Picton LVA Addendum Modelling Report

Stonequarry Creek and Nepean River – Flow and Water Quality

Sydney WATER

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Report version: 2

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Executive summary

Picton Water Recycling Plant (WRP) is currently exceeding its capacity to manage recycled water due to growing development in its catchment. Sydney Water has explored different options to vary the WRP's Environmental Protection Licence (EPL) to allow a continued discharge into Stonequarry Creek whilst it seeks to maximise reuse and implement new treatment processes.

A suite of technical reports were commissioned to accompany a Licence Variation Application (LVA). This report documents the Source modelling of baseline and future scenarios to support analysis of the predicted impacts of the proposed 'worst case' discharge regimes on:

- Water quality (Sydney Water, 2021a)
- Hydrology (Aurecon, 2021) and
- Ecological waterway values (CT Environmental, 2021).

These reports inform Sydney Water's assessment of potential environmental impacts and LVA.

The modelling describes the expected changes from the current baseline (A) and compliant baseline (B) to the future scenarios (C1, C2 and C3). The analysis of the modelling outputs allows comparison between the simulated discharge regimes, and informs recommendations on preferred future management approaches.

Key outcomes

The modelling of future scenarios predicts greater volumes of **discharge from the WRP**, as well as increased nutrient loads and increased frequency of discharge, but a decrease in the loads of bioavailable nitrogen discharged. The average annual simulation for future scenario C2 show that relative to the current scenario (A) and the EPL compliant scenario (B) there are:

- Increased volumes discharged (2.1 times current average annual discharge volume, 2.4 times discharge for the EPL compliant scenario), volumes in Table 3-3.
- Increased frequency of discharge (from an average of 153 days per year current (or 110 days per year for EPL compliant scenario) to an average 183 days per year), frequency (%) in Table 3-3.
- Increased TN load (1.3 times current average annual discharge TN loads, 1.5 times discharge for the EPL compliant scenario), loads in Table 3-6.
- Increased TP load (2.0 times current average annual discharge TP loads, 2.4 times discharge for the EPL compliant scenario), loads in Table 3-6.
- Decreased bioavailable NOx (0.4 times current average annual discharge NOx loads, 0.5 times discharge for the EPL compliant scenario), loads in Table 3-6.

- Decreased concentrations in treated water (0.6 times TN conc discharged in the current scenario (reflecting average conditions in recent years), 0.2 times the NOx conc discharged in the current scenario), concentrations in Table 3-2.
- Decreased concentrations in treated water relative to the 50%ile EPL 10555 limits with additional treatment:
  - future TN concentrations discharged at 40% of current EPL 50ile (6 mg/L)
  - future TP concentration 25% of current EPL 50%ile (0.2 mg/L).

In **Stonequarry Creek (N911):**

- Median and mean TN concentrations in the future scenarios are similar to the current scenario (A), but the median increases relative to the compliant baseline (B)
- Mean NOx concentrations decrease for the future scenarios relative to the current scenario and are similar to mean concentrations for the compliant baseline (B). Median NOx concentrations for C2 are similar to the baseline scenarios (A and B)
- Median TP concentrations increase relative to the baseline scenarios. Mean TP concentrations remain similar across all scenarios

In the **Nepean River (N91)** small increases are

- Median and mean concentrations are similar to the current scenario (A) for future scenarios (C1-C3). Median TN concentrations increase for future scenarios relative to the compliant baseline (B), but the mean is similar.
- The highest NOx concentrations in scenarios A and B are reduced for the future scenarios due to additional treatment, reducing the probability of exceedance for concentrations above 0.3 mg NOx/L. Mean and median NOx concentration decrease for future scenarios relative to the current scenario (A) and are similar to the mean for the compliant scenario B.
- Mean TP concentrations are similar across scenarios. Median TP concentrations increase slightly relative to current scenario (A) and compliant baseline (B) due to increased frequency of discharge.

The **WRP contributