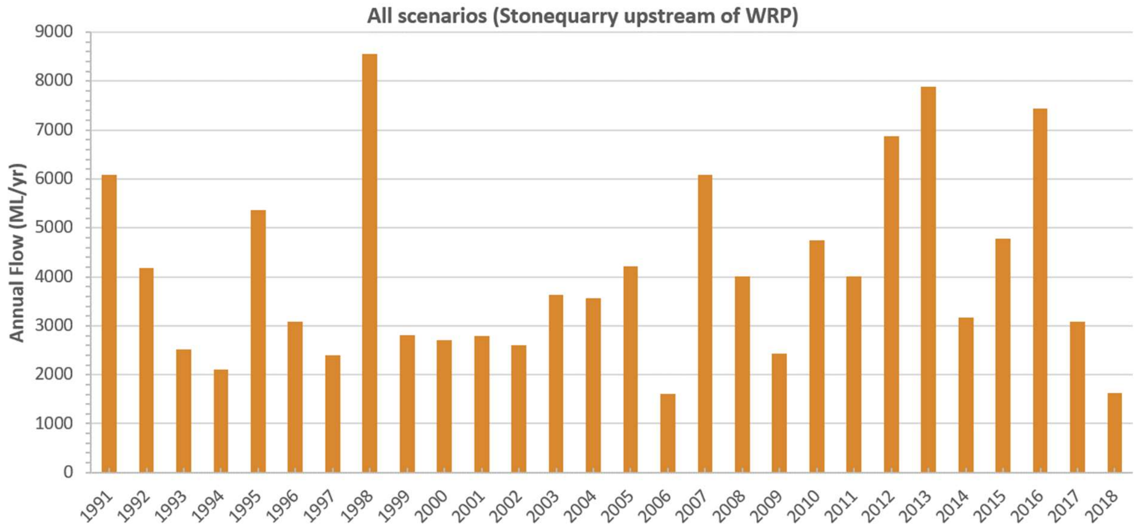


Figure 5-2 Modelled mean annual flows – N911B Stonequarry Creek Upstream of WRP discharge

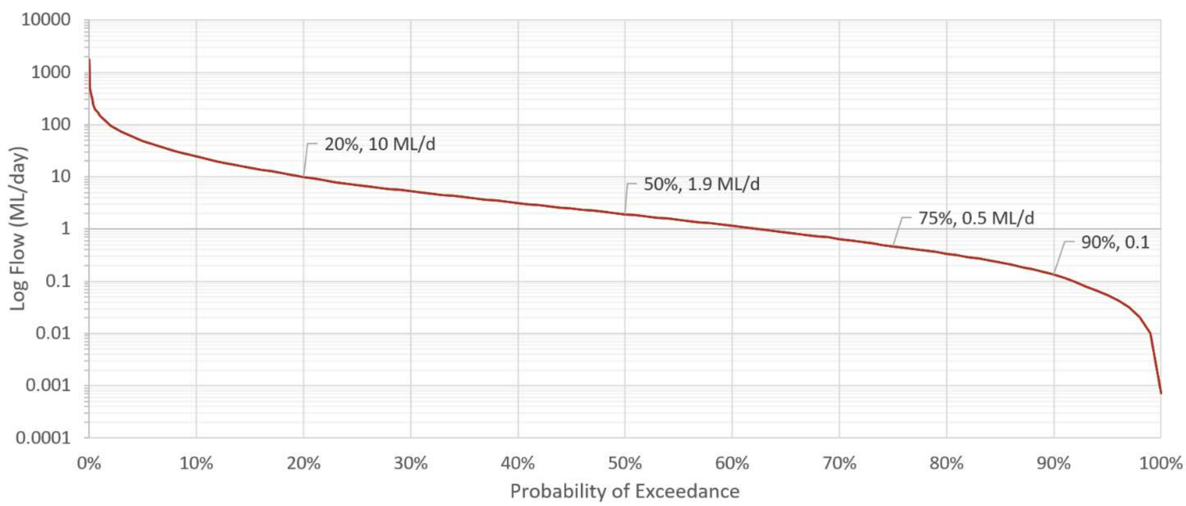


Figure 5-3 Modelled flow duration curve - N911B Stonequarry Creek Upstream of WRP discharge

These results show that there is unlikely to be a significant cease to flow period, noting that the model and the flow gauges are somewhat constrained at representing cease to flows well, but even so, the very low flow periods (<0.01 ML/d) only occur around 3% of the time so this would indicate that some baseflow is likely to be present most of the time.

Annual variability is significant as shown in Figure 5-2, with wet years producing more than 4 times the annual flow of dry years.

Flows downstream of the WRP – Scenario 1 (Baseline) and Scenario 2

Discharges to Stonequarry Creek from the WRP are simulated to occur in Scenario 1 (baseline) and Scenario 2 (future with 60 ha additional irrigation area). These models provide an indication of the additional flow contributions to Stonequarry as a result of the WRP discharges. In the model, this location is marked as N911 being downstream of both the flow monitoring and discharge points. Comparison with the upstream results as shown above is also included for reference.

Table 5-3 Modelled flows summary – N911 Stonequarry Creek downstream of WRP discharge

	N911		N911 B
Metric	**Scenario 1 Baseline**	**Scenario 2 SQ_60**	**Upstream N911 B**
Mean Annual Flow (ML/yr)	4578	4691	4086
Mean Annual Flow Frequency (days/yr)	365	365	365

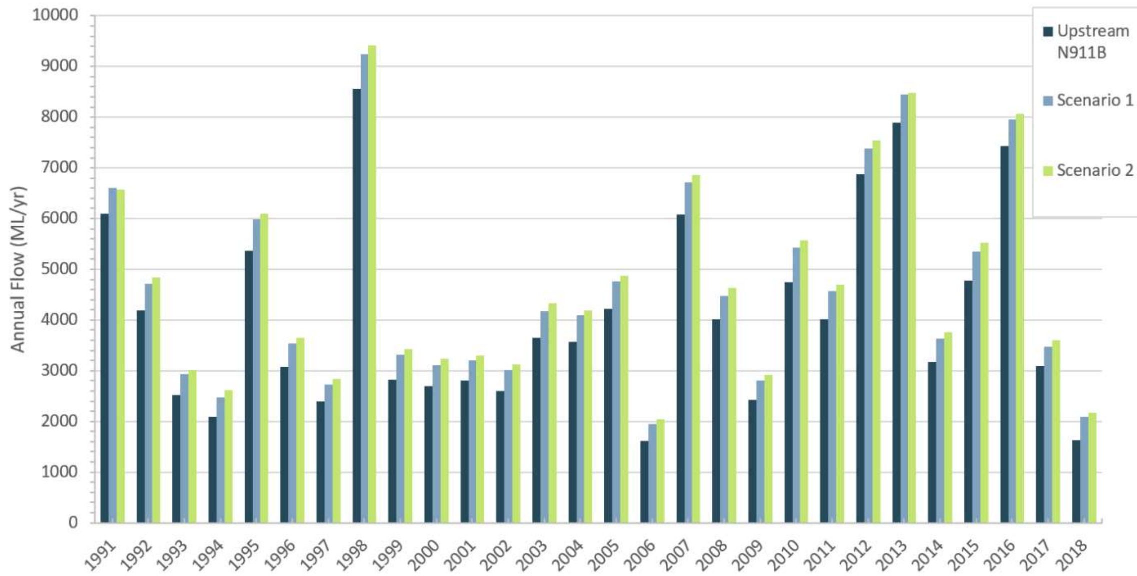


Figure 5-4 Modelled mean annual flows – N911 Stonequarry Creek Downstream of WRP discharge

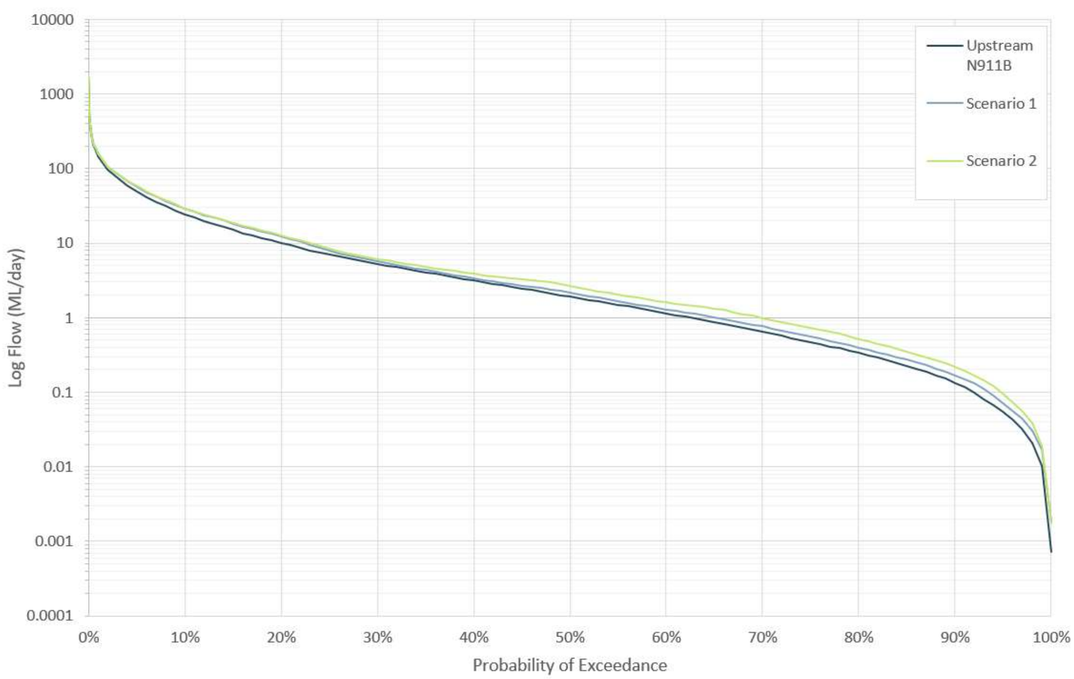


Figure 5-5 Modelled flow duration curves – N911 Stonequarry Creek Downstream of WRP discharge

These results show that the WRP discharge is simulated as increasing mean annual flows in the creek by around 12% in the baseline condition. In the future with additional discharges to Stonequarry Creek, as represented in Scenario 2, the proportion of flow in Stonequarry from the WRP is expected to be on average around 15%, so an increase of 3% above the current baseline. Given the flow and WRP variability, there will be periods of time where discharge exceeds 25% of the flow in the creek and periods where no discharge occurs, as noted further below.

Discharge from the WRP – All scenarios

Discharge from the WRP is shown below for all scenarios with the numeric WRP discharge modelled results (Table 5-4) and graph of year to year variability in discharge (Figure 5-6). Note in Scenarios 3 and 4 the discharge is simulated to a new location in the Nepean River, downstream of Maldon Weir. The WRP discharge in all scenarios is the excess flows from the irrigation storages after irrigation reuse, so represents those flows which may overflow when inflows exceed the irrigation demand and no additional storage is available in the effluent storages. Discharges to Stonequarry Creek (Scenarios 1 and 2) includes both precautionary and emergency discharges. For Scenario 3 and 4, discharge to the Nepean River have been modelled to maintain target water levels in the storage dams at the farm to allow water to be reserved for reuse, but also provide sufficient freeboard in these dams to limit the risk of spill from the dams in extreme storm events. The model is structured to operate the irrigation storages and discharges differently hence the discharge is slightly more in scenario 3 with 60 ha additional reuse (average 638 ML/y) than for Scenario 2 with the same amount of reuse (average 605 ML/y).

Table 5-4 *Modelled flows summary – WRP discharge*

WRP_Discharge				
Metric	**Scenario 1 Baseline**	**Scenario 2 SQ_60**	**Scenario 3 NP_60**	**Scenario 4 NP_0**
Mean Annual Inflow to WRP (ML/yr)	~ 1,000	~ 1,500	~ 1,500	~ 1,500
Mean Annual Discharge to waterways (ML/yr)	492	605	638	860
Discharge as a proportion of typical inflow	~ 50%	~ 45%	~ 45%	~ 60%
Mean Annual Discharge Frequency (days/yr)	123	155	217	280
Discharge as proportion of Stonequarry Creek flow (%)	12%	15%		
Discharge as proportion of Nepean River flow (%)			1%	1%
Productive agricultural area irrigated (ha)	119	179	179	119
Proportion of *time* non-compliant discharge occurs in Stonequarry Ck (discharge when creek flow is below 8 ML/d)	11%	20%	0%	0%
Proportion of *volume* discharged into Stonequarry Ck that is non-compliant with current EPL (creek flow below 8 ML/d)	12%	24%	0%	0%

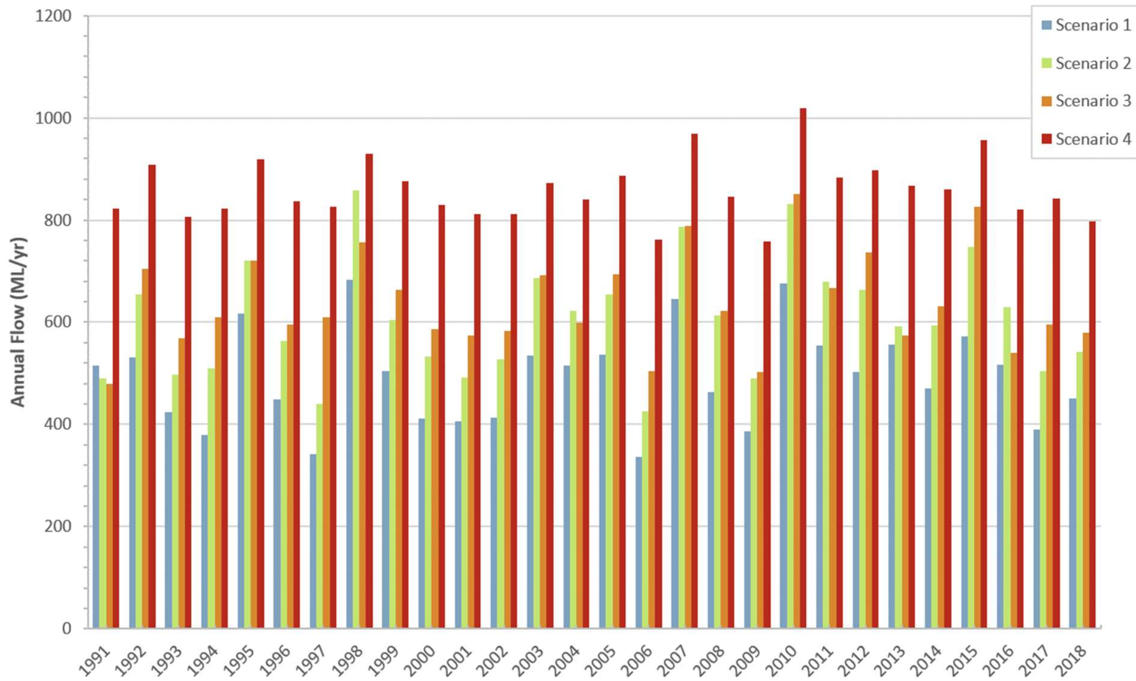


Figure 5-6 *Modelled mean annual flows –WRP discharge*

These results indicate that modelled discharge from the WRP as a proportion of flows in the Nepean River is very low, approximately 1% of the mean annual flow (Table 5-4). They also indicate the proportion of time and volume that is non-compliant with the current EPL licence for Stonequarry Creek discharges based on the simulated results. If WRP discharge is directed to the Nepean River, there is very little or no discharge expected to Stonequarry Creek (and hence no precautionary discharge or excess discharge). The compliance rules for any discharge to the Nepean River are not known at this time, so compliance with these future rules is not determined.

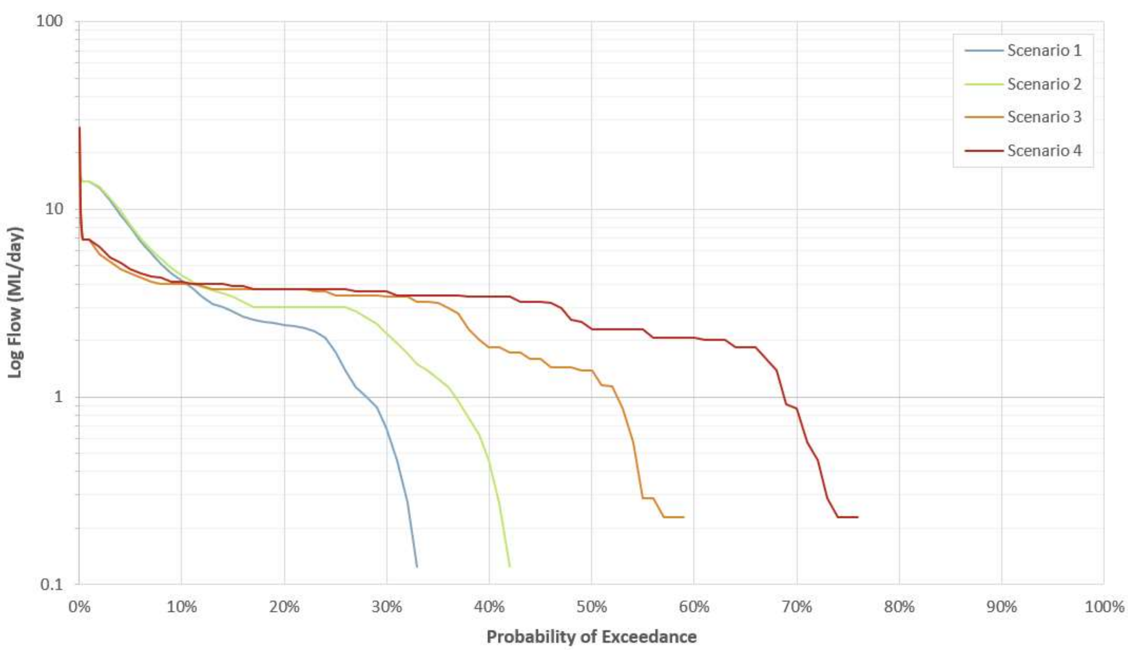


Figure 5-7 *Modelled flow duration curves – WRP discharges to Stonequarry (Scenario 1&2) and Nepean (Scenario 3&4)*

The flow duration curves (Figure 5-5) show that in Scenarios 1 and 2, the amount of time that discharges occur is < 50% of the time given that discharges are minimised as much as possible, but this approach presents challenges operationally in extreme weather periods, given dam levels are generally higher. For Scenarios 3 and 4, greater operational flexibility is possible given the assimilative capacity of the Nepean, hence the periods when flows occur is simulated to increase, and the dam storages can be maintained at a lower operating level allowing for greater capacity for wet weather inflows.

Nepean River – changes to flow under all scenarios

For flows in the Nepean River the results below indicate the total flows downstream of the proposed discharge point but prior to the confluence between Stonequarry Creek and the Nepean River (Table 5-5). In Scenario 1 and 2, these results are simply the upstream flows at Maldon Weir (N92), whereas in Scenario 3 and 4, the flows increase, reflecting the discharge from the WRP with an additional 60 ha of irrigation area (Scenario 3) or just the existing irrigation area (Scenario 4).

Table 5-5 *Modelled flows summary – Nepean River downstream of new discharge location (u/s of Stonequarry confluence)*

	Nepean River downstream of new discharge			
Metric	Scenario 1 Baseline	Scenario 2 SQ_60	Scenario 3 NP_60	Scenario 4 NP_0
Mean Annual Flow (ML/yr)	59026	59026	59664	59885
Difference relative to Baseline (ML/y)	0	0	638	859
%			1.1%	1.5%
Mean Annual Discharge Frequency from WRP to Nepean River (days/yr)	0	0	217	280

The results show the contribution of the WRP flows to the Nepean River in Scenarios 3 and 4 is small (Table 5-5), approximately 1.1% of the mean annual flow for Scenario 3 and 1.4% with Scenario 4.

Downstream of the confluence with Stonequarry Creek at N91, the change to average annual flows for all scenarios can be seen and compared with the baseline (Table 5-6).

Table 5-6 *Modelled flows summary – N91 Nepean R d/s of Stonequarry confluence*

	N91			
Metric	Scenario 1 Baseline	Scenario 2 SQ_60	Scenario 3 NP_60	Scenario 4 NP_0
Mean Annual Flow (ML/yr)	63690	63821	63835	64057
Difference relative to Baseline (ML/y)	0	131	145	367
Mean Annual Discharge Frequency from WRP to waterways (days/yr)	123	155	217	280

The results show that Scenario 4, with no additional irrigation area beyond the existing 119ha results in the largest overall increase in flows, with similar results between the 60ha additional irrigation scenarios regardless of discharge to Stonequarry or the Nepean River. There is a slight increase in flows in the Nepean River of approximately 0.2% predicted in both Scenarios 2 and 3 when compared to baseline and 0.5% for Scenario 4, so the flows in the Nepean River are unlikely to significantly alter between the current baseline and the future projected WRP flows. The flow duration curves and year on year graphs have not been included for N91 and N92 as they show insignificant differences across the whole flow range and it is only the numeric results above which clearly show the small changes. The frequency of discharge from the WRP could be refined with adjustments to the discharge regime, but the overall trends for these scenarios are clear. The effectiveness of reuse on nearby farms is not yet known (and there are implications for assumptions in the model), however the scenarios reflect the expected benefits associated with increased reuse.

5.5 Constituent loads

The modelled contributions of the WRP to Stonequarry Creek or the Nepean River show relatively small changes to flow, but these volumes also influence constituent loads such as nitrogen and phosphorus. The model simulates total nitrogen (TN), total phosphorus (TP), oxides of nitrogen (NOx) and soluble reactive phosphorus (SRP) however the bioavailable forms of the nutrients are represented as simply ratios of TN and TP, hence their behaviour is identical in terms of changes in loads. Once further information is available from monitoring the performance of the denitrification filters, the model could be refined to simulate any trends.

Whilst there is an increase in discharge volumes with scenario 2 relative to the baseline, the model indicates a slight reduction in loads (due to the additional treatment reducing discharge concentrations from 4 mg TN/L to 3 mg TN). Substantial variation is expected year to year but with important trends in the predicted median annual loads for the modelled time series (Figure 5-8) and the same trends reflected in the average annual loads (Table 5-7).

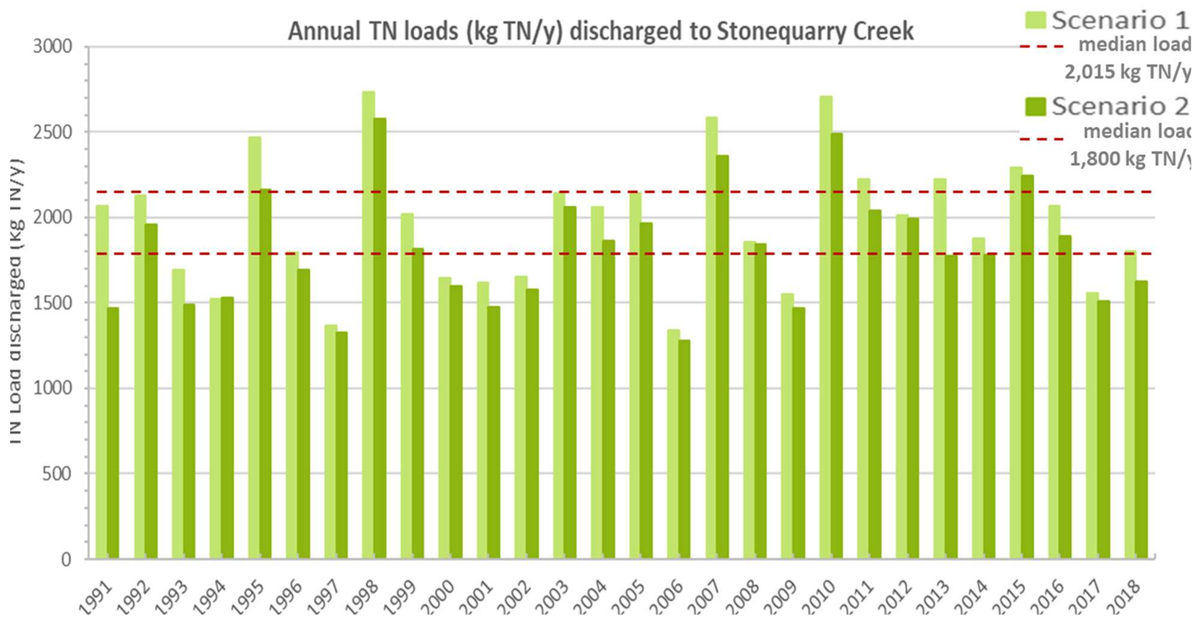


Figure 5-8 *Modelled mean annual loads TN – WRP discharge to Stonequarry Creek (Scenario 1 and 2)*

The model outputs, and comparison with actual discharge from the WRP, show:

- The median annual TN load for scenario 1 (baseline) is 2,015 kg TN/y (simulation of 1991-2018 climate data with average inflow to WRP fixed at 2.7 ML/d).
- The median annual TN load reduces slightly to around 1,800 kg TN/y for scenario 2, reflecting the benefits expected from denitrification filters in reducing TN concentrations and loads (and NOx).
- Similarly the average annual load is predicted to decrease slightly from 1,969 kg TN/y (Scenario 1 baseline) to 1,816 kg TN/y (Scenario 2) as shown in Table 5-7 below.

- Both scenarios exceed the current EPL (1,460 kg TN/y), but are well below the Hawkesbury Nepean Framework load allocation for Picton WRP (approximately 4,000 kg TN/y).
- Year to year the loads are highly variable due to changes in rainfall, inflows and reuse (range for Scenario 2 from 1,300 – 2,600 kg TN/y in the modelled time series variability).
- The actual average annual discharge from Picton WRP between 2014-2020 was 1,891 kg/y. Note the actual average TN load discharged shows even greater variability (from 326 kg TN in 2017-18 to 3,369 kg TN in 2016-17). The modelling assumptions conservatively reflect reuse to ensure discharge to waterways is not underestimated, and that the long term average is consistent with the water usage that have been realised (4 ML/ha/y). The long term usage reflects operational constraints like biosolids application and disruption due to infrastructure works that are not reflected in the model. Disruption in 2016-17 included works to upgrade to irrigation pumps.

Scenario 3 reflects discharge under a future scenario with increased WRP inflows, increased reuse and discharge (after treatment) to a new location on the Nepean River, just downstream of Maldon Weir. Scenario 4 is similar but with no expansion of reuse to nearby farms (unable to implement or ineffective in operation). Substantial variation year to year is expected (Figure 5-9), but with less variation for Scenario 4.

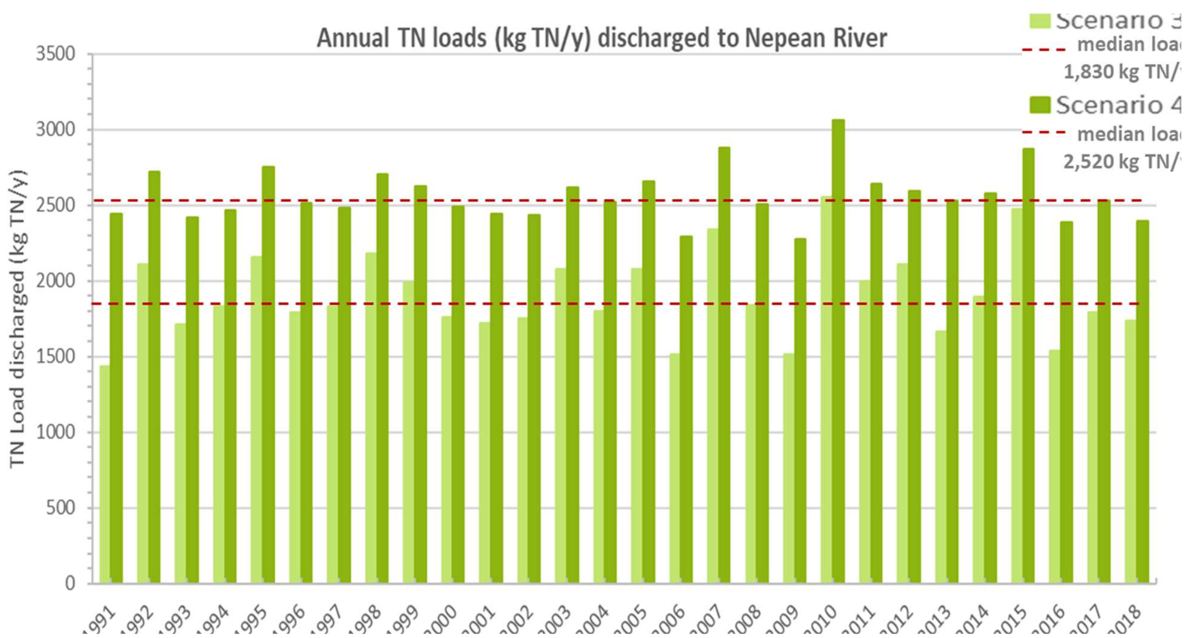


Figure 5-9 *Modelled mean annual loads TN – WRP discharge to Nepean River (Scenario 3 and 4)*

- The median annual TN load for scenario 3 is 1,830 kg TN/y, and 2,523 kg TN/y for scenario 4.
- Similarly the average annual load is predicted to decrease slightly from the baseline (1,969 kg TN/y) to 1,899 kg TN/y (Scenario 3) as shown in Table 5-7 below. With increased inflows but no increase in irrigation area, the load would increase to an average to 2,563 kg TN/y (Scenario 4)

While graphical results are useful to visualize the variability in loads year to year and comparison between scenarios, the tabulated values are also shown so the differences are clear. The modelled TN and TP loads are presented (Table 5-7) for the WRP discharge, Stonequarry Creek and Nepean River recording points to show the changes in both.

Table 5-7 *Mean annual loads for all scenarios*

	Mean Annual Loads			
Metric	**Scenario 1 Baseline**	**Scenario 2 SQ_60**	**Scenario 3 NP_60**	**Scenario 4 NP_0**
WRP discharge **TN Load** (kg/yr), Average across the 1991-2018 time series	1969	1.816	1,899	2,563
Median across the 1991-2018 time series	2,015	1,800	1,830	2,520
WRP discharge **TP Load** (kg/yr)	49	61	64	86
Stonequarry Creek				
N911B u/s WRP discharge TN Load (kg/yr)	6,544	6,544	6,544	6,544
N911B u/s WRP discharge TP Load (kg/yr)	385	385	385	385
N911 d/s WRP discharge TN Load (kg/yr)	8,513	8,360	6,544	6,544
N911 d/s WRP discharge TP Load (kg/yr)	434	445	385	385
Nepean River				
Nepean d/s new WRP discharge TN Load (kg/yr)	23,680	23,680	25,579	26,240
Nepean d/s new WRP discharge TP Load (kg/yr)	900	900	964	986
N91 d/s SQ confl TN Load (kg/yr)	32,337	32,210	32,267	32,931
N91 d/s SQ confl TP Load (kg/yr)	1,342	1,354	1,357	1,379

WRP loads to Stonequarry Creek - similar for future Scenario 2 relative to baseline

These results show that the increase in TN loads between upstream and downstream of discharges into Stonequarry Creek in Scenarios 1 and 2 is 30% for the baseline scenario and 28% for the future scenario (2) and 13% and 16% for TP loads (with TP conservatively simulated). It is expected that a reduction in TN loads would occur between the baseline and future scenario 2 because even though WRP discharge flows increase, there is a reduction in TN concentrations assumed (from 4mg/L to 3mg/L with the addition of denitrification filters in the WRP process) and the additional 60 ha of additional irrigation area (increased from 119ha to 179ha). Scenarios 3 and 4 do not discharge to Stonequarry Creek and therefore the results do not change from the upstream values.

WRP loads to Nepean River – small relative to load in waterway

Conversely for the Nepean River, Scenarios 1 and 2 do not discharge to the Nepean River, so the loads do not change from those at Maldon Weir and are not unimpacted (from the WRP) loads. The modelled increase in TN in the Nepean from Scenarios 3 and 4 is 8% and 11% respectively, and for TP 7.1 and 9.6%.

Cumulative loads at N91 – remain similar, and reduce with greater reuse

Downstream of the Stonequarry confluence, the results indicate the impacts of all the scenarios on the Nepean River. Only Scenario 4, which has no additional reuse, shows an increase in TN loads above the baseline, whereas Scenarios 2 and 3 have a slight reduction in TN loads due to the additional reuse as well as improved treatment performance with denitrification. For TP, the loads all increase as the TP concentration is the same for the baseline and future in the discharge (assumed to be 0.1 mg/L). Overall, TN reduces by 0.4% and 0.2% in Scenarios 2 and 3 below baseline, whereas for Scenario 4 there is a 1.8% increase predicted. For TP, there is a 0.9, 1.1 and 2.8% increase in loads above baseline for Scenarios 2, 3 and 4 respectively.

Catchment loads and improved urban water management

The loads in the waterways upstream of the discharge locations represent only a small proportion of the pollutants generated from land uses across the catchment which are then reduced through various interception and instream processes. The loads discharged from the Picton WRP are relatively small compared to the catchment loads, highlighting the opportunity for improved waterway outcomes with better stormwater management (in addition to improved treatment and reuse of recycled water from the Picton WRP). This Source model does not simulate the nutrient processing within the catchment, but focusses on calibration to the points of interest for this project.

5.6 Constituent concentrations

Constituent concentrations are simulated also in the model at all points, and can be evaluated in a similar manner to loads. Given the variability in concentrations in catchment runoff, representation of concentrations is better simulated through box and whisker plots. These show the mean, median, 75th and 25th percentiles as the box itself and central line, with the whiskers indicating the range of the next quartiles excluding outliers. Outliers are represented by dots beyond the top whisker as indicated in the figure below.

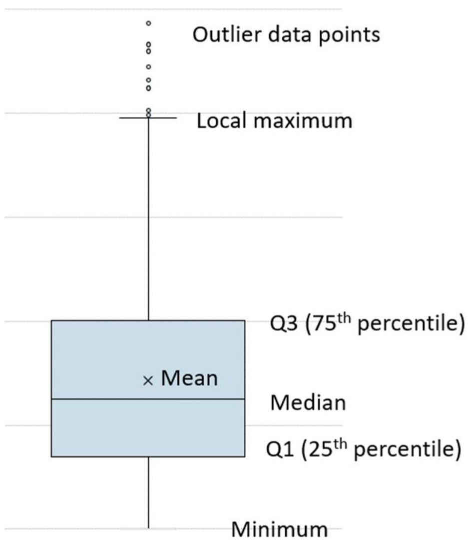


Figure 5-10 *Box and whisker plot interpretation*

Stonequarry Creek concentrations

The baseline scenario (1) has been modelled to reflect the existing conditions. Scenario 2 reflects increased discharge to Stonequarry Creek for a configuration with future inflow to the WRP of 4 ML/d.

The upstream water quality site (N911 B) is simulated in the model and provides a benchmark for comparison with the water quality simulation downstream of the discharge point (N911).

The box and whisker plot below shows the results for both the upstream and the two relevant discharge scenarios for both TN and TP.

For Stonequarry Creek the difference between the upstream and downstream concentrations of each day of the model simulation is also calculated and then ranked from highest to lowest. The comparison of scenarios for this ranked increase in concentrations as a result of discharge from the WRP can provide further understanding of the proportion of time and the magnitude of the change in waterway concentrations expected downstream of the WRP.

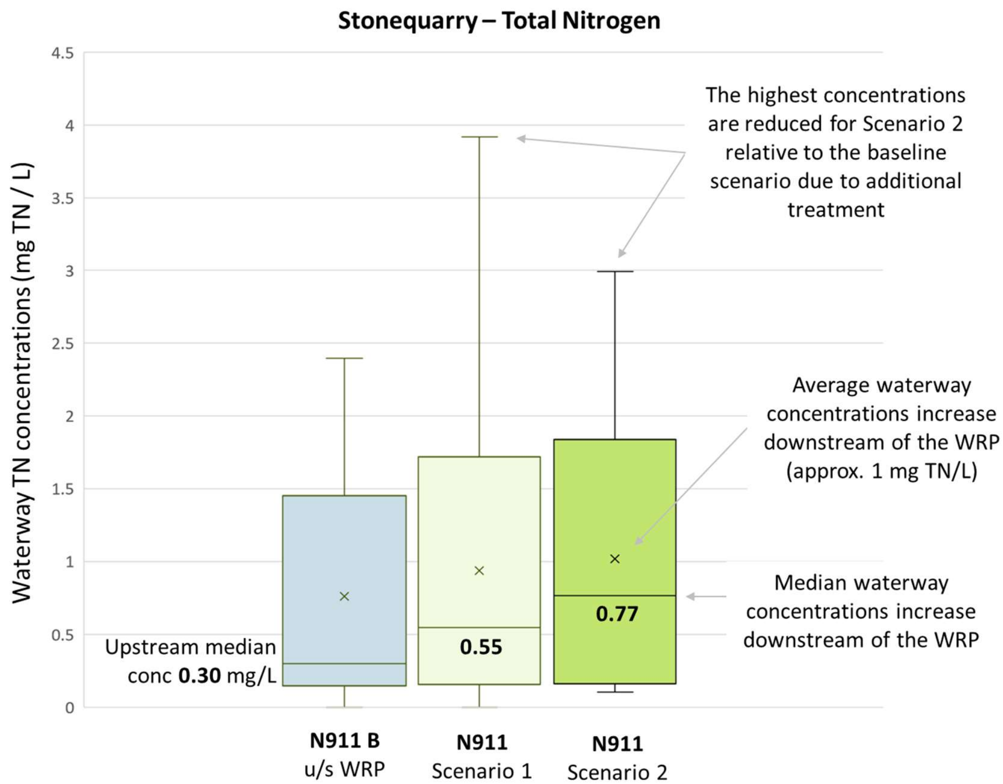


Figure 5-11 *TN concentrations in Stonequarry Creek – Scenarios 1 and 2 relative to upstream concentrations*

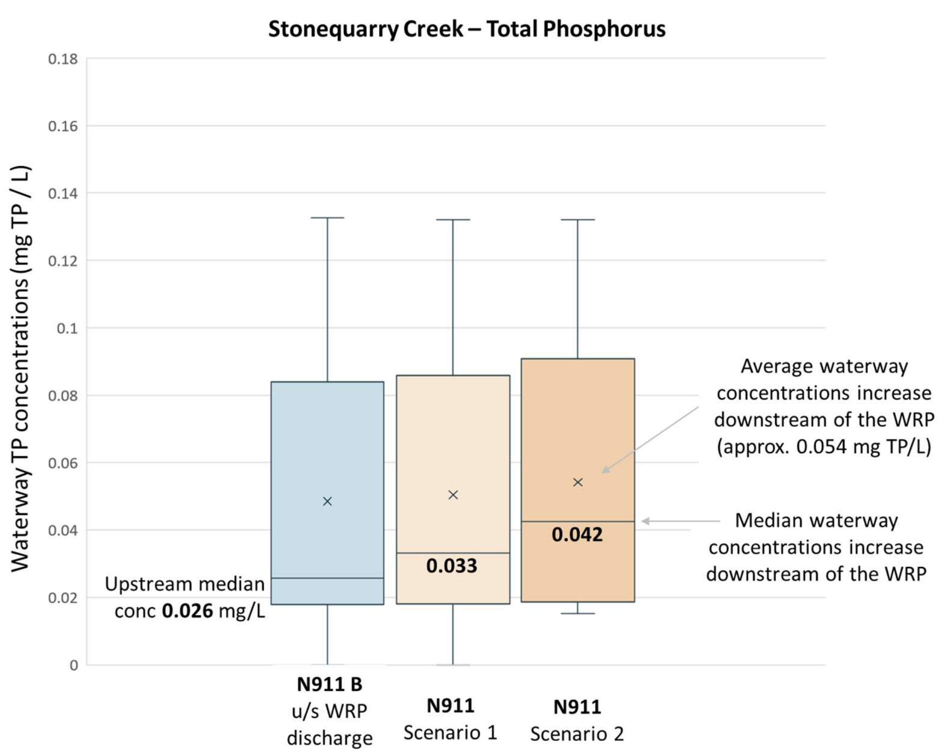


Figure 5-12 *TP concentrations in Stonequarry Creek – Scenarios 1 and 2 relative to upstream concentrations*

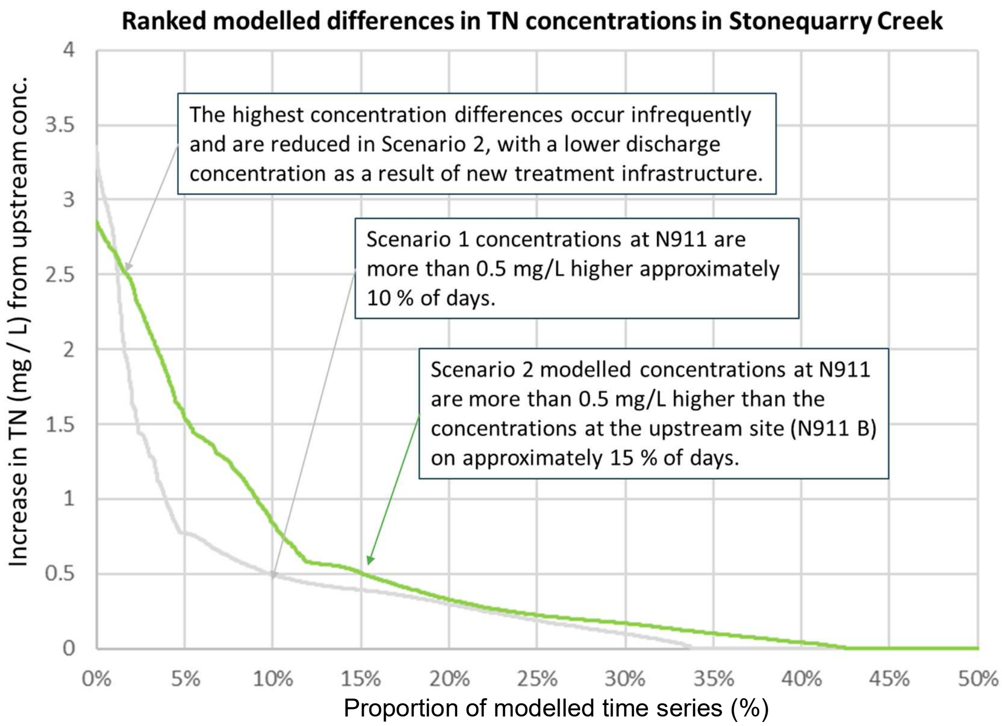


Figure 5-13 *Ranked increase in modelled daily TN concentrations in Stonequarry Creek – Scenario 1 and 2*

Figure 5-11 and Figure 5-12 indicate that the baseline and future scenario where discharge occurs to Stonequarry Creek show an increase in median concentrations though the interquartile range remains relatively similar. Currently, the model indicates an increase in median TN concentration from 0.3 mg/L to 0.55 mg/L between upstream and downstream for the baseline scenario, however this increases to 0.77 mg/L in Scenario 2. This is slightly counterintuitive as the discharge loads actually decrease slightly, but because discharge increases in frequency and volume, an increase in waterway concentrations results. While the total load change is minimal, and lower TN concentrations are simulated in the discharge, the waterway will see an increase in concentration. From the underlying data, the results show that under future WRP inflows, the discharges to Stonequarry are more frequent (from 123 to 155 days per year) such that the influence on concentrations is larger, as the concentration decreases in Stonequarry Creek are only small in comparison to the change in discharge frequency.

Conclusions from modelling TN concentrations – scenarios 1 and 2

- The modelled site on Stonequarry Creek upstream of the WRP (N911B) has a median concentration of 0.3 mg TN/L, meeting both the ANZG (0.35 mg/L) and reference site objectives (Nepean River – 0.31 mg/L). This aligns with monitored data showing a noticeable improvement in water quality in the 3 km between the Picton township and the site upstream of the WRP.

- Scenario 1 shows higher concentrations downstream of the discharge point (median 0.55 mg/L and average 0.95 mg TN/L). Concentrations increase by more than 0.5 mg/L about 10% of the time.

- Scenario 2 shows further increase in concentrations as discharge volumes increase, and discharge occurs more frequently (median 0.77 mg/L and average 1.02 mg TN/L). Concentrations increase by more than 0.5 mg/L about 15% of the time.

For total phosphorus, the results are consistent with the changes in loads and flows, with concentrations increasing from 0.026 to 0.033 mg/L comparing upstream to downstream for the baseline scenario, increasing to 0.042 mg/L in the future scenario. Again, the interquartile range doesn't change significantly between the upstream and both downstream scenarios.

Conclusions from modelling TP concentrations – scenarios 1 and 2

- The model uses conservative assumptions for TP concentrations (0.1 mg/L) which we expect to occur only infrequently (median concentration between 2014-2020 was 0.03 mg/L TP), however there are times when these very low TP concentrations from the WRP cannot be guaranteed.

- The model simulation aims to highlight the potential impact on waterway concentrations when TP performance is not ideal. The modelled increases in median and average concentrations with these conservative assumptions provides confidence that the measured water quality changes will be less than those simulated, and are not expected to impact waterway health.

- Our monitoring programs will continue to assess changes with comparison of upstream and downstream, focusing on indicators of impact linked to nutrients (like weed growth, impacts on macroinvertebrate communities and algae).

Similar graphs representing the changes for bioavailable forms of TN and TP have been developed. These show similar trends, with the modelling assumptions for discharge concentrations based on simple proportional relationships between Oxidised Nitrogen (NOx) and TN, and between Filterable Reactive Phosphorus (FRP) and TP. The proposed denitrification filters are expected to reduce NOx considerably. The model relationships can be refined with additional data once available. The preliminary NOx graphs are included in Appendix D.

Nepean River concentrations

Within the Nepean River, concentrations are influenced by the magnitude of flows from upstream in comparison to those from the WRP. As indicated in the loads and flows discussions above, these are not as significant proportionally to the discharges entering Stonequarry simply because the upstream catchment is considerably larger in the Nepean River. In terms of analysing the data in the Nepean, the model uses a fixed boundary condition of observed flows and concentrations in the Nepean River at Maldon River, rather than simulating the entire catchment. Prior to 2012, the datasets available did not have measured TN and TP concentrations, so prior to that time, constant monthly concentrations were derived in order to determine the contributions to loads, but this obviously has a significant impact on calculating medians and interquartile ranges, as shown by the timeseries of TN concentrations below. There were also periods of no flow records so these would also influence the calculation of concentration statistics.

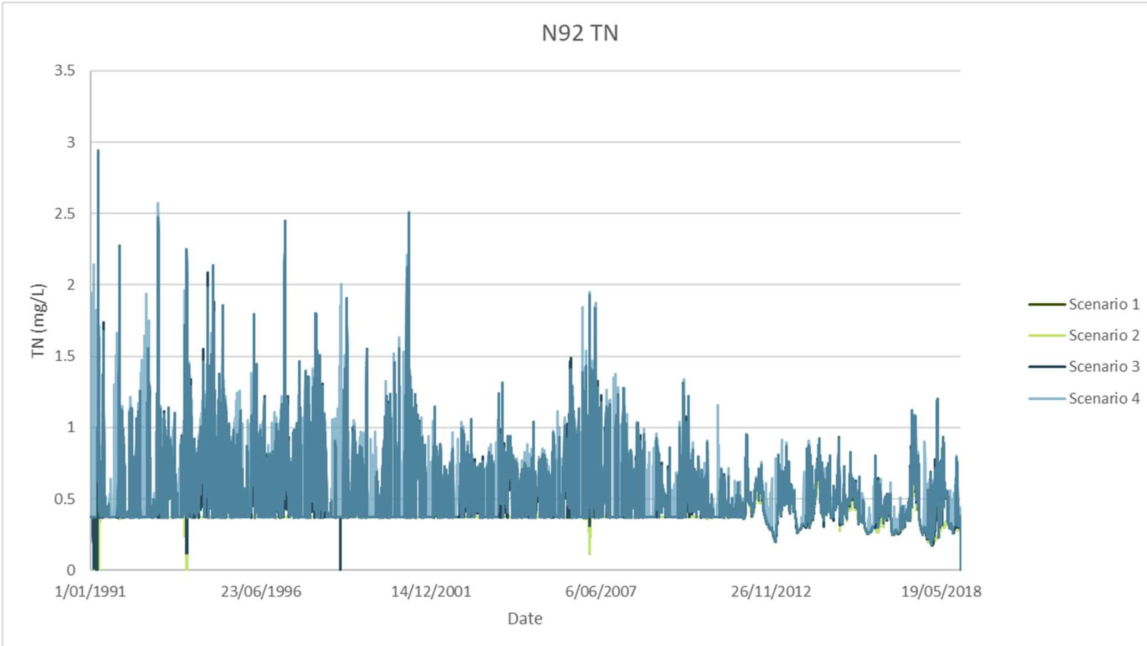


Figure 5-14 *Modelled time series TN conc – N92 Nepean R u/s of Stonequarry confluence*

We have therefore constrained the box and whisker plots to the period 1/1/2012 – 31/12/2018 to show how the WRP interacts with the observed (rather than calculated) TN and TP concentrations in the Nepean River. These are presented in the charts below.

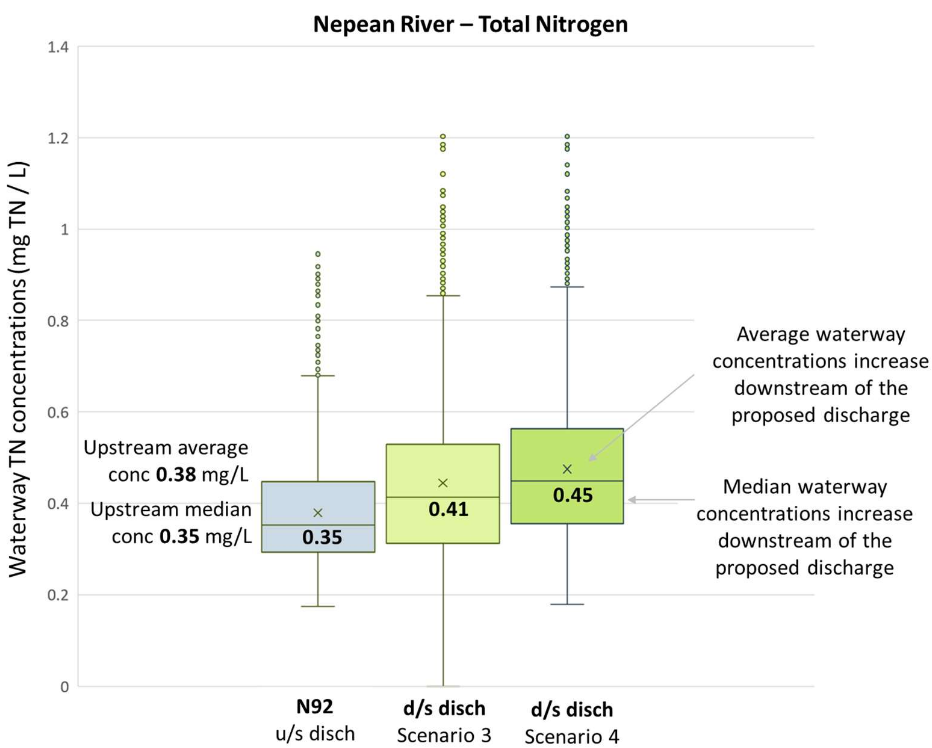


Figure 5-15 *TN concentrations in the Nepean River - Scenarios 3 and 4 relative to upstream concentrations*

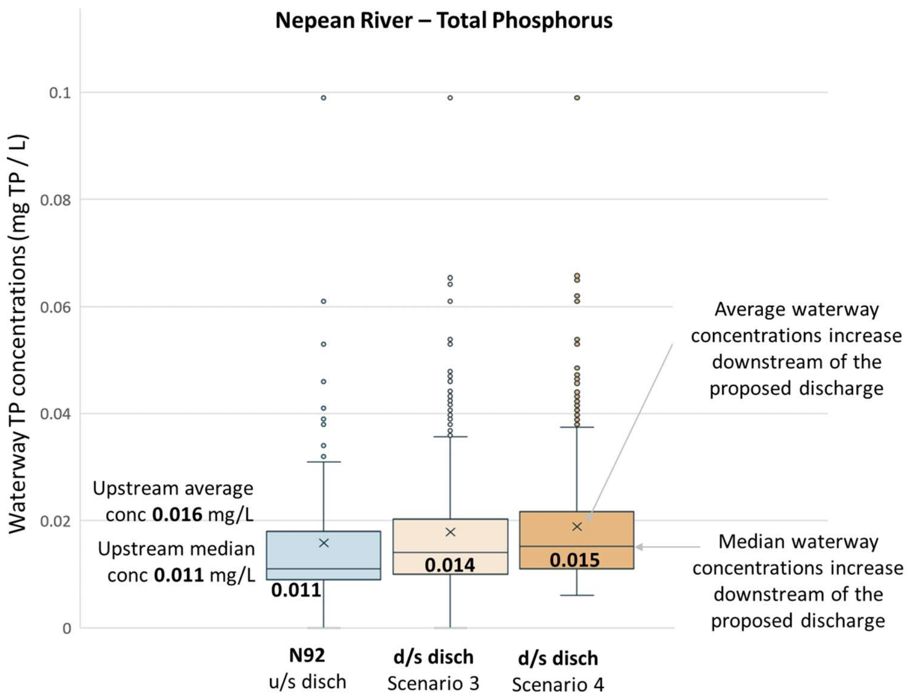


Figure 5-16 *TP concentrations in the Nepean River - Scenarios 3 and 4 relative to upstream concentrations*

These two box and whisker plots show the impacts of the WRP discharge for Scenarios 3 and 4 when discharge is simulated to flow to the Nepean River. The median TN concentration is predicted to increase from 0.35 to 0.41mg/L for Scenario 3 and to 0.45 mg/L in Scenario 4. The interquartile ranges are also predicted to increase slightly for both of these scenarios in comparison to the upstream range.

The results for location N91 in the Nepean provides insight into how each of the scenarios change in comparison to the existing baseline condition and are shown below.

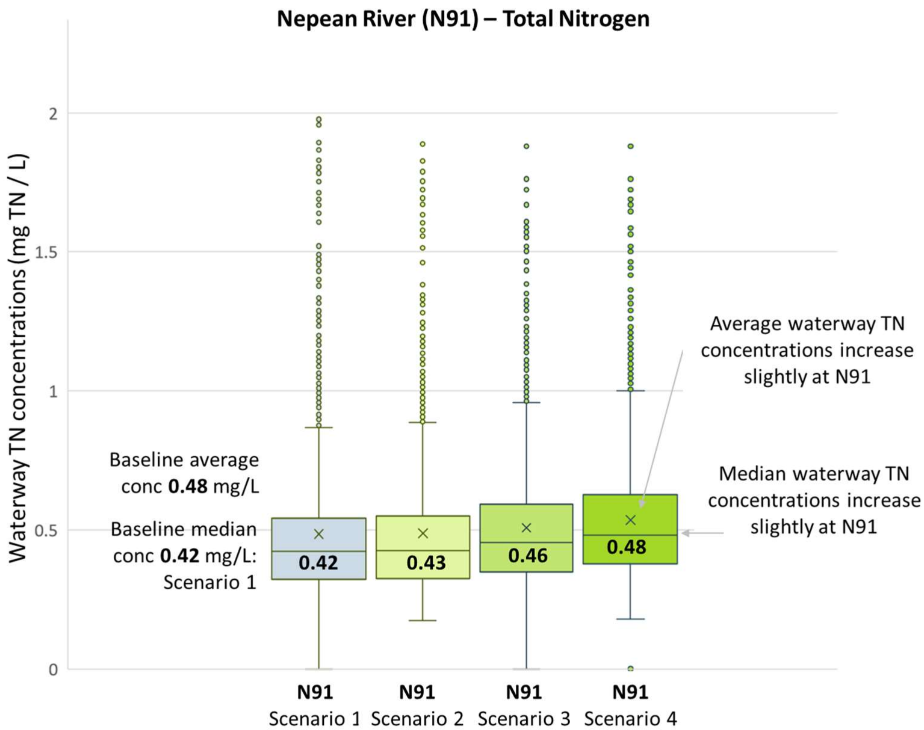


Figure 5-17 *TN concentrations in the Nepean River – N91 downstream of SQ*

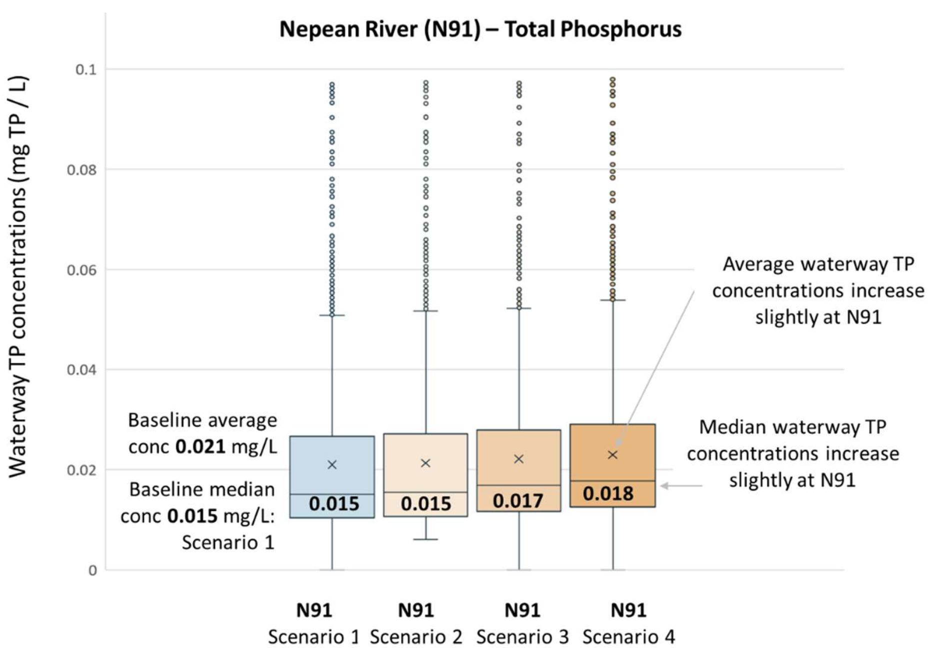


Figure 5-18 *TP concentrations in the Nepean River – N91 downstream of SQ*

The N91 results show that the future Stonequarry discharge scenario (2) demonstrates very minimal change in Nepean River water quality, with the median TN concentration increasing slightly from 0.42 to 0.43 mg/L and the TP increasing from 0.15 to 0.16 mg/L. The interquartile ranges also only very slightly change. For the future scenarios discharging to the Nepean River, the concentrations increase to 0.46 and 0.48 mg/L for TN in Scenarios 3 and 4 respectively, with TP increasing to 0.17 and 0.18 mg/L.

5.7 Discussion

Overall, these results indicate that discharge from the WRP does now and will in the future result in changes in concentrations in Stonequarry Creek in comparison to the upstream conditions. This is expected given the upstream catchment area largely results in episodic runoff, though some baseflow is relatively persistent with minimal cease to flow periods. The baseline scenario (1) provides an adequate correlation with the existing condition to allow the model to be used for predictions of future outcomes under alternative future scenarios (2, 3 and 4).

Future increases in WRP inflows are expected due to population growth in the service catchment, however TN loads to Stonequarry Creek can be mitigated to at least the current baseline loads (or slightly below), with increased irrigation reuse and the denitrification treatment proposed. Concentrations will increase regardless though, even with further reuse and the discharge concentrations reduced to TN 3 mg/L. Conservative simulation of TP concentrations indicates that TP loads and concentrations are predicted to increase more than the current baseline, as the volumes discharged increase.

In the Nepean River, both future scenarios (3 and 4) where discharge is directed to the Nepean will result in increases in flows, loads and concentrations, but proportionally these are smaller in magnitude compared to the of change in waterway concentrations predicted in Stonequarry Creek, due to the higher river flows.

The future Stonequarry discharge scenario (2) with increased irrigation area shows changes in the 1.3 km reach of Stonequarry Creek, from the WRP to the confluence with the Nepean River, but shows the least changes to flows, loads and concentrations in the Nepean River given the smaller volumes discharged.

This highlights the dilemma in managing future WRP discharges. While discharges to Stonequarry Creek will see changes in flows, loads and concentrations in the Creek, it will have minimal impact on the Nepean River. Conversely, scenarios where discharges are directed to the Nepean will remove impacts to Stonequarry Creek, but are predicted to change flows, loads and concentrations in the River. Neither provides a clear indication of which is “better”, only that there are differences in where the impacts are likely to be located.

6 References

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel and T. L. Veith (2007). "Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations." Transactions of the ASABE 50(3): 885–900

7 Appendix A – Available Data

This section provides further detail about the data that is available for the development of the Source model. The initial model was created in 2019.

7.1 Topography data

Digital Elevation Model (DEM) data (from 2011) was sourced from Spatial Services NSW (along with 2012 aerial imagery) and was available at a one metre by one metre grid resolution across the entire Stonequarry catchment (Figure 7-1). The DEM is used for subcatchment delineation, with 48 subcatchments delineated in the Stonequarry Creek model, where 5 larger catchments were previously used for Sydney Water's previous Hawkesbury Nepean River and South Creek Water Quality Modelling Project (blue polygons in image below). This delineation will also provide the basis for building the node and link network for the model (see also section 3.3 – Model build).

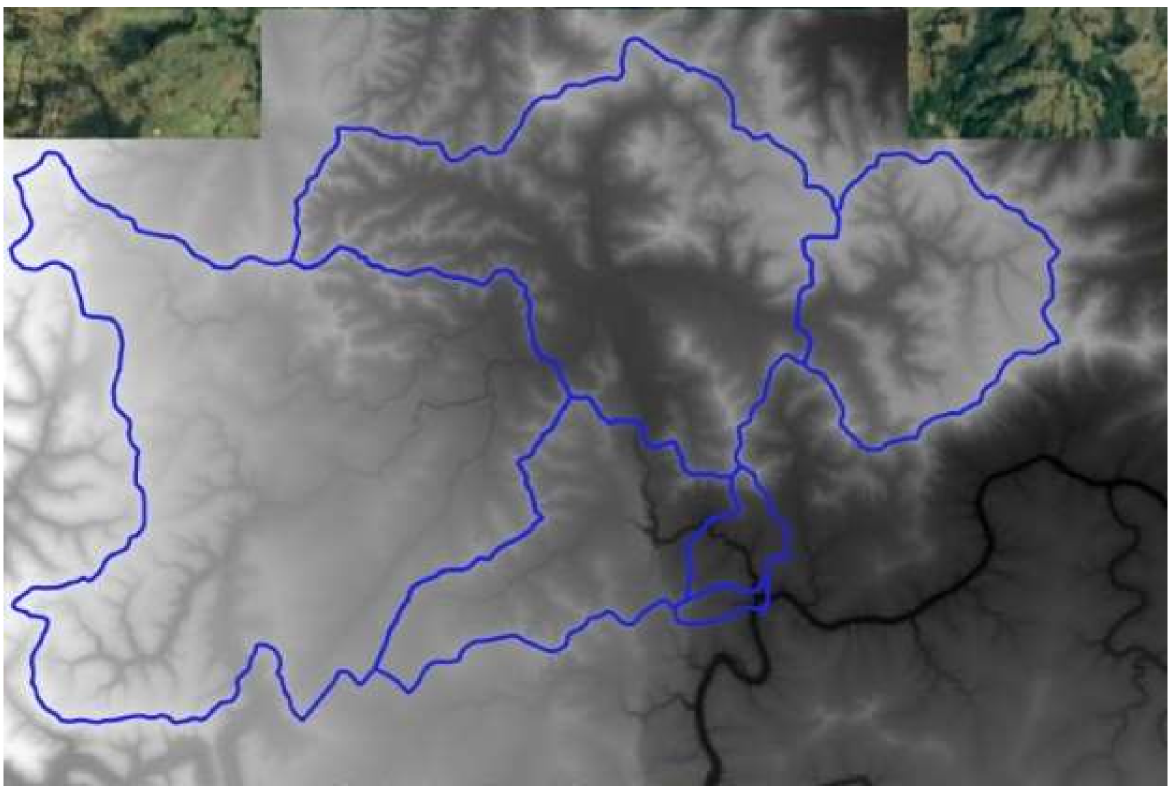


Figure 7-1 Digital Elevation Model data extent – Stonequarry Creek, previous catchment delineation

7.2 Climate data

Rainfall and evaporation data are required to create the modelled runoff from Stonequarry Creek. To facilitate this rainfall, solar exposure and temperature data were sourced from relevant agencies.

Rainfall

Hourly rainfall data was obtained at six Sydney Water gauges in the catchment and was supplemented by two daily gauges from the Bureau of Meteorology. Data availability is summarised in Table 7-1 with the spatial distribution outlined in Figure 7-2.

Table 7-1 Rainfall data availability

Gauge	Name	Time step	Start Date	End Date	Missing Data
568166	Picton (Cedar Creek)	Hourly	30/06/1990	3/09/2002	3.5%
568295	Lakesland Road	Hourly	30/03/1983	30/10/2002	8.6%
563053	Wombat Pinch	Hourly	10/06/1981	9/10/2002	1.5%
568352	Thirlmere (Rail Museum)	Hourly	15/08/2000	3/12/2018	0.4%
568053	Picton WRP	Hourly	9/04/1998	1/01/2019	16.1%
568350	Picton Bowling Club	Hourly	7/11/2003	3/12/2018	8.0%

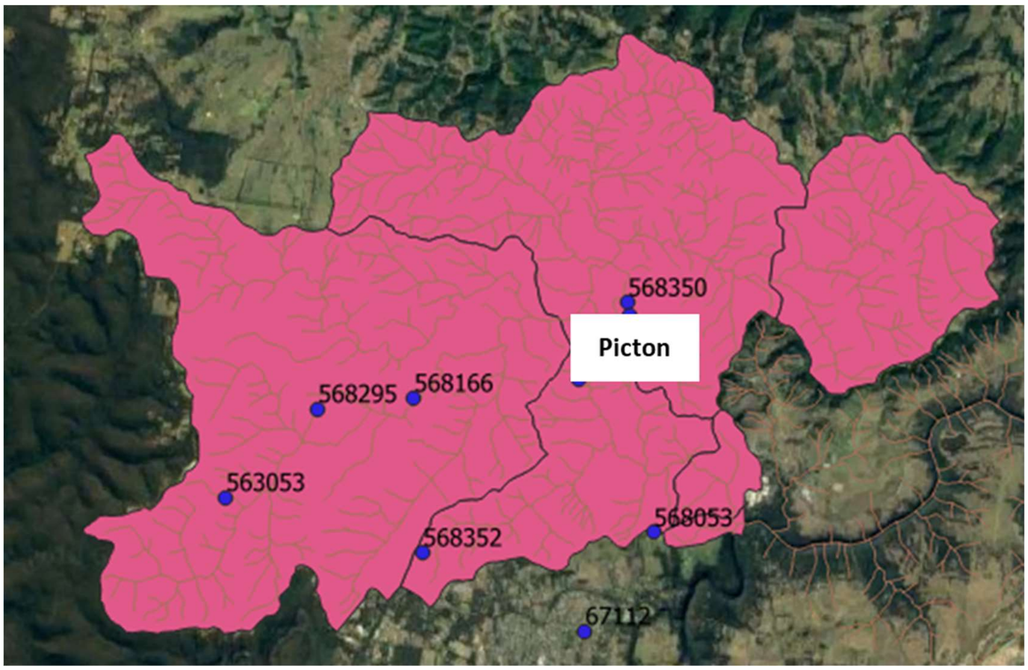


Figure 7-2 *Rainfall gauge locations*

Evaporation

Solar exposure data was available at 14 stations in the region at a daily time step. Solar exposure is used as an equivalent to evaporation through a standard mathematical conversion (using the Penman Monteith method). Data availability is summarised in Table 7-2 with the spatial distribution outlined in Figure 7-3. To disaggregate the evaporation (once converted) to an hourly time step, an hourly temperature record, sourced from Sydney Water's South Creek Water Quality Modelling Project was obtained to use as the pattern.

Table 7-2 Evaporation data availability

Gauge	Location	Time Step	Start Date	End Date	Missing data
068166	Buxton	Daily	1/01/1990	6/01/2019	4.50%
068007	Camden Brownlow Hill	Daily	1/01/1990	6/01/2019	4.51%
068214	Camden Bridge	Daily	1/01/1990	6/01/2019	4.49%
068235	Camden IPS	Daily	1/01/1990	6/01/2019	9.26%
068257	Campbelltown	Daily	1/01/1990	6/01/2019	4.50%
068122	Cawdor	Daily	1/01/1990	6/01/2019	4.50%

068211	Cordeaux Dam	Daily	1/01/1990	6/01/2019	4.50%
068200	Douglas Park	Daily	1/01/1990	6/01/2019	4.52%
068216	Menangle Bridge	Daily	1/01/1990	6/01/2019	4.51%
068254	Mount Annan	Daily	1/01/1990	6/01/2019	4.50%
068212	Nepean Dam	Daily	1/01/1990	6/01/2019	4.50%
068125	Oakdale	Daily	1/01/1990	6/01/2019	4.54%
068052	Picton Council Depot	Daily	1/01/1990	6/01/2019	4.50%
068159	Wedderburn	Daily	1/01/1990	6/01/2019	4.52%

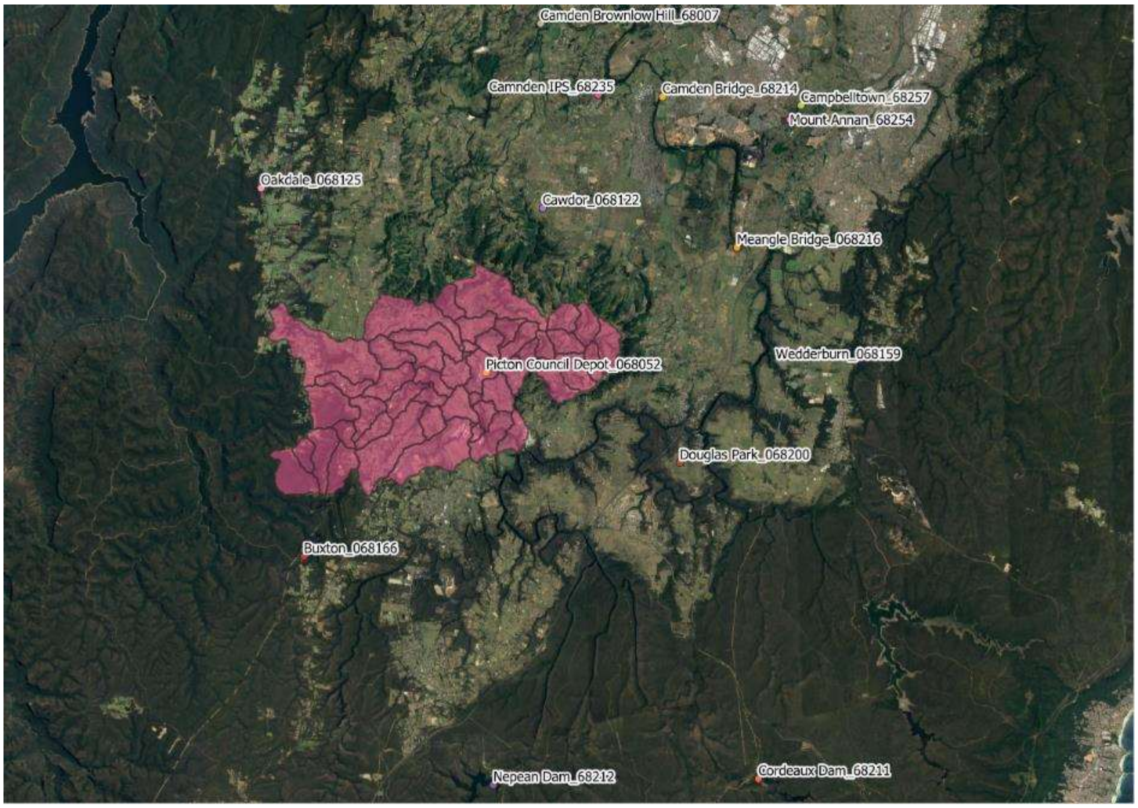


Figure 7-3 *Evaporation gauge locations*

7.3 Streamflow data

Streamflow data was used to calibrate and validate the rainfall runoff modelling of the Stonequarry Creek catchment and as an input for the Nepean River simulation. Data is available for 3 streamflow gauges:

- 212053 Stonequarry at Picton township (Webster Street near rail viaduct), (approximately 3 km upstream of the WRP discharge point), with data from Water NSW available for the period from December 1990 to January 2019 at a sub-daily timescale (generally 10 to 15 minute intervals).
- 2122006 Stonequarry Creek at Picton WRP, approximately 60 m downstream of the Picton WRP discharge point) from June 1997 to December 2018 at 15 minute intervals.
- 212208 Nepean River, measuring flow over Maldon Weir, upstream of the confluence with Stonequarry Creek.

The locations of relevant streamflow gauges are shown in Figure 7-4.

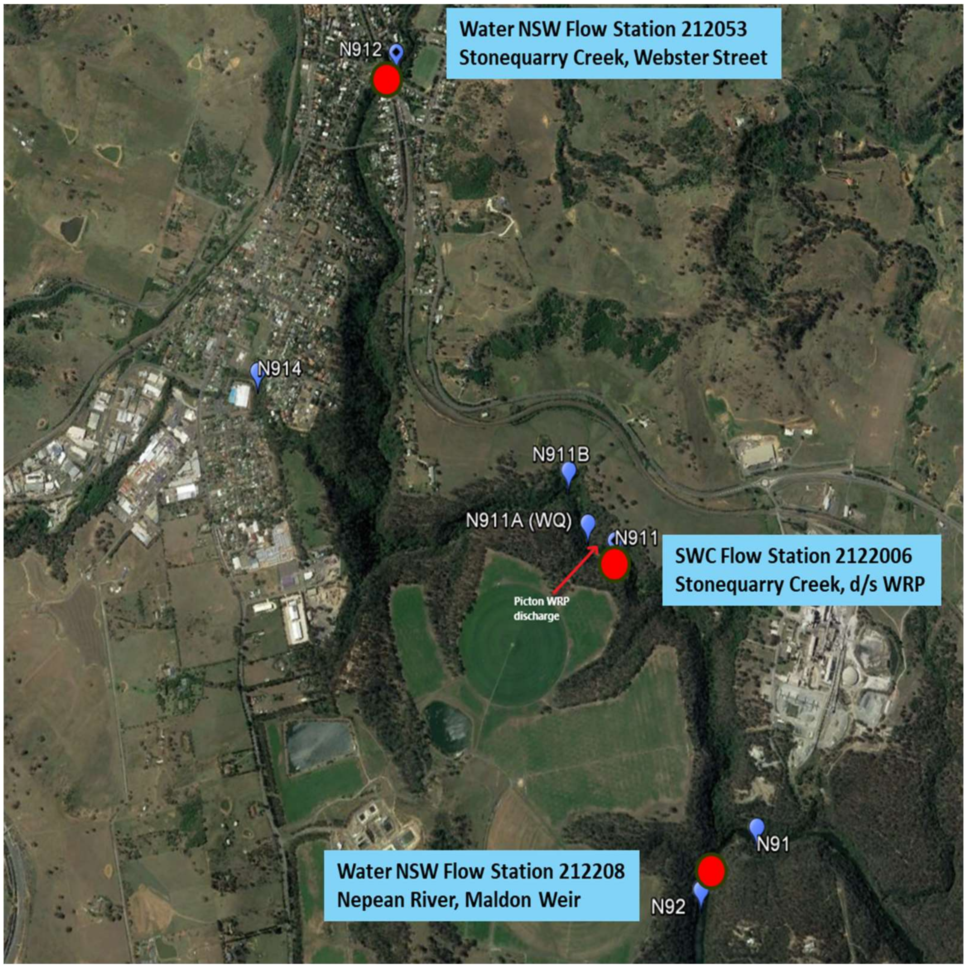


Figure 7-4 *Streamflow gauge locations*

There are challenges for the accuracy of data at each of these streamflow gauges as they are all in natural streams with 'control structures' that are not ideal and involve accuracy trade-offs between different flow ranges.

212053 Stonequarry Creek at the Picton township (WaterNSW, Webster St, Picton)

- Figure 7-5 show a view of the gauge control within the natural creek form and the associated pool with gauge equipment. The gauge's low flow control structure is a wide, flat rock bar, and is poorly suited to measuring flow with precision during low to medium flow conditions.
- The water depth is measured in a rock pool, with the bed and banks of the waterway vulnerable to change with erosion and deposition and any impacts on vegetation
- A small change in the measured water level at low flows (5cm) results in recorded flows from less than 0.5 ML/d to more than 2 ML/d.
- The focus for WaterNSW is on gauge accuracy during higher flows, with effort to understand the flows at depths of 2 – 9m and on securing ratings when flow depth is greater than 1m in coming years.

Figure 7-5 Stonequarry Creek gauge 212053 (Picton Township) View of gauge control

2122006 Stonequarry Creek at Picton WRP (Sydney Water)

- To improve the gauge control, a new weir structure was constructed at the end of 2017. The concrete weir is formed between two rocks, with water depth measured in the pool behind the weir structure.
- The gauge is vulnerable to sedimentation, fallen trees and other debris that can result in changed flow conditions. Photographic records are now regularly taken to confirm when significant changes occur and trigger the need for a response. Regular gauge ratings are also done by Sydney Water's Hydrometrics team (approx. 4 each year at this site). This allows the correlation between water depth and flow to be verified and changes to the 'rating table' made if required
- The major flooding event in mid-2016 destroyed the previous gauge structure and substantially altered the shape of the creek channel at the gauge location. Further large events in early 2017 presented challenges for re-establishing a rating curve at this site.
- The calibration of this gauge has been targeted on achieving accuracy in measuring the lower flow ranges (aligning with creek flow requirements for WRP discharge in EPL10555).
- This gauge is the key location for the Source modelling calibration.

Figure 7-6 Stonequarry Creek gauge at Picton WRP 2122006 – View of gauge control, pool and gauge equipment

212208 Nepean River, at Maldon Weir (Water NSW)

- o The gauge control is a large ogee weir with a significant elevation drop – this structure is very well suited to measuring large to very large flows accurately, though not well suited to measuring lower flows, particularly during dry conditions, where the indicated flow rate is overly sensitive to the measured water level above the weir
- o Water level is measured approximately 30m upstream of the weir
- o Physical access to maintain and carry out gaugings has been noted as very difficult by the current gauge operator
- o The gauging section (where confirmatory flow gauging work is carried out) is a riffle zone below the Maldon Weir.

Figure 7-7 Nepean River flow gauge212208 – View of gauge control structure and downstream boulder field

Further discussion of the flow gauging data is provided in Appendix B (section 8).

7.4 Land use data

Land use data is available for 2017 conditions, 2030 conditions and 2056 conditions. The 2017 coverage (Figure 7-8) will be used to represent current land use. Only minor changes in land use are expected in the short-medium term horizon so land use is not altered for the future 4 ML/d scenarios (expected 3 – 10 year horizon).

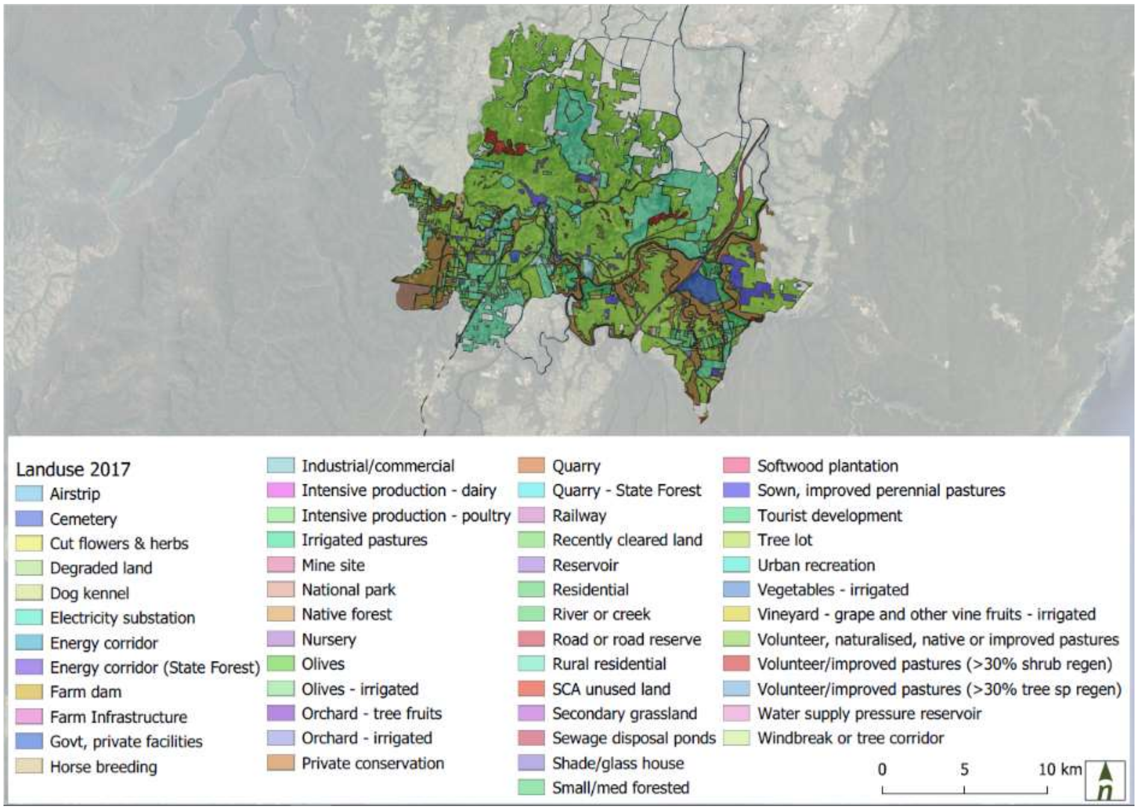


Figure 7-8 Land use map (2017)

7.5 Water Recycling Plant

Inflow trends to the Picton WRP are used to determine the parameters linked to wet weather inflows (% runoff contribution and contributing sewer catchment area), through comparison with trends across multiple years.

Flows are monitored at multiple locations with the key locations:

- inflow to the treatment plant,
- flow through the filters from the Equilisation Basin,
- discharge to Stonequarry Creek from the Western Dam
- reuse from the Eastern Dam (to a 92 ha irrigation area)
- reuse from the Western Dam (to a 27 ha irrigation area).

Flow gauges measuring inflows to the plant were known to be unreliable prior to 2019 when a new magflow meter was installed. The best data available for the model development and calibration is the pumped flows through the treatment filters.

7.6 Sewer network overflow locations

When the wastewater network was constructed, Emergency Relief Structures or sewer overflows were designed, particularly at pumping stations (see Figure 7-9). These designed overflows ensure that when wet weather flows enter the network and exceed the capacity of the system, discharge occurs at controlled locations rather than within dwellings or from the lids of access chambers.

Modelled simulations of the sewer network provide predicted discharge frequency at these locations and these infrequent discharges are included in the model.

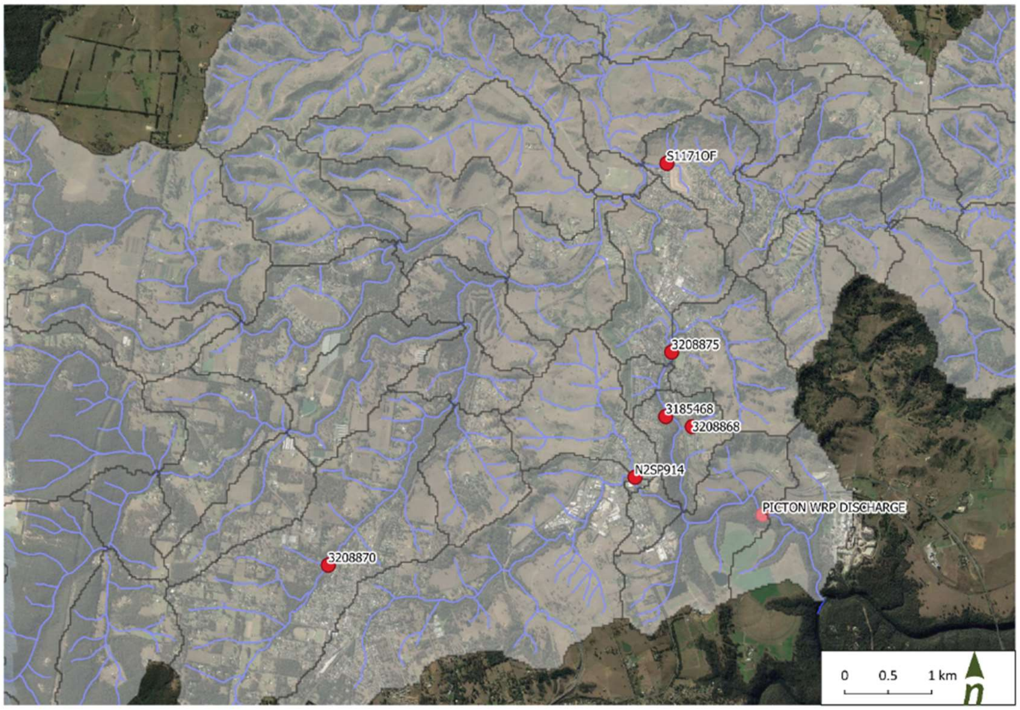


Figure 7-9 Water Recycling Plant (WRP) and sewer overflow discharge locations (at pumping stations)

7.7 Other point source discharge data

Discharges from industry (like Wollondilly abattoir just south of the Stonequarry Catchment) are not represented in the model.

Bargo and Buxton are serviced with a pressure sewer network and a transfer pipeline connects to the sewer network – and contributes to the inflows to the Picton WRP. This transfer is not represented in the model.

7.8 Water quality data

Observed water quality data is available at the locations outlined below and shown spatially in Figure 7-10:

- N912: Stonequarry Creek at Picton
- N914: Redbank Creek upstream of Stonequarry Creek
- N911B (N911B): Stonequarry Creek upstream of Picton WRP discharge
- N911: Stonequarry Creek downstream of Picton WRP discharge
- N92: Nepean River at Wilton Park (Maldon Weir)
- N91: Nepean River downstream of Stonequarry Creek
- Inflow to Picton WRP
- Discharge from Western Dam to Stonequarry Creek
- Extraction from Eastern Dam for Irrigation

Measurements are available from 2006 onwards at the Picton WRP and from 2012 onwards on the waterways.

Figure 7-10 Water quality monitoring locations

8 Appendix B – Flow monitoring data analysis (Aurecon)

Stonequarry Creek Flow Monitoring Data

Background

The allowable precautionary discharge from Sydney Water's Picton Water Recycling Plant (WRP) to Stonequarry Creek is governed by the observed flow rates within the creek. There are two key flow gauging stations on Stonequarry Creek.

- 2122006 is owned and operated by Sydney Water and located approximately 30-40m downstream of the discharge location from the Picton WRP
- 212053 is owned and operated by WaterNSW and is located approximately 3.2 km upstream of the Picton WRP, in the Picton township, near Webster Street and the Railway Viaduct.

The EPA have previously questioned discrepancies between the flows measured at the two stations. The gauge accuracy is important as determines the allowable discharge under the current Environmental Protection Licence (EPL) conditions.

Sydney Water are also currently in the process of evaluating reuse and discharge options given the need to expand the capacity of the plant. A new discharge regime to Stonequarry Creek will seek to minimise concentration impacts in low flow conditions, but also seek greater flexibility than under the current precautionary protocol. The assessment of potential impacts of discharge on Stonequarry Creek is dependent on the expected flow regimes within the creek. Sydney Water will likely seek a variation to their current EPL in late 2020.

The objective of this interim document is to evaluate this discrepancy, as well as its applicability to the flow ranges governing the current allowable discharges as well as potential future discharges.

Gauge locations

The metadata associated with the two gauges being evaluated is provided in **Table 8-1** and their mapped locations are shown in **Figure 8-1**. Contributing catchments and land use zoning (NSW DPIE, 2020) are indicated in **Figure 8-2,** with the zone classification shown in

Table 8-2.

Table 8-1 Location of streamflow gauges

ID	Details
212053	Owner/operator: WaterNSW Date commenced: November 1990 Location: Stonequarry at Picton township (Webster Street) - Downstream of the weir at the Picton Baths Catchment area: 83 km^2 Primary land uses: Rural and primary production (farming) Distance upstream of the WRP discharge location: 3.2 km

ID	Details
2122006	Owner/operator: Sydney Water Date commenced: June 1997 Location: Stonequarry Creek at Picton WRP Catchment area: 96 km^2 Primary land uses: Rural and primary production (farming) Distance downstream of the WRP discharge location: 30-40 m

Figure 8-1 Plan view of the stream monitoring locations

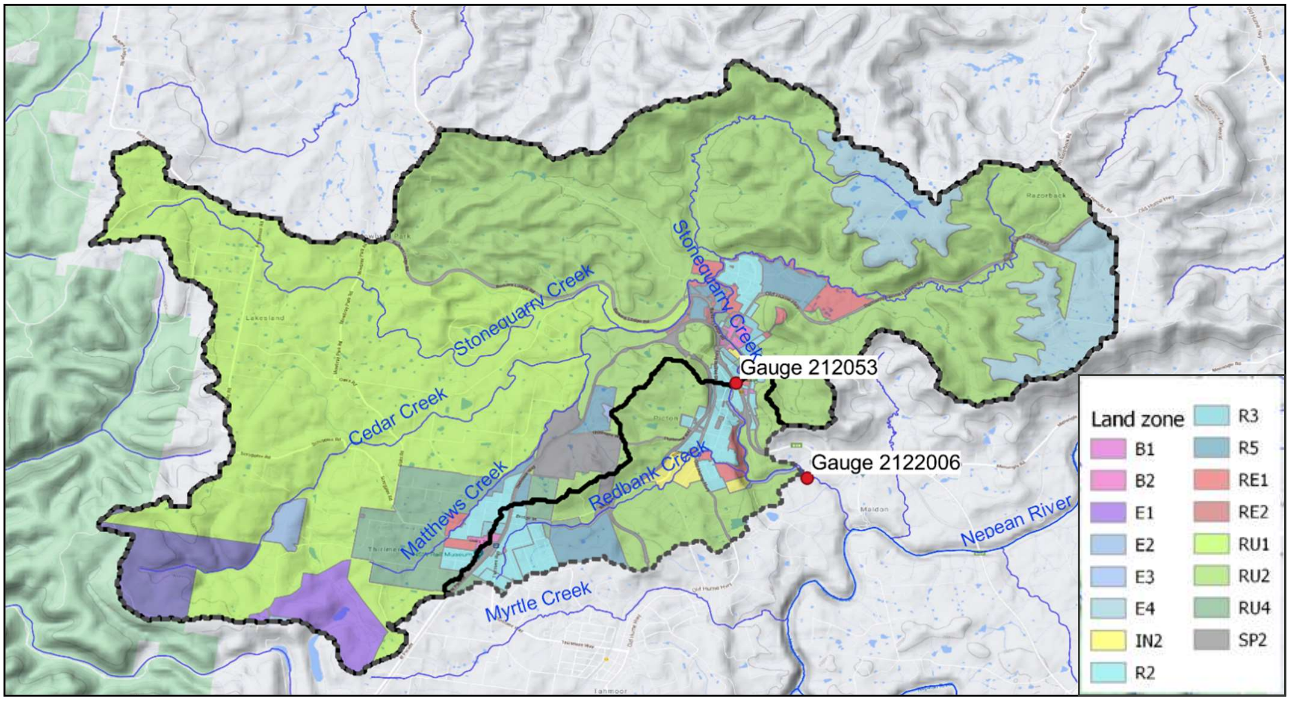


Figure 8-2 Catchment delineation and land use zoning

Table 8-2 Land zone classification

B1	Neighbourhood Centre	**B2**	Local Centre	**E1**	National parks and Nature Reserves
E2	Environmental Conservation	**E3**	Environmental Management	**E4**	Environmental Living
IN2	Light Industrial	**R2**	Low Density Residential	**R3**	Medium Density Residential
R5	Large Lot residential	**RE1**	Public Recreation	**RE2**	Private Recreation
RU1	Primary Production	**RU2**	Rural Landscape	**RU4**	Primary Production Small Lots
SP2	Infrastructure				

Sydney Water's Hydrometric team are continually working to improve the performance of the flow gauging at the Stonequarry Creek site – despite the challenges with a natural stream gauge. The images below show the configuration of the gauge's current flow control structure and water level sensor in the pool behind the small weir.

Figure 8 3 shows the flow over a concrete weir structure between rocks in Stonequarry Creek. Figure 8 4 shows the pool of water behind the weir structure where the water level monitoring allows correlation with flow over the weir.

Figure 8-3 - Flow over a concrete weir

Figure 8-4 - Pool of water behind the weir and gauge equipment

Record comparison

The recorded flow rates, as published by WaterNSW and provided by Sydney Water, were compared for the period between January 2014 and July 2019.

Figure 8-5 shows the two datasets plotted together on a logarithmic scale, thus highlighting divergences in the recorded low flow regions. For the period between January 2016 and January 2020 the WaterNSW gauge indicates significantly lower flows than the Sydney Water gauge, particularly for flowrates less than 1 ML/d.

The SWC datasets contains periods of verified "Good quality data" as well as estimated data values. Both these datasets are indicated. All WaterNSW data for this gauge over this time period is currently indicated as "130 - Not quality coded - subject to change".

The dataset generated when subtracting the corresponding WRP discharges rates from the SWC gauge (which is located downstream of the discharge) is shown along with the WaterNSW gauge data in **Figure 8-6**. This results in a slightly better correlation for the discharge periods, most evident in the post Jan 2020 records.

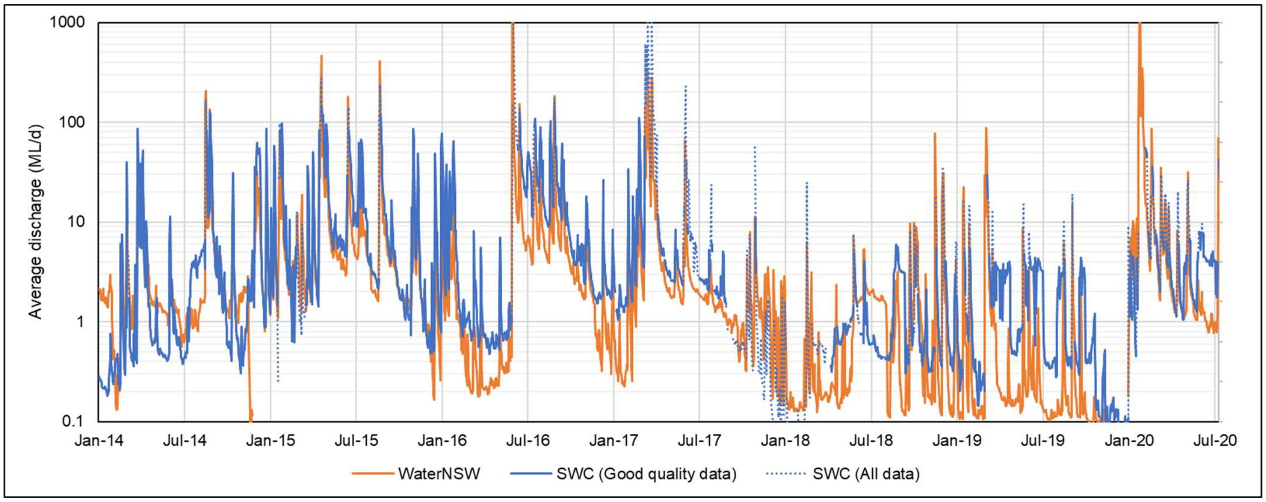


Figure 8-5 **Recorded average daily flowrates**

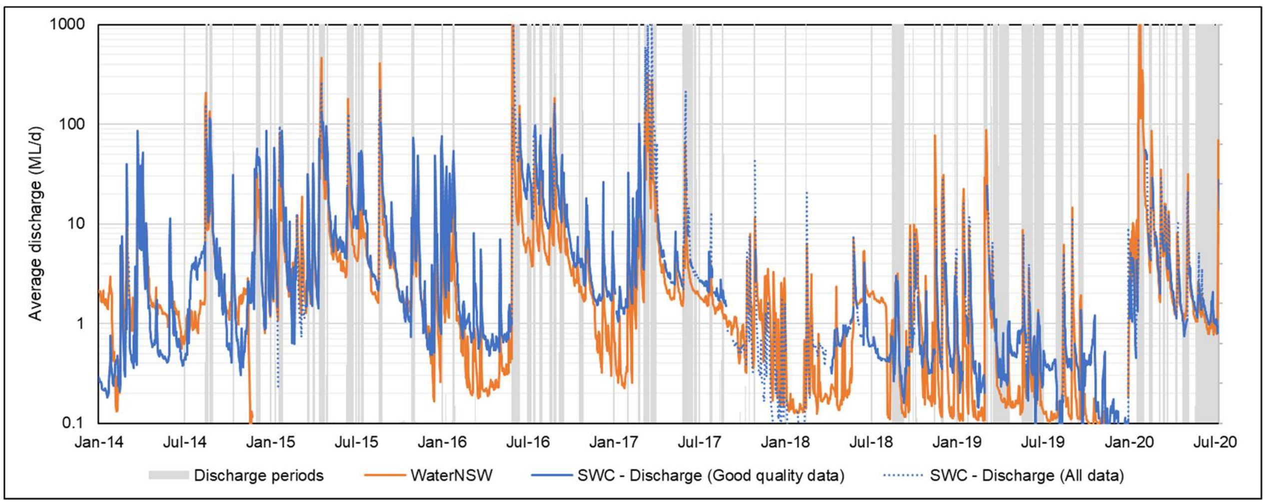
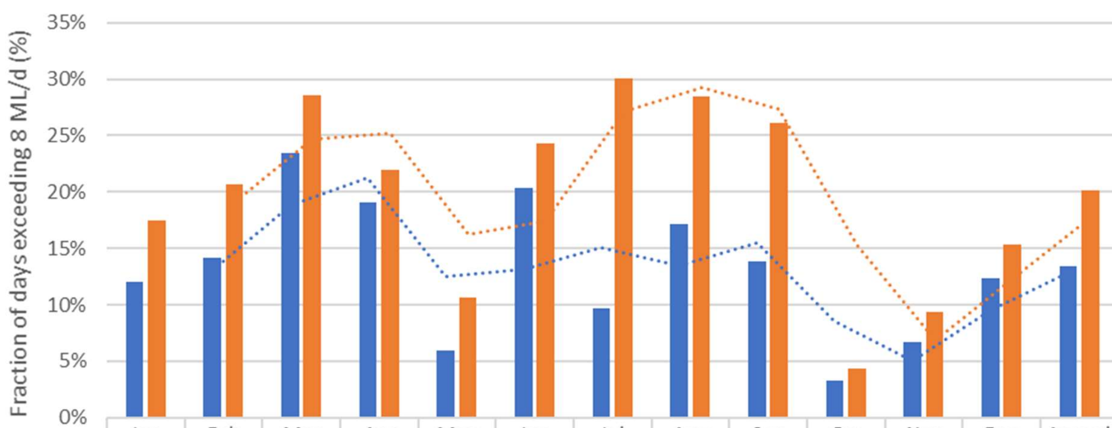


Figure 8-6 **Average daily flowrates (SWC gauge data adjusted to account for discharge)**

A box and whisker plot, shown in **Figure 8-7**, with average daily flowrates grouped per month for the two stations, indicates the median, quartiles and 1.5 the Inter quartile range (IQR) observed. February through October indicates higher 25th percentile values (bottom of the box) at the Sydney Water gauge, with the remaining months indicting equal and slightly higher values for the WaterNSW gauge.

The graph in **Figure 8-7**, compares the fraction of days with flows exceeding 8 ML/d at the two locations. Throughout the year the “SWC gauge – Discharge” dataset indicates more occurrences of exceed the threshold value. This variance is most significant during the late winter months of July, August and September, with flows measured during July indicating three times higher likelihood of the “SWC -Discharge” values exceeding the threshold value.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
WaterNSW	12%	14%	24%	19%	6%	20%	10%	17%	14%	3%	7%	12%	13%
SWC - Discharge	18%	21%	29%	22%	11%	24%	30%	28%	26%	4%	9%	15%	20%

Figure 8-7 Monthly fraction of days with flow exceeding 8 ML/d (Jan 2014 – July 2020)

Cumulative distribution curves (CDF) or flow duration curves have been developed representing the two datasets (WaterNSW gauge data and SWC gauge data – WRP discharge rates) and are shown in **Figure 8-8**. This graph confirms that the Sydney Water gauge is recording higher values throughout most of the observed flow range. Three key values have been highlighted; these are:

- Probability of exceeding 8 ML/d (the current EPL threshold above which discharge is allowed): The WaterNSW gauge indicates a probability of 13%, compared to the SWC gauge indication of 20%. Thus, using the flowrates from the WaterNSW gauge would result in almost half of the understood available discharge time.
- Median or 50th percentile: Both datasets have a similar median flowrate of around 1.5 ML/d
- Flows below 0.6 ML/d: A significant divergence in the low flow range of the curves, with the WaterNSW data showing an unnatural steepening of the curve gradient before flattening out again.

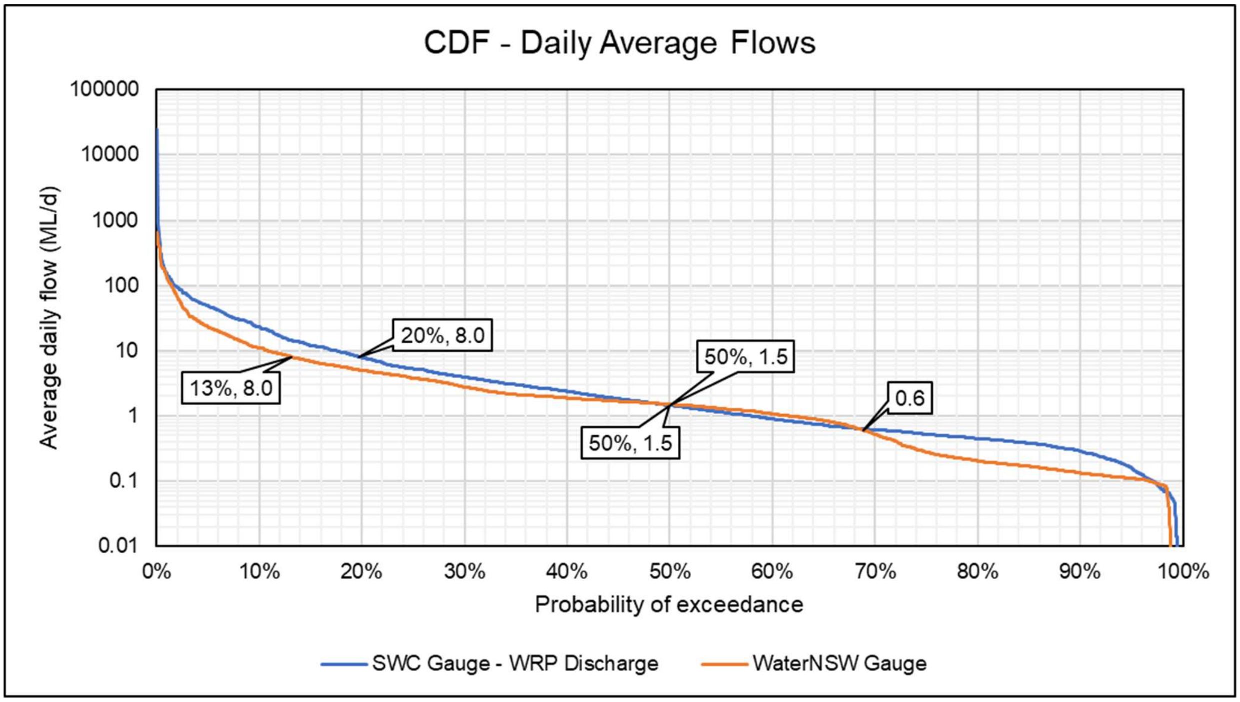


Figure 8-8 **CDF comparison**

Disparity considerations

Spot measurement

During a site visit on the 25th of August 2020 the below observation of the recording at each gauge was made:

- Gauge 2122006 (SWC): 2.7 ML/day
- Gauge 212053 (WaterNSW): 2.1 ML/day

These values show a variance of almost 30% between the upstream and downstream measurements.

Contributing catchments

As indicated in **Table 8-1** the catchment area contributing flows to the creek at the location of the downstream gauge (SWC / 2122006) is approximately 13 km^2 larger than the catchment at the upstream gauge (WaterNSW / 2122006), an increase of around 15%.

A small tributary, Redbank Creek, discharges to Stonequarry Creek between the two gauges. The Redbank Creek catchment covers an area of approximately 8 km^2 and incorporates parts of both Thirlmere and Picton townships. The remainder of the catchment is undeveloped or agricultural land. Local mining within this catchment by Tahmoor Coal has resulted in local subsidence in the Creek bed, which likely results in minor water volumes being lost along its reaches.

Natural seeps or springs are also known in the area and may discharge between the two flow gauges.

Rating curve development

WaterNSW: WaterNSW have provided their July 2020 Rating Review report as well as their 2017-2020 Station Review report for their Stonequarry gauging station. Gaugings taken at the site between 2016 and 2020 show greater deviation from the rating curve values for the low flow ranges (red box in **Figure 8-9**). A major discrepancy between measured flow rates at the same stage (0.334 m) is also observable (blue box in **Figure 8-9**) – correlating with measurements before and after the major flood event in mid 2016.

WaterNSW

Site 212053 STONEQUARRY CREEK AT PICTON
VarFrom 100.00 Stream Water Level
VarTo 141.00 Discharge Rate
Period 15/12/2015 - 01/01/2021

Date	Number	Stage	Flow	Deviation	Area	Velocity	Meth
09:39_19/04/2018	104.0	0.287	0.080000	-57.40	0.1000	0.840	WA
07:47_03/03/2016	93.0	0.293	0.340000	23.71	0.2500	1.350	WA
10:11_02/05/2016	94.0	0.295	0.360000	15.25	0.2700	1.340	WA
11:37_10/05/2016	95.0	0.303	0.850000	47.34	0.2700	3.210	WA
10:58_22/02/2017	101.0	0.327	1.290000	-4.80	0.2600	4.910	WA
09:06_01/03/2016	92.0	0.334	1.850000	12.46	0.3000	6.100	WA
08:44_29/11/2016	100.0	0.334	0.480000	-70.82	0.1900	2.580	WA
09:28_31/05/2017	103.0	0.341	1.690000	-9.72	0.2700	6.280	WA
09:14_23/03/2020	106.0	0.344	1.610000	-18.58	0.2400	6.660	WA
07:56_05/06/2019	105.0	0.358	2.030000	-20.11	0.3100	6.590	WA
09:14_25/05/2020	107.0	0.376	3.120000	-6.99	0.2200	14.380	WA
10:19_14/09/2016	99.0	0.421	6.070000	-0.05	0.3900	15.420	WA
09:55_14/09/2016	98.0	0.422	5.530000	-10.08	0.4200	13.250	WA
10:37_11/08/2016	97.0	0.429	6.750000	0.52	0.3800	17.660	WA
10:29_29/03/2017	102.0	0.482	14.040000	5.30	0.4700	29.920	WA
08:04_10/06/2016	96.0	0.571	37.960000	7.20	0.5900	64.070	WA

* after gauge number indicates Weighted Mean Gauge Height method

Figure 8-9 Gaugings in stage order for the 2016 to 2020 period

WaterNSW have noted the following in relation to this gauge:

- Their primary interest is in the higher flow ranges, and the current site location has been selected to accurately measure medium to high flowrates
- Council has recently done work on the banks around the gauging station site, potentially impacting/changing the rating curve at this point
- They are currently updating the quality codes used throughout their monitoring network, hence the “130 - Not quality coded - subject to change” codes currently appended to all data

As with any active flow monitoring location the rating curve is dynamic and is constantly undergoing minor tweaks each time new gaugings are taken, thus there is the potential for published data to be changed

Conclusion

Historically there has been a discrepancy between the flows reported at the WaterNSW gauge and those reported at the Sydney Water gauge. Sydney Water's primary interest lies within the low to mid-range flows as this governs the allowable precautionary discharge volumes. Several potential reasons for the discrepancies have been noted, and there is evidence to suggest that the flows measured at the WaterNSW gauge may not be accurately representative of the flows occurring within Stonequarry Creek at the WRP discharge location. Furthermore, the WaterNSW gauge has been setup to accurately measure medium to high flows with less emphasis on the low flow range. Given the current understanding, the acceptance of the Sydney Water gauge data is supported for the purposes of defining the low flow regime.

References

NSW DPIE (2020): *Environmental Planning Instrument - Land Zoning* (**https://www.planningportal.nsw.gov.au/opendata/dataset/environment-planning-instrument-local-environmental-plan-land-zoning**) accessed 21 October 2020

9 Appendix C – Further details on Model Build Parameters

9.1 Point source flows

Sewer discharges were modelled by Sydney Water's MOUSE software and aggregated to the Source model's sub catchment scale. As the sewage network was only commissioned in the Stonequarry Creek catchment in 2000, the time series were extended back to 1990 with zero values. There are minimal overflows within the time series. The overflow events are outlined in Table 9-1.

Table 9-1 Sewer overflow event volumes

Catchment	Flow Period	Total Volume (kL)
13	5/6/2016 3pm – 6pm	76
33	21/3/2011 6pm – 7pm	23
33	10/2/2012 6pm – 8pm	44
33	18/4/2012 9pm – 11pm	28
33	27/1/2013 4pm – 6pm	33
33	28/1/2013 5pm – 29/1/2013 3am	463
33	5/6/2016 4am – 10pm	1,752
34	28/1/2013 6pm – 29/1/2013 3am	658
34	5/6/2016 8am – 9pm	1,199
17	10/2/2012 7pm	36
17	28/1/2013 10pm – 19/1/2013 2am	607
17	5/6/2016 6am – 9pm	4,762
37	28/1/2013 6pm – 29/1/2013 5am	3,578
37	5/6/2016 7am – 11pm	8,169

The only point discharge within the system is the Picton WRP. Its flow is represented by the sewage treatment plant node within the Source model. The following options have been selected for the model:

1. Dry Weather Treatment Type is Intermittent Treatment Processes. This is the option to select which time series pattern is used to generate dry weather runoff and water quality. Intermittent Treatment Processes (ITP) is also known as IDAL with the other option Continuous Treatment Processes (CTP) also known as BNR.
2. Recycled Water Type is None. This is the option to select which recycled water options (irrigation, dual reticulation or both) are required. Should one of the other options be specified then it selects which recycled water time series patterns to use.
3. Wet Weather Treatment Type can be anything. This is due to the different options (PST and Non-PST) not being implemented in the upgrade of this node by eWater from an earlier version of Source to current.
4. Median Flow is 2.708 ML/d calculated based on the time series of flows (Figure 9-1). from the filters within Picton WRP.
5. Median Recycled Water Irrigation Demand: Not used
6. Median Recycled Water Irrigation Demand: Not used
7. Dry Weather CTP Flow Ratio: Not used
8. Effluent Quality Sensitivity: Not used

9. Urban Catchment Area is 600 ha which represents the contributing sewage catchment area to the Picton WRP during wet weather events. Noting that this is less than the total sewage network area as not all contributes under wet weather.
10. Runoff fraction is 2% and represents that 2% of the rainfall which falls during a rainfall event reaches the sewers. The urban catchment area and contributing rainfall were determined with comparison to ranked daily inflow across multiple years.
11. Number of rainfall time steps to average is 8. This averages the rainfall across multiple time steps to represent that the infiltration rate into sewers are slower than the model time step (hourly).
12. Maximum flow for full treatment is 42 L/s. This is the limit at which full treatment switches to partial (wet weather treatment).
13. Recycled water irrigation ratio: Not used
14. Recycled water reticulation ratio: Not used
15. Dry weather ITP flow ratio is the time series pattern that is multiplied by the median flow to obtain the dry weather flow discharge from the treatment plant. The pattern has been obtained from Sydney Water's South Creek project and represents the West Camden Treatment Plant (Figure 9-2) as there is not enough reliable data at Picton WRP to provide a representative pattern.

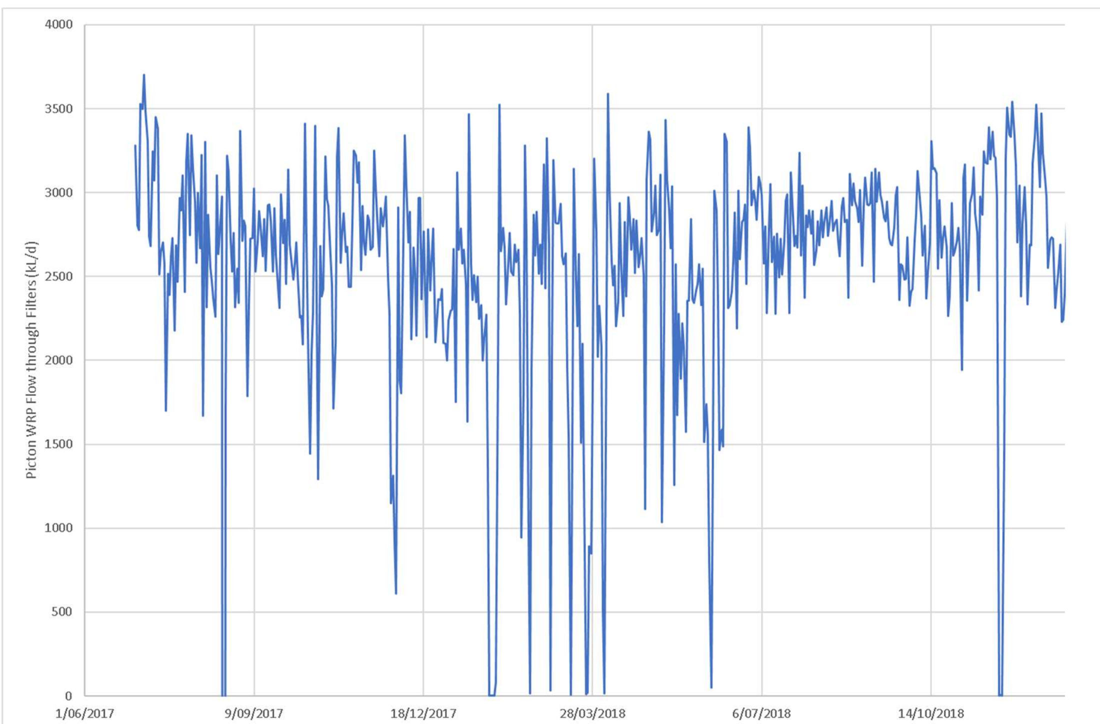


Figure 9-1 Picton WRP Dry Weather Flows

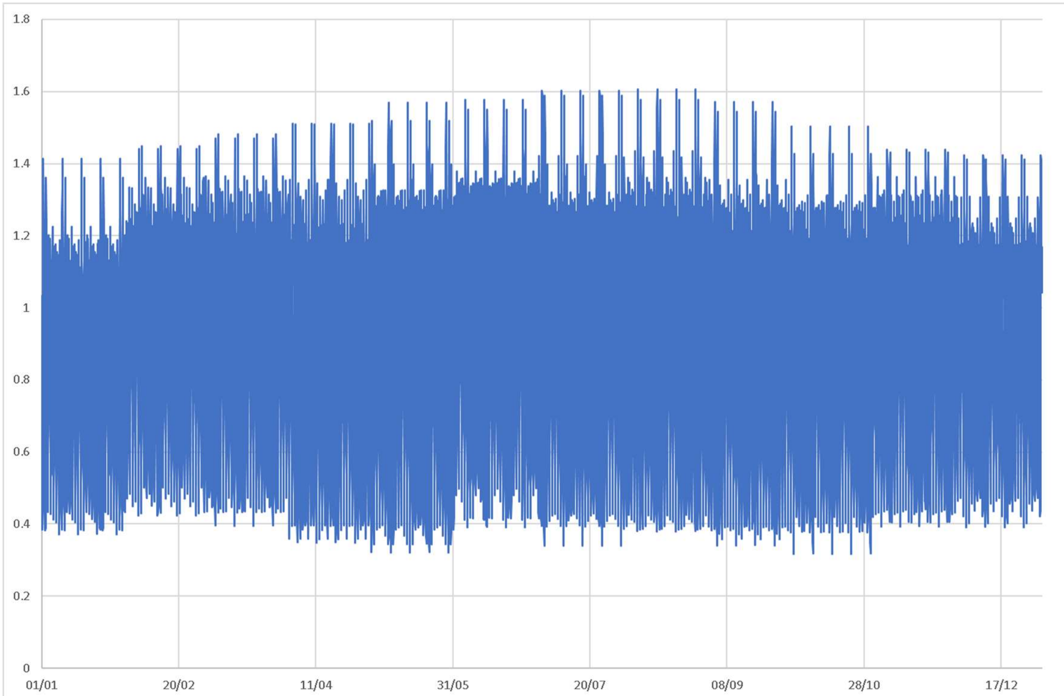


Figure 9-2 Dry Weather pattern – average inflow multiplier with daily and seasonal variability

9.2 Catchment runoff

Flow from catchments in generated using a rainfall runoff model. Two models were selected to represent catchment runoff in the Stonequarry Creek catchment – GR4J and the sub daily SIMHYD model. These were chosen as modelling can occur at an hourly time step and to be consistent with Sydney Water's South Creek modelling approach. Parameters for the model were determined using the PEST optimisation software with some additional refinement to ensure water quality could also be modelled (i.e. contains quick flow and slow flow components). The calibration parameters are detailed in Table 9-2 for the sub daily SIMHYD model and for the GR4J model, noting that the Water functional unit contains no rainfall runoff model. Calibration results are shown and discussed in Section 4.

Table 9-2 Calibrated sub daily SIMHYD rainfall runoff parameters for Stonequarry Creek

Grouping	Functional Unit	Impervious Threshold	RISC	Pervious Fraction	SMSC	Infiltration Shape	Infiltration Coefficient	Interflow Coefficient	Recharge Coefficient	Baseflow Coefficient
Forest	Forest	1	0	1	400	3.521	400	0	1	0.003
Built	Urban	1	0	0.9	20	0.458	217.648	0	0.845	0.221
	Commercial									
	Infrastructure/Utilities									
	Industrial									
Cleared	Mining	1	0	1	364.539	9.105	249.105	0.749	1	0.3
	Open Space									
	Environmental Living									
	Horticulture									

Table 9-3 Calibrated GR4J rainfall runoff parameters for Stonequarry Creek

Grouping	Functional Unit	k	C	x1	x2	x3	x4
Cleared	Grazing	1	0.015	686.048	-0.592	21.183	4
	Peri Urban						

9.3 Water quality generation at Picton WRP

Picton WRP is represented as a Sewage Treatment Plant node in Source. In addition to the flow generation discussed in Section 9.1, water quality generation from the plant as represented in the model is outlined below. The following water quality parameters were considered:

- Median sewer (inflow) concentration in dry weather
- Median plant outflow concentration in dry weather
- Median sewer (inflow) concentration in wet weather (due to stormwater)
- Wet weather removal efficiency (proportion of constituent removed)
- Time series of factors to vary the concentration out of the plant

Wastewater inflow concentrations

The observed sewer concentration is outlined in Figure 9-3 and has a median value of 59.5 mg/L. There was no clear information on the change in sewer concentration under wet weather conditions as well as the removal efficiency of wet weather treatment processes at the plant. For this modelling it has been assumed that the water entering during wet weather events contain significantly lower constituent concentrations than during dry weather. Values of 20 mg/L for TN for the wet weather concentration (as an example) and 50% removal efficiency have been applied as starting values.

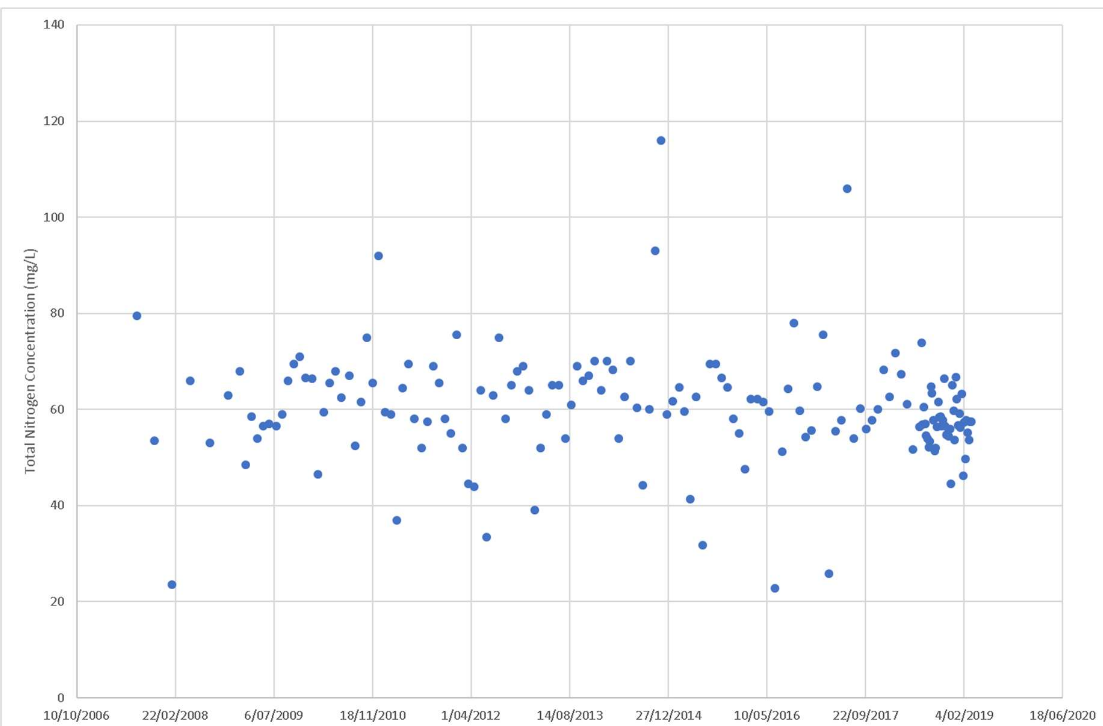


Figure 9-3 Picton WRP observed sewer (inflow) Total Nitrogen concentration

Treated wastewater TN concentrations - historical

The water quality measurements for Picton WRP are focused on the water discharged from the dams (for reuse or discharge), with limited information available on the water quality between various treatment units within the WRP. The water quality in the dams varies with residence time and the natural seasonal decay processes that can result in quite low TN and NOx when conditions are favourable. The median and mean TN concentrations in recent years are just over 4mg/L (Figure 9-4). The baseline scenario adopts 4 mg/L as the simulated TN concentration to avoid simulation of excessive seasonal TN decay in the dams, and allow for greater clarity in the communication of key trends (simplifying the variability in discharge concentrations where the distribution in concentrations is challenging to simulate effectively).

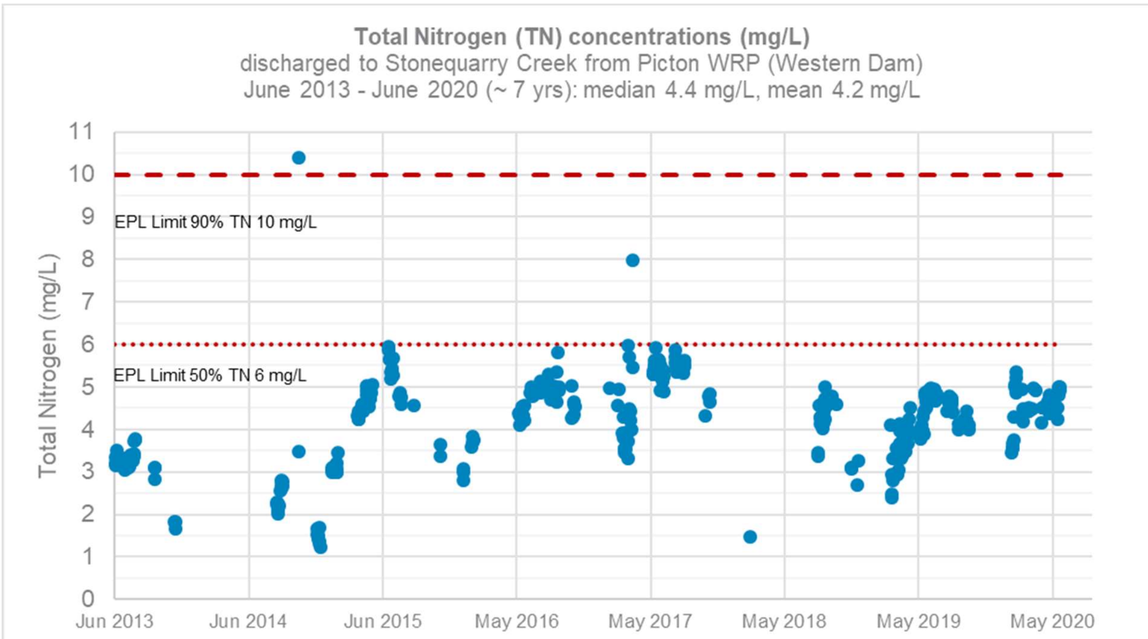


Figure 9-4 Historical data - total nitrogen concentrations discharged to Stonequarry Creek

Treated wastewater TN concentrations - future

Recent and planned upgrades to the Picton WRP (new IDALs and proposed denitrification filters) are expected to improve the treatment performance. As data becomes available, the modelled TN concentrations can be updated to simulate the treatment performance. The distribution of concentrations from the proposed denitrification filters is not known at this stage to allow for a suitably robust and complex representation in the model. The assumed concentration for the future scenarios (3 mg/L TN) is expected to be conservative, with a median concentration likely to be between 2.5 – 3 mg/L TN, and effective buffering of potential concentration spikes with the Equilisation Basin before the denitrification filters and the Western Dam after the filters. Deviations from this expected concentration would only occur infrequently when expected treatment performance fails, and buffering in the dams is also overwhelmed. This unpredictable outcome is not able to be represented accurately in the model.

Treated wastewater TP concentrations

Total Phosphorus concentrations are carefully controlled with alum dosing to ensure that the water quality of the Western Dam is maintained (less algae growth) and discharge to Stonequarry Creek minimises the nutrient concentrations that could stimulate weedy plant growth.

The median and mean TP concentrations in recent years are 0.03-0.06 mg/L (Figure 9-5). The annual loads discharged are highly variable (Table 9-4) particularly in relation to the volumes of recycled water discharged.

The baseline and future scenarios conservatively adopt 0.1 mg/L as the simulated TP concentration to avoid simulation of excessive sedimentation in the dams, and allow for greater clarity in the communication of key trends (simplifying the variability in discharge concentrations where the distribution in concentrations is challenging to simulate effectively).

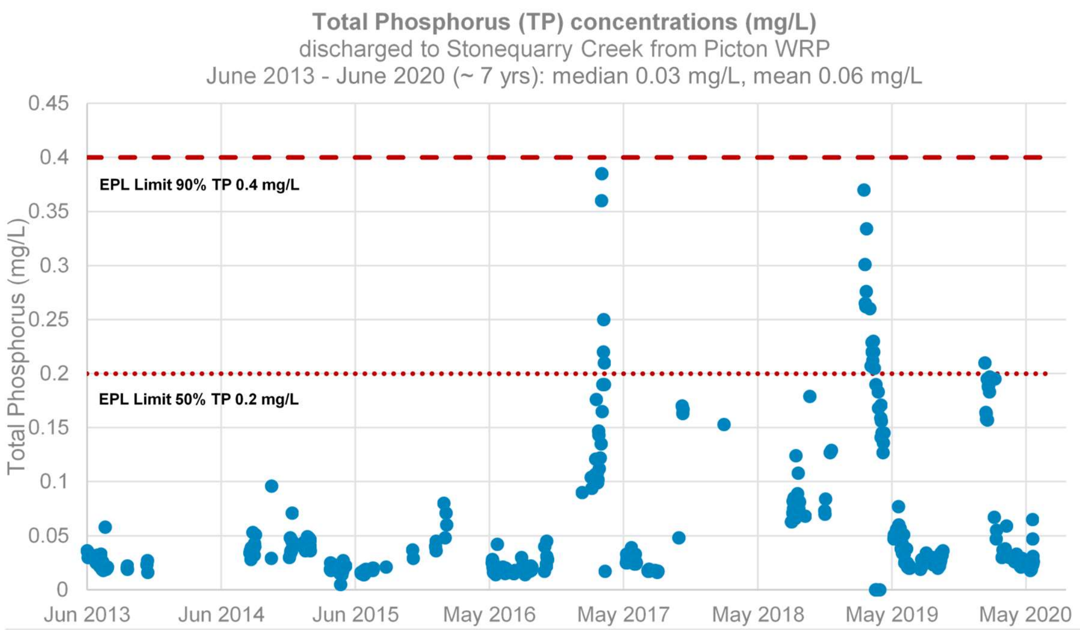


Figure 9-5 Historical data - total phosphorus concentrations discharged to Stonequarry Creek

Table 9-4 Picton WRP mass loads at discharge point

Year	TN (kg)	TP (kg)
EPL limit	1,460	73.0
2014-15	2,236	16.6
2015-16	1,810	12.5
2016-17	3,369	55.0
2017-18	326	5.1
2018-19	1,320	45.8
2019-20	2,286	39

Sewer overflow concentrations

The last point source of water quality are the sewer overflows. For this model these have a fixed concentration of 65 mg/L for TN based on the concentration values used in the Sydney Water South Creek Source model.

9.4 Diffuse runoff water quality

To generate water quality loads from the catchments, constituent generation models were used to provide inputs from each functional unit (land use) within each of the catchments. The model selected was the Event Mean Concentration / Dry Weather Concentration (EMD/DWC) model to provide differing baseflow and quick flow components to create constituent runoff from the Source model. The final parameters from these models are outlined in Table 9-5.

While these parameters provide an appropriate representation of the overall catchment load within Stonequarry Creek, should land use change be examined in the future using this model, it is recommended that greater graduation in the parameterisation of land use types is undertaken.

Table 9-5 Source model EMC and DWC concentrations

Functional Unit	EMC (mg/L)	DWC (mg/L)
Grazing	2.3	0.28
Horticulture	2.3	0.28
Water	N/A	N/A
Peri Urban	2.3	0.28
Forest	0.9	0.1
Urban	2.3	0.28
Infrastructure/Utilities	2.3	0.28
Industrial	2.3	0.28
Mining	0.9	0.1
Open Space	2.3	0.28
Environmental Living	2.3	0.28
Commercial	2.3	0.28

Nepean River at Maldon Weir

Maldon Weir is approximately 120 m upstream of the confluence of the Nepean River and Stonequarry Creek and sits outside of the Stonequarry Creek catchment area. Stream flow and Water Quality and Maldon Weir has been included into the model to enable flow and nutrient analysis for the part of the Stonequarry Creek downstream of the Picton WRP. Hourly stream flow data for the Nepean River at Maldon Weir along with sample concentration data for Total Nitrogen with varied sample intervals. A continuous hourly Total Nitrogen data set was developed for input to the Source model by linearly filling the sample data between sample dates and then assigning the infilled values to every hour on that date (Figure 9-6). The final Total Nitrogen hourly data set that was input into the Source model was extended to include the dates between 1990 to 2012 using a Total Nitrogen concentration value of 0.3725 mg/L.

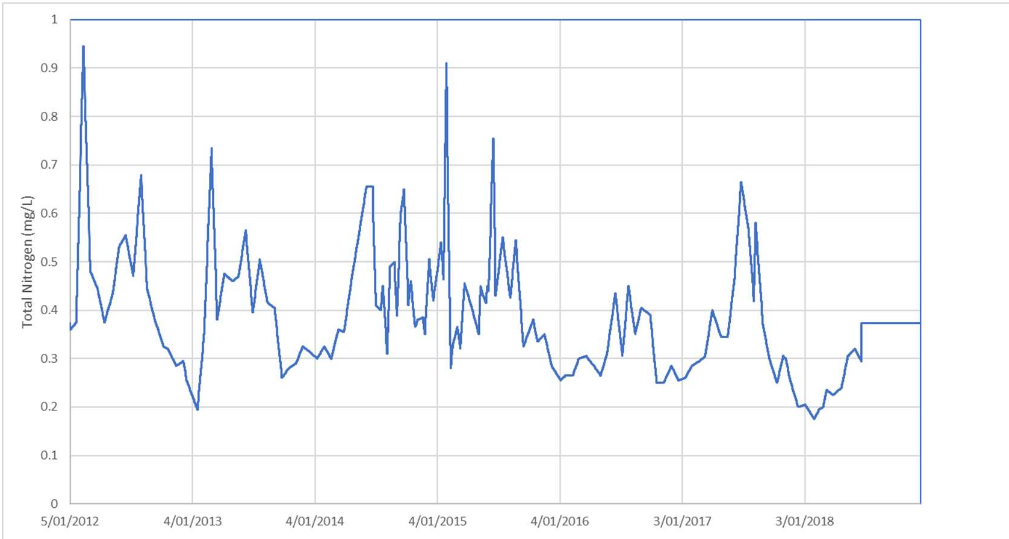


Figure 9-6 Infilled Total Nitrogen Concentration at Maldon Weir

9.5 Irrigation and transfer between dams

There are two irrigation demands that extract water from the dams at Picton WRP. A MEDLI per hectare demand series was supplied by Sydney Water to represent the required extraction pattern required for irrigation. One demand extracts water from the Eastern Dam (92 hectares) and the other extracts water from the Western Dam (27 hectares). Each are represented by a Water User Time Series Demand as a function (MEDLI time series by their respective areas).

Water is transferred between the Eastern and Western Dams. To facilitate this a minimum flow node is used to move water between the two dams. The maximum transfer rate is 15 ML/d which translates to 625 kL per time step (hour). The equation used to set the transfer is:

$$if\ \frac{Eastern\ Dam\ Volume_t}{Eastern\ Dam\ FSV} < 1\ Then\ 15\frac{ML}{d}\ else\ 0\frac{ML}{d}$$

Where:

- Eastern Dam Volume$_t$ is the current time step storage volume
- Eastern Dam FSV is the full storage volume (FSV) of Eastern Dam. Noting that the FSV is not the full storage of the dam, the difference is air space for wet weather events.

Water is also released from the Western Dam to Stonequarry Creek based on the flow rate in Stonequarry Creek

$$if\ \frac{Western\ Dam\ Volume_t}{Western\ Dam\ FSV} < 0.8\ Then\ (see\ below)\ else\ 0\frac{ML}{d}$$

$$if\ Stonequarry\ Flow < 8\ Then\ 0\frac{ML}{d}\ else$$
$$Minimum\ of\ 14\frac{ML}{d}\ and\ \frac{Stonequarry\ Flow}{4}$$

Where:

- Western Dam Volume$_t$ is the current time step storage volume

- Western Dam FSV is the full storage volume (FSV) of Western Dam. Noting that the FSV is not the full storage of the dam, the difference is air space for wet weather events.
- Stonequarry Flow, the flow in Stonequarry Creek upstream of the discharge (in reality measured at gauge immediately downstream)

Evaporation on the two dams also have rainfall and evaporation applied to them. Evaporation is applied with a pan coefficient of 0.7 representing the reduction in evaporation from large bodies of water. In addition to this there is a decay of ~150 days applied to the Total Nitrogen in the storage, representing the change in Total Nitrogen concentration from residence time in the two Dams. This number was applied based on outcomes of work Sydney Water had commissioned. It should be noted that based on the observed Total Nitrogen concentrations, this decay reduction may reduce the concentrations more than reality.

Lastly there is a splitter node implemented in the model to split the flow from Picton WRP between the two dams. All flows above 42 L/s are sent directly to Eastern Dam, with anything up to 42 L/s sent to Western Dam.

9.6 Precautionary and Excess Discharge Rules

To enable the simulation of the Precautionary and Excess Discharges from the Picton WRP to either Stonequarry Creek or the Nepean River, the operating rules for when discharges can be released from the Western Dam to either Stonequarry Creek or to the Nepean River have been configured into the model.

Precautionary Discharge Rule

The objective of the Precautionary Discharge is to maintain the storage volume of the Western Dam below 213.1 mAHD. If the storage level of the Western Dam is below 213.1 mAHD there is no required discharge. If the storage level is above 213.1 mAHD the flow in Stonequarry Creek above the discharge location must be greater than 8 ML/day.

Precautionary Discharge is controlled by a Minimum Flow Requirement Node configured with the Precautionary Discharge Rule below:

```
IF ($mvWD_StorageLevel<=213.1, IF($SQ_US_WRP<8,0,MIN(0.25*$SQ_US_WRP,14)),0)
```

Where:

$mvWD_StorageLevel = Western Dam Storage Level (mAHD)

$SQ_US_WRP = Stonequarry Creek Stream Flow at current timestep (ML/Day)

For Scenarios with discharge to the Nepean River. 63.

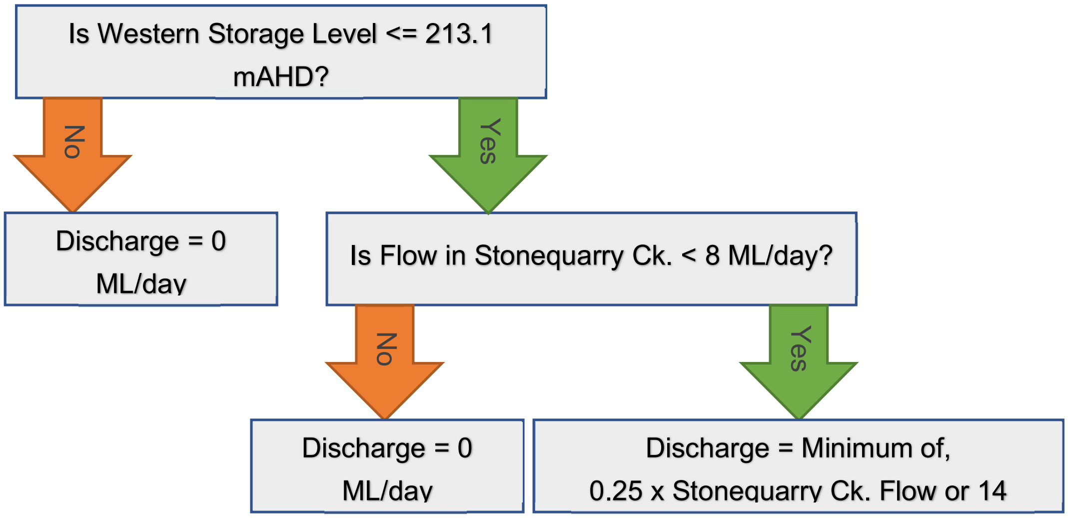


Figure 9-7 Rule for Precautionary Discharge

Excess Discharge Rule

The objective of the Excess (or Emergency Operating Protocol) Discharge Rule is to control the discharge from the Western Dam as the storage level approaches the maximum level in an attempt to avoid the spills of water that have a higher constituent concentration. This operating rule includes 'ON' and 'OFF' operating criteria (Table 9-6), and requires multiple testing of the initial condition to determine if the storage level of the Western Dam is less than 213.6 mAHD, to determine if the Excess Discharge needs to continue after being initially triggered, as indicated in Figure 9-8.

Table 9-6 Excess Discharge Operating Rule

Operating Rule	Western Dam	
	On Level (m)	Off Level (m)
Excess Discharge Tier 1: If Stonequarry Ck. > 2 ML/Day then Min (Stonequarry Ck. Flow or 15 ML/Day)	> 5.1	N/A
Excess Discharge Tier 2: 3 ML/Day	> 5.6	< 5.3
Excess Discharge Tier 2b: 6 ML/Day	> 5.75	< 5.6

Excess Discharge are also controlled using a Minimum Flow Requirement Node configured with the Excess Discharge Rule below:

IF($mvWD_StorageLevel>213.1,IF($mvWD_StorageLevel>213.6,IF($mvWD_StorageLevel>513.75,6,IF($mvWD_StorageLevel>213.3,3,IF($SQ_US_WRP>2.5,MIN($SQ_US_WRP,15),0))),IF($SQ_US_WRP>2.5,MIN($SQ_US_WRP,15),0)),0)

Where:

$mvWD_StorageLevel = Western Dam Storage Level (mAHD)

$SQ_US_WRP = Stonequarry Creek Stream Flow at current timestep (ML/Day)

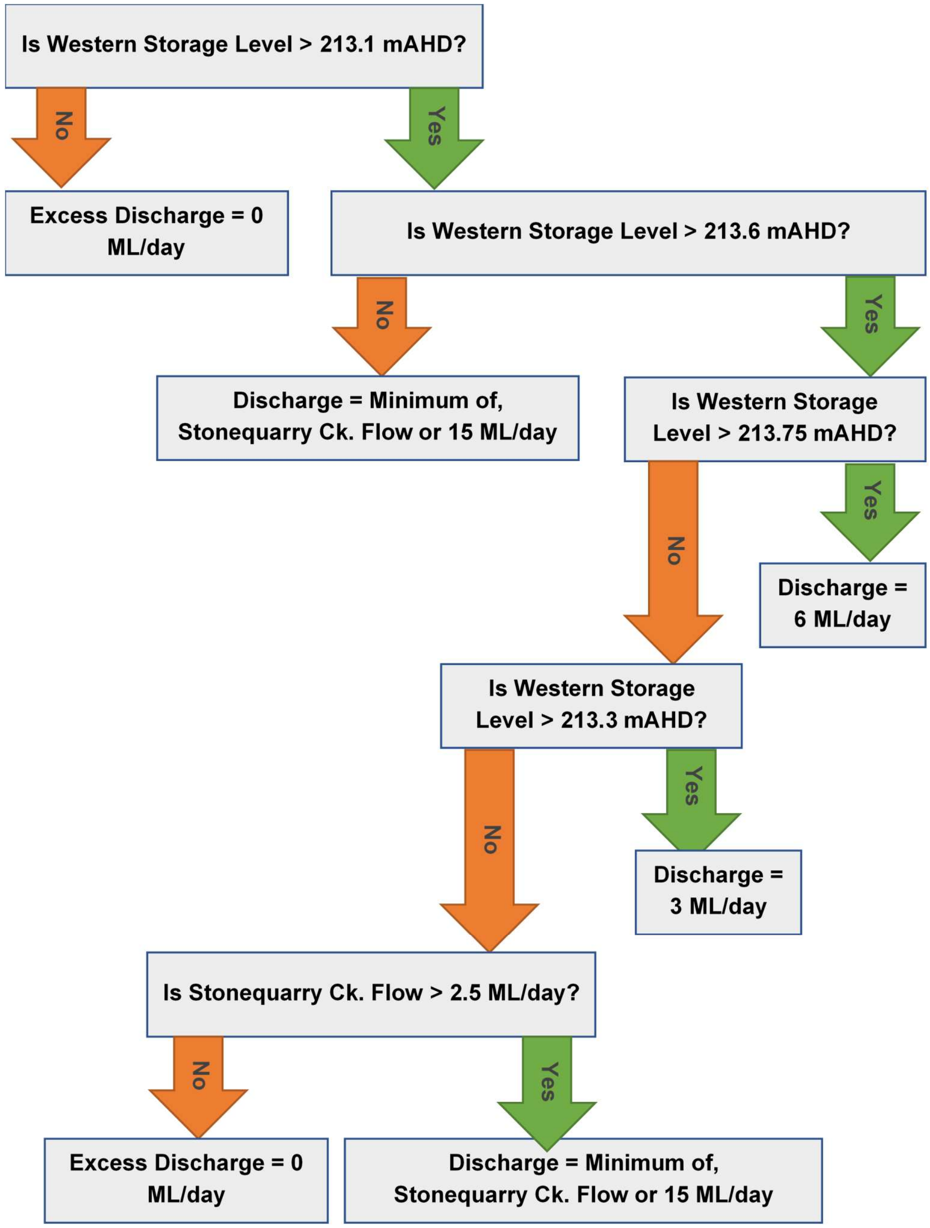


Figure 9-8 Rule for Emergency Operating Protocol for discharge of excess effluent

9.7 Spills from dams

The model allows for spills from the Eastern and Western Dams that may occur infrequently in the model.

In reality, extreme events that risk spills from dams may be prevented with actions by the plant operators such as

- seeking to transfer between dams
- seeking to increase discharge to waterways in the preceding week to prevent spills occurring and
- maintaining a water level higher than the target in the dams over a short period.

The model may not predict the inflow precisely for a given storm event due to:

- Simplification of the likely spatial rainfall variability in the model to two broad regions, rather than the likely high rainfall heterogeneity likely during intense storms
- Flow generation conveyed to the WRP being simulated more efficiently (all significant rainfall producing increased sewer flows) in the model than occurs in a real sewer network

The analysis of simulated spills from the existing dams provides an important check on the model, and where other parameters may need further optimisation. Where only small volumes are discharged, and where this occurs relatively infrequently, the model time series outputs and the corresponding statistics are still able to be used for the intended purpose of the model (comparison between future management options).

10 Appendix D – Further details on model calibration and validation

10.1 Total Nitrogen calibration

Figure 10-1 to Figure 10-7 show time series of the Total Nitrogen concentrations at each of the calibration locations.

Key items from these results are:

- Picton WRP to Stonequarry Creek captures the range of variability within the observed data of the recent period but is higher than the observations earlier in time. This indicates that concentration or load of Total Nitrogen entering the Western Dam or how the Western Dam processes Total Nitrogen has changed over time.
- Picton WRP irrigation (from Eastern Dam) models less variability that in the observed data indicating that the decay applied to the storages does not capture the entire variability within the dam and that there are other processes occurring.
- N914 captures the range of variability of the observed data.
- N912 captures the majority of variability in the observed data, however a couple of values are outside the modelled variability. These higher observations may not be representative of typical catchment flows.
- N911 captures the range of variability appropriately as shows clearly the effect of discharges from Picton WRP.
- N911B, despite being in such close proximity to N911, shows a very different profile as it is not affected by the Picton WRP discharges. It shows that the catchment conditions are represented appropriately.
- N91 results show that the Nepean River and Stonequarry concentrations are being captured appropriately. However, the observations are all at the lower end of the modelled results, with events spiking above the observed variability. This could be due to attenuation of Total Nitrogen concentrations at the downstream end of Stonequarry Creek, or more likely, the observations are captured on dry weather flow days.

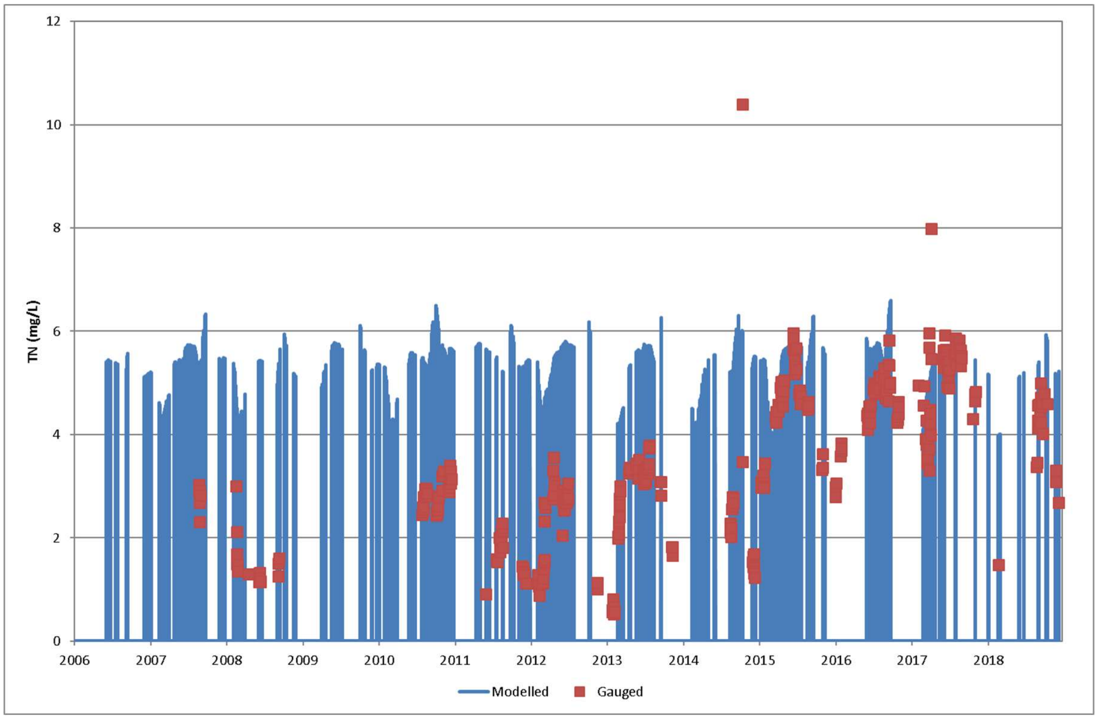


Figure 10-1 Discharge to Stonequarry Creek Total Nitrogen hourly time series

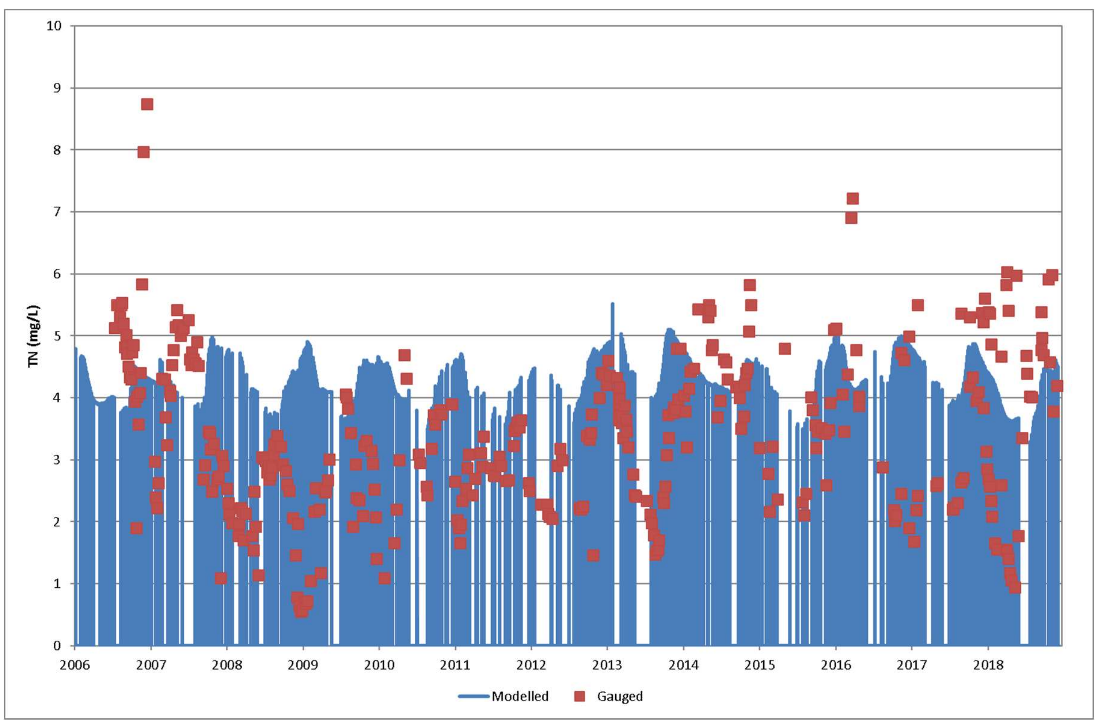


Figure 10-2 Eastern Dam irrigation extraction Total Nitrogen hourly time series

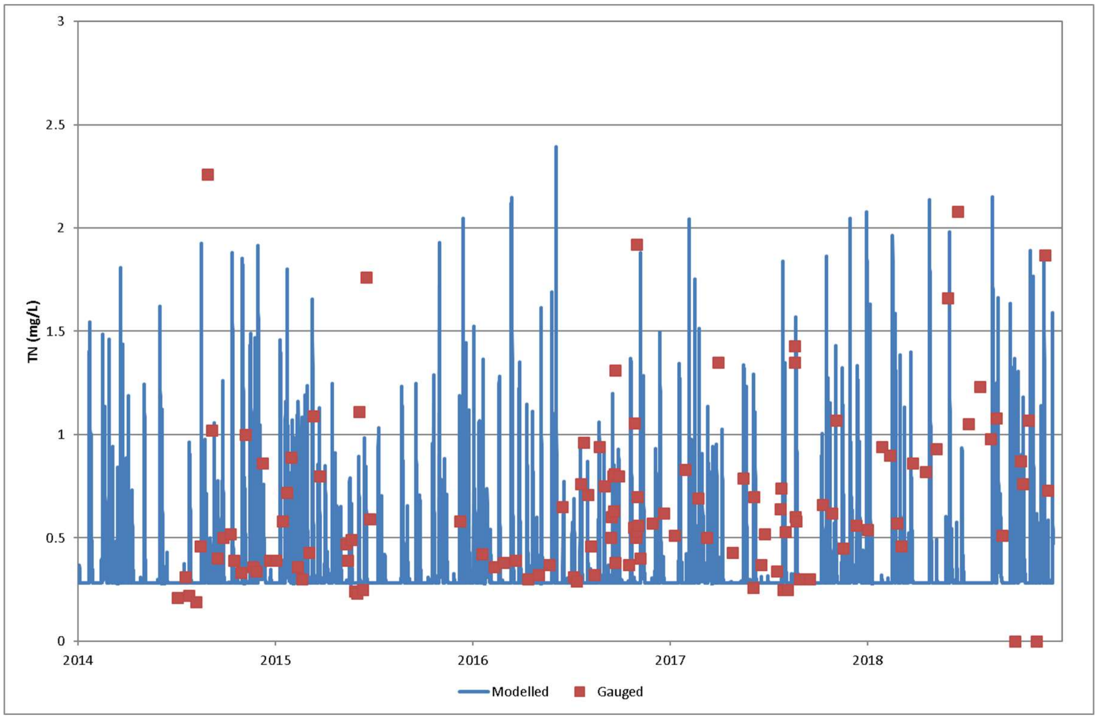


Figure 10-3 N914 Total Nitrogen hourly time series

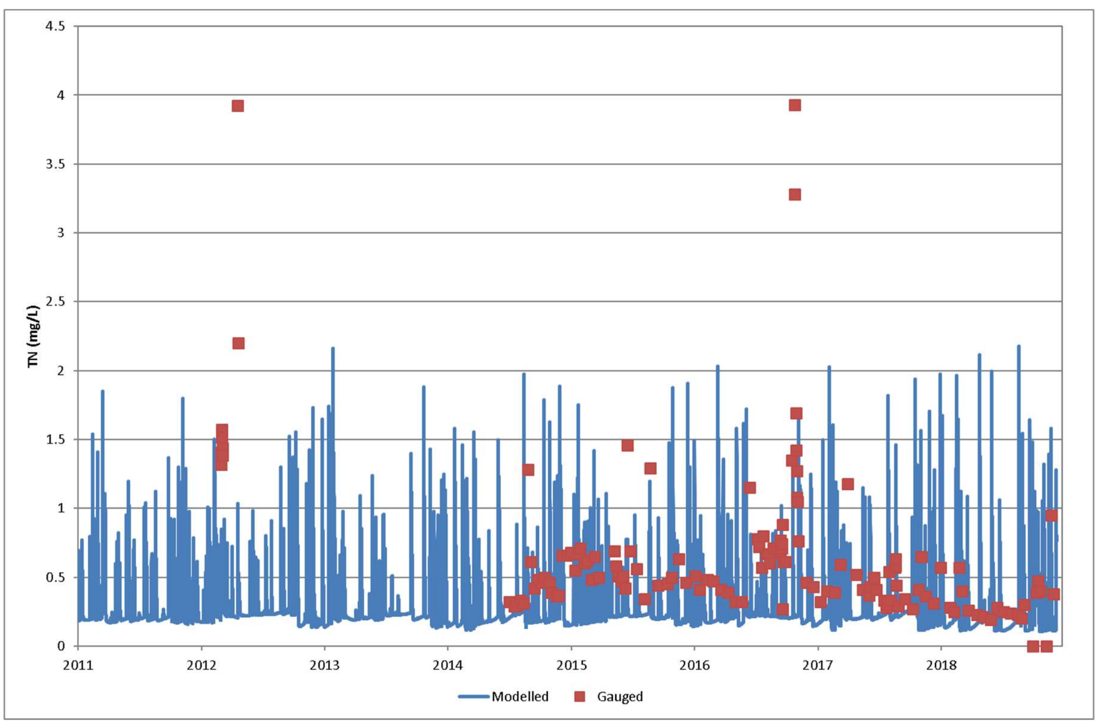


Figure 10-4 N912 Total Nitrogen hourly time series

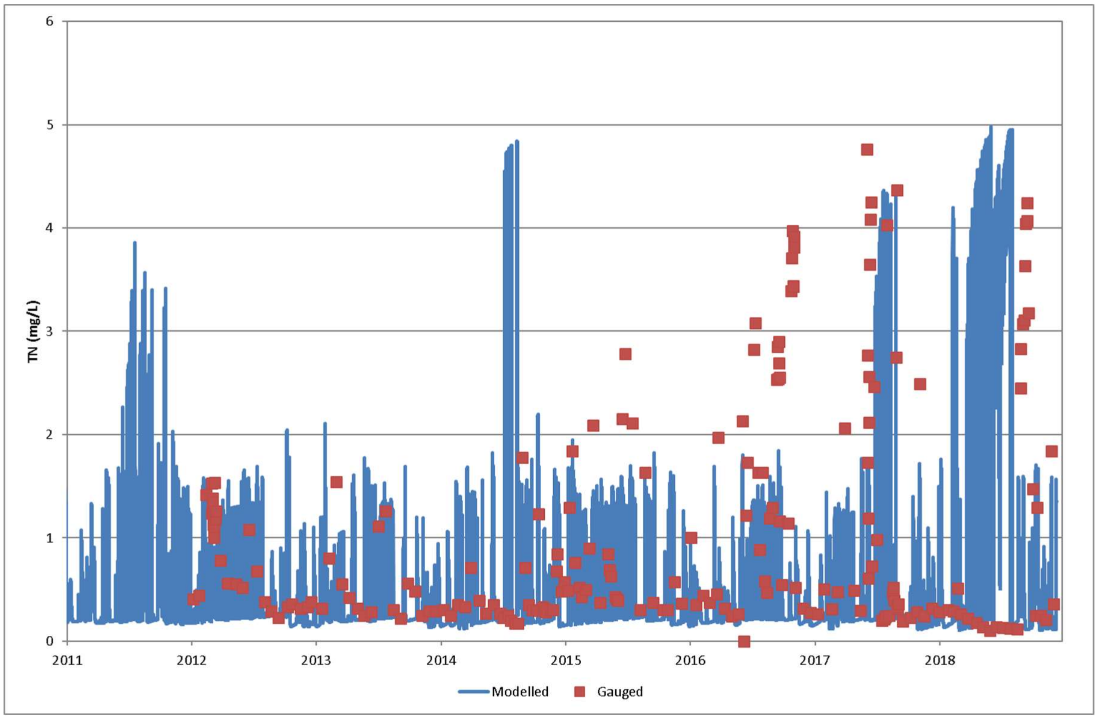


Figure 10-5 N911 Total Nitrogen hourly time series

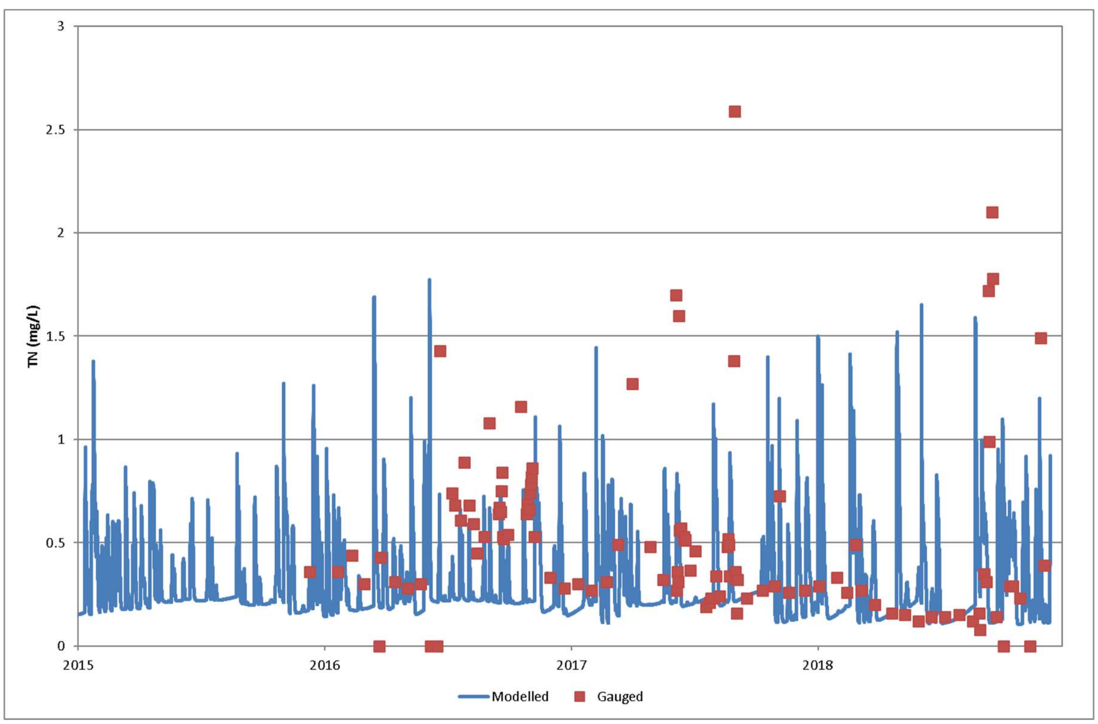


Figure 10-6 N911B Total Nitrogen time series

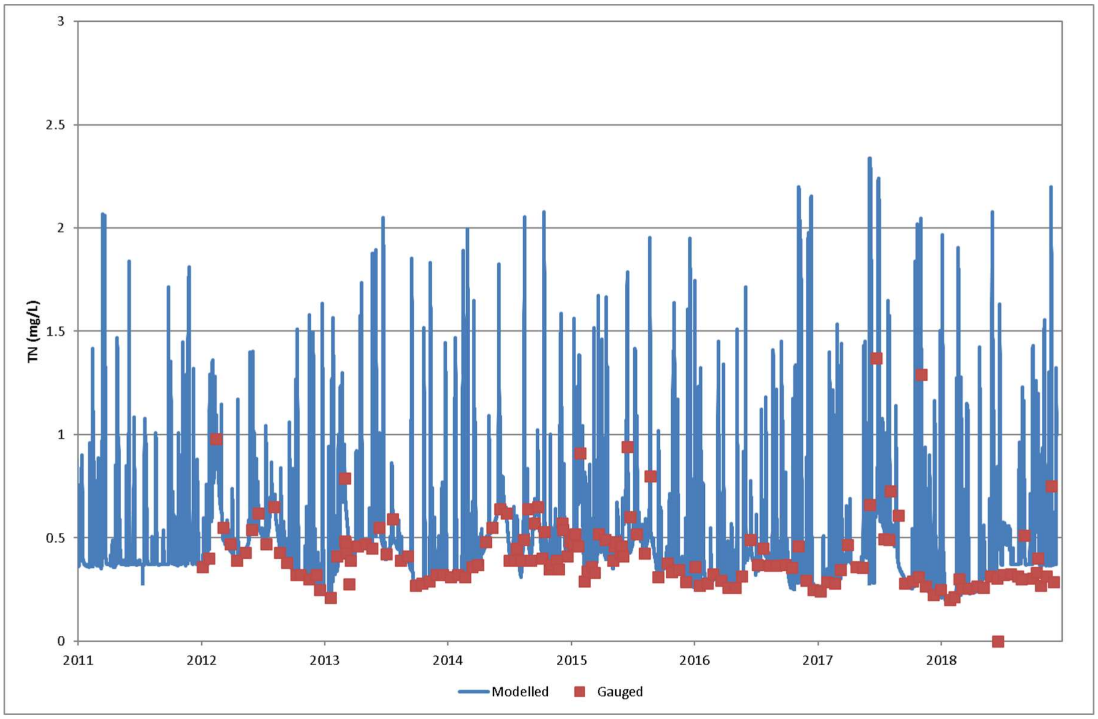


Figure 10-7 N91 Total Nitrogen hourly time series

10.2 Other constituents – Oxides of nitrogen

Derivation of Oxides of Nitrogen and Filterable Reactive Phosphorus Concentrations

The Oxides of Nitrogen (NOx) and Filterable Reactive Phosphorus (FRP) concentrations have been derived through regression analysis of the observed TN and NOx, and TP and FRP data for Maldon Weir that was provided by Sydney Water. Regression analysis involved investigating the trend of all data, seasonal and monthly data. For seasonal and monthly data points if the measurement was taken in a season or month the value was allocated to that season or month without any data manipulation applied to the value.

Total Nitrogen and Nitrogen Oxides

Regression analysis of the TN and NOx data by month provided the best relationship between the two constituents (Table 10-1). Regression analysis plots for TN and NOx are shown in Figure 10-8 and Figure 10-9.

The modelled timeseries compared to the observed point data for NOx in the Nepean River at Maldon Weir (Figure 10-10) shows that the model is responding in a very similar manner to what is observed in the point sample data and is reproducing the peaks and troughs of the sample data quite well across the late 2011 to 2018 period.

Table 10-1 Monthly functions for the estimation of NOx

Month	Function	R^2
January	NOx = 0.6322 x TN - 0.1143	0.9202
February	NOx = 0.4432 x TN - 0.0768	0.757
March	NOx = 0.5632 x TN - 0.1009	0.7015
April	NOx = 0.8425 x TN - 0.1805	0.7211
May	NOx = 1.0084 x TN - 0.2359	0.7724
June	NOx = 0.9299 x TN - 0.2147	0.8334
July	NOx = 0.7304 x TN - 0.0932	0.912
August	NOx = 0.8063 x TN - 0.1463	0.8148
September	NOx = 0.5086 x TN - 0.0348	0.7824
October	NOx = 0.7461 x TN - 0.1348	0.7557
November	NOx = 0.4787 x TN - 0.0572	0.6537
December	NOx = 0.6143 x TN - 0.1154	0.7034

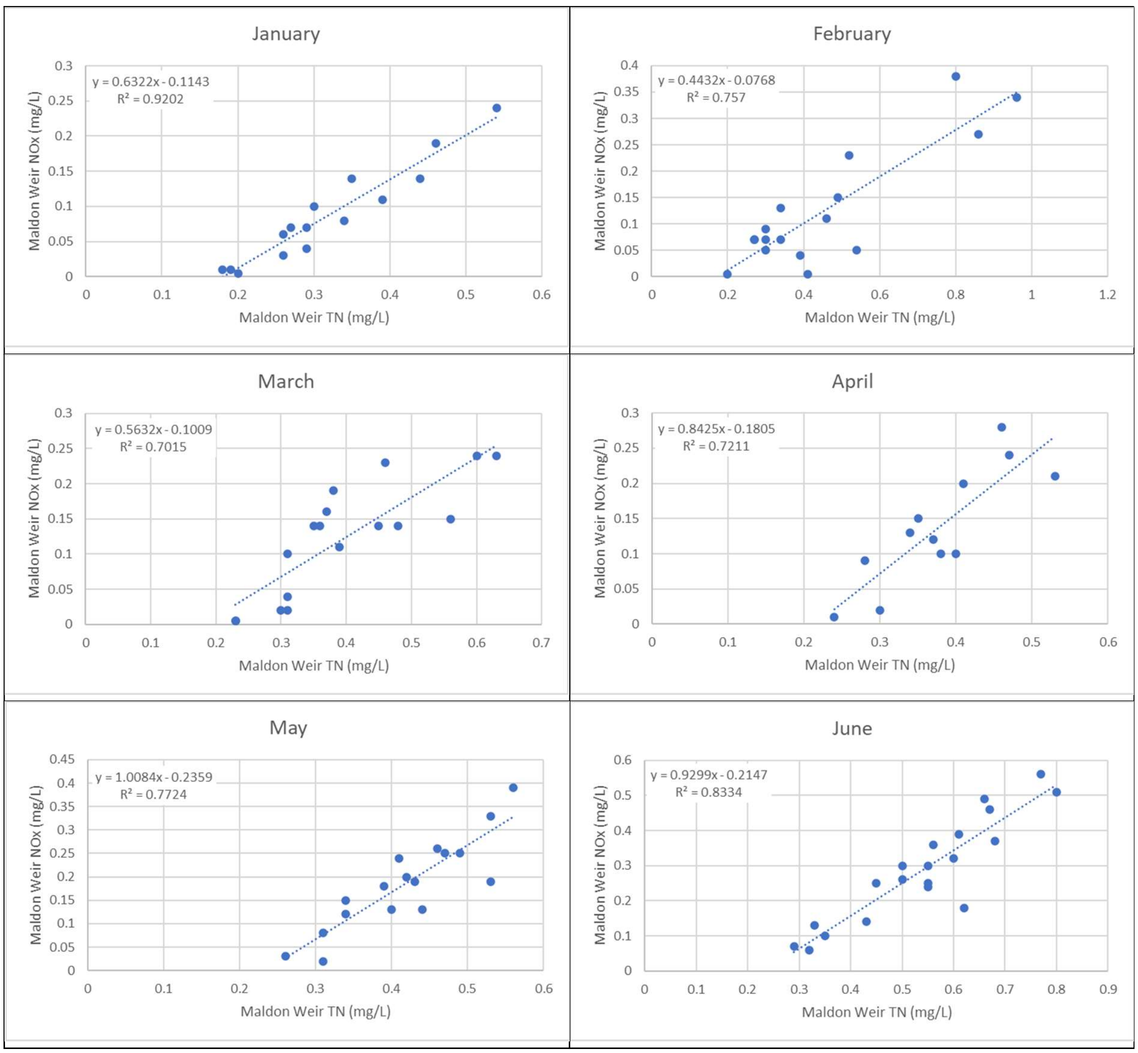


Figure 10-8 TN and NOx Regression Analysis Plots – January to June

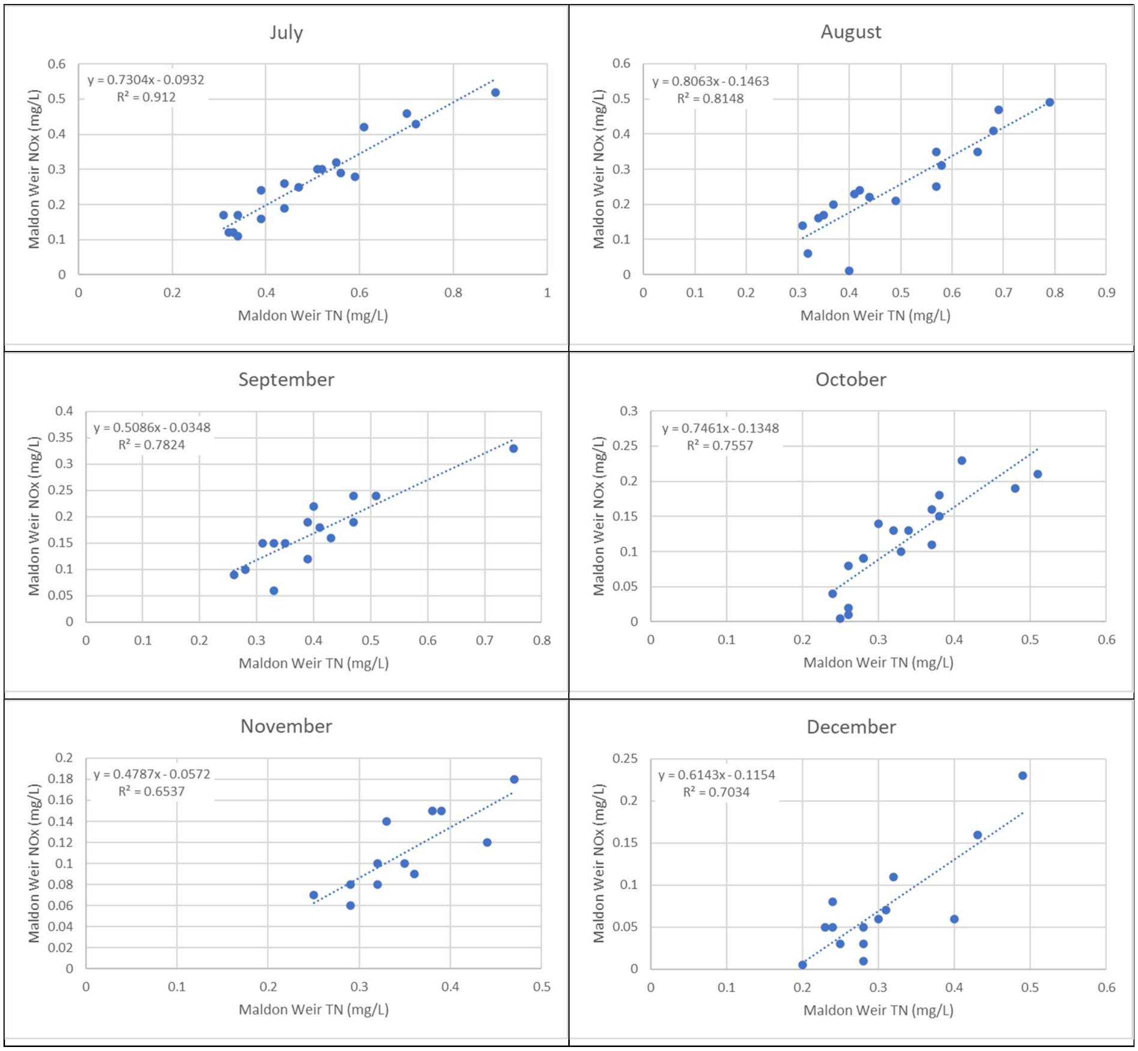


Figure 10-9 TN and NOx Regression Analysis Plots – July to December

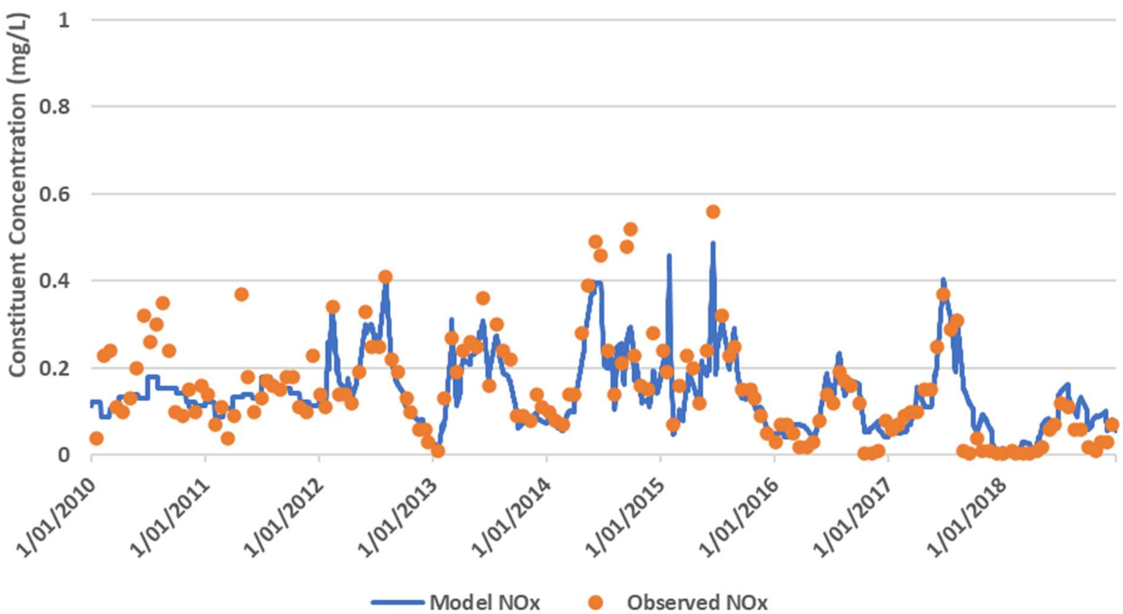


Figure 10-10 Observed and Modelled NOx at Maldon Weir

Preliminary results with NOx assumptions adopted

Discharge concentrations for NOx and FRP were simulated as 60% of TN and TP. As discussed in section 5, preliminary results for NOx are simulated for the various scenarios on the basis of these initial assumptions. There is potential to refine the NOx relationships as more data becomes available. It is expected that the summer periods where natural decay of NOx in our storage dams is high will further reduce NOx concentrations.

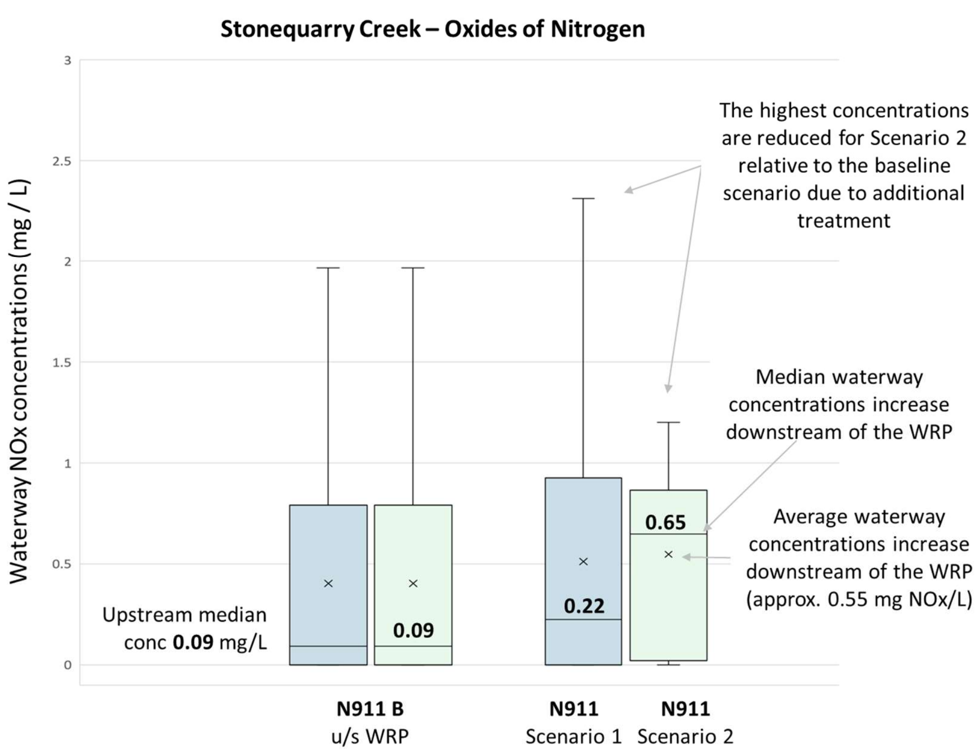


Figure 10-11 Modelled NOx Stonequarry Creek – Scenarios 1 and 2 with comparison upstream of WRP

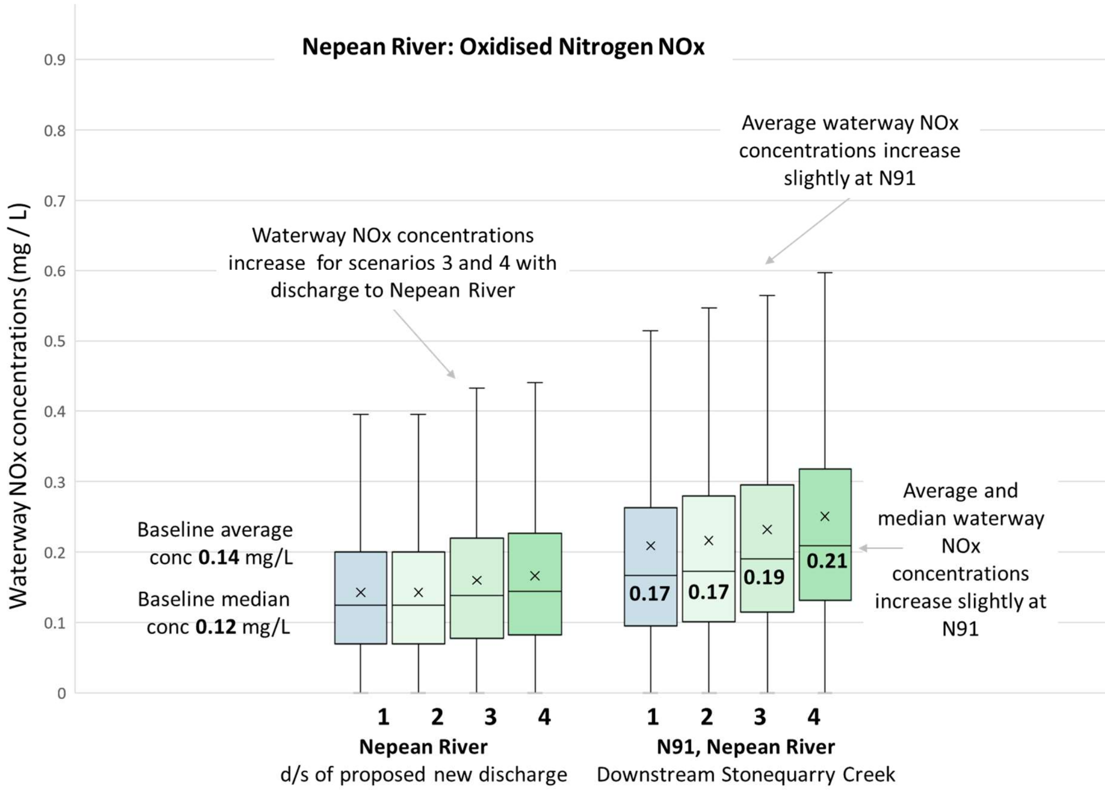


Figure 10-12 Modelled NOx Nepean River – upstream and downstream of confluence with Stonequarry Creek

10.3 Other constituents – Phosphorus (TP and FRP)

Total Phosphorus and Filterable Reactive Phosphorus

Regression analysis of the observed TP and FRP indicated that grouping the data by season provided the best relationship between the two constituents (Table 10-2). Regression analysis plots for TP and FRP are shown in Figure 10-13.

Table 10-2 Seasonal functions for the estimation of FRP

Season	Function	R^2
Summer	FRP = 0.6084 x TP - 0.0021	0.8557
Autumn	FRP = 0.6846 x TP - 0.0029	0.8406
Winter	FRP = 0.6914 x TP - 0.0021	0.8641
Spring	FRP = 0.8396 x TP - 0.0047	0.9314

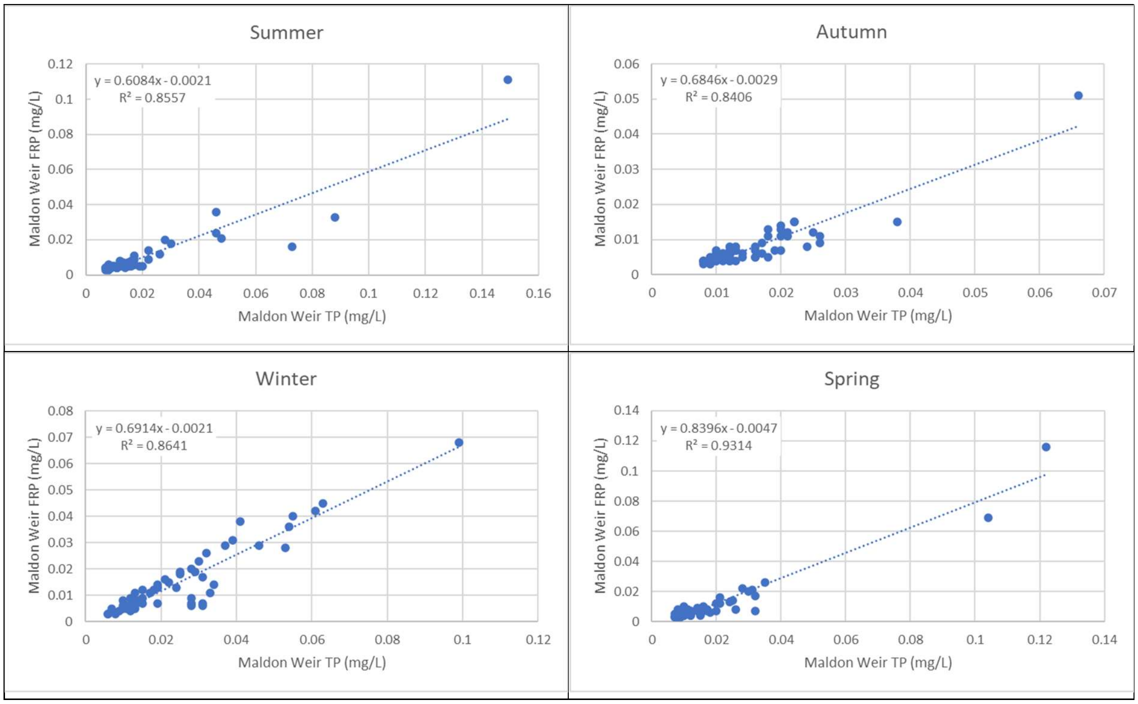


Figure 10-13 TP and FRP Regression analysis plots

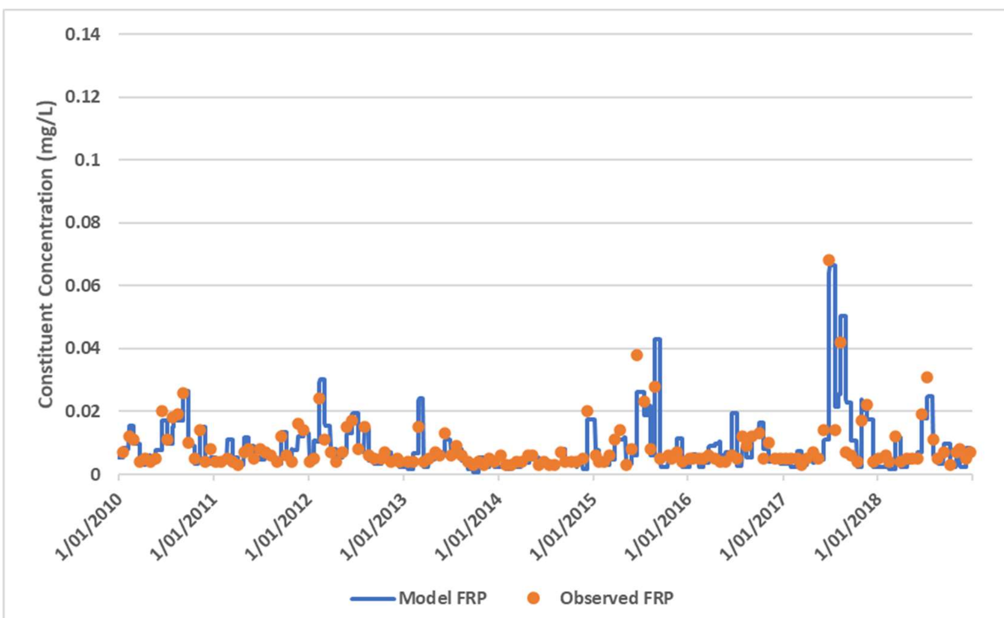


Figure 10-14 Observed and Modelled FRP at Maldon Weir

If the highest values were treated as outliers and removed from the analysis and the intercept is set to zero the TP to FRP relationship in each season is improved (Figure 10-15) , however fewer of the observed peak events are matched by the modelled and the baseflow concentration is slightly lower than the observed values (Figure 10-16).

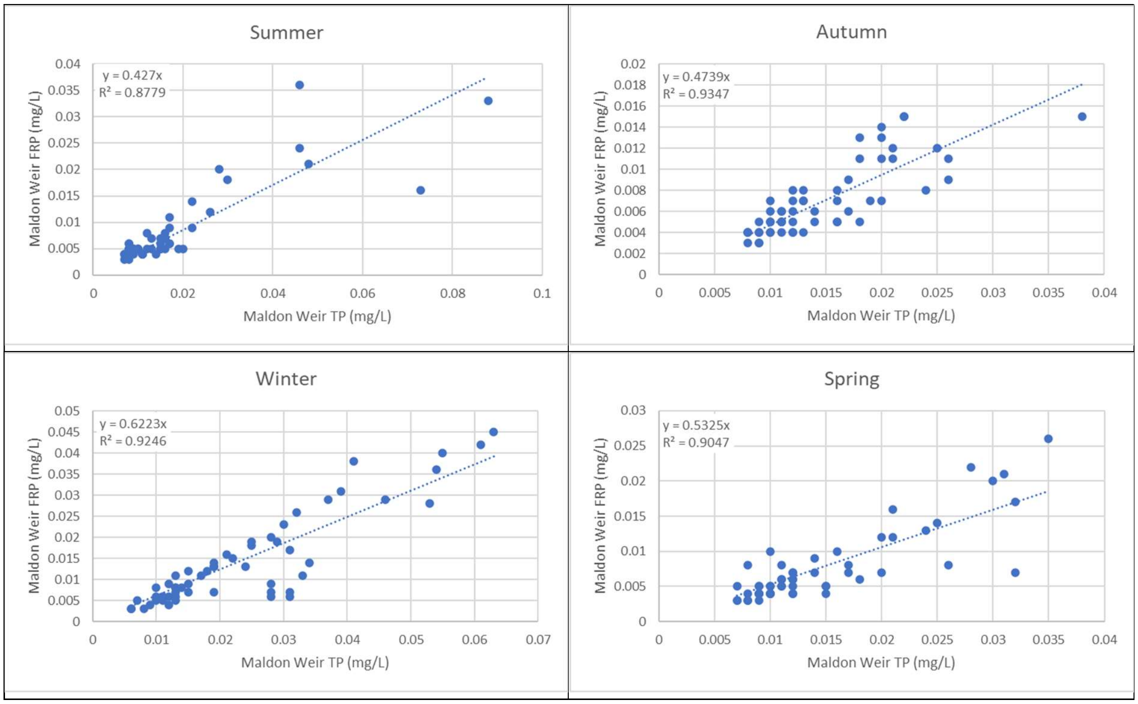


Figure 10-15 TP and FRP Regression analysis plots – Maximum Values Removed

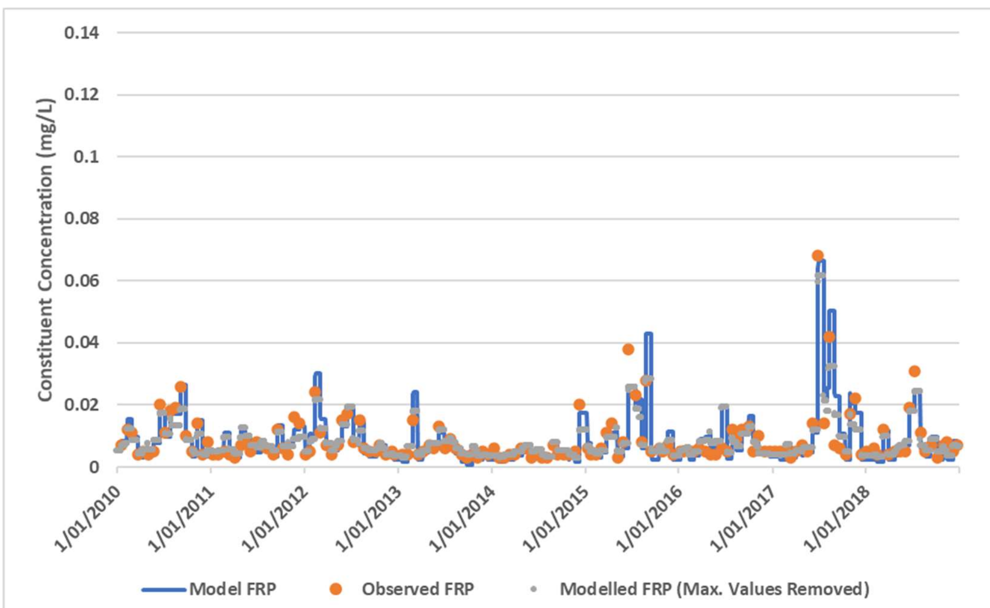


Figure 10-16 Observed and Modelled FRP at Maldon Weir – Maximum Values Removed

By including the higher values in the regression analysis, and not setting the Intercept Value the model is simulating the high and low range of values better than it does after removing the high values from the analysis and forcing the zero intercept.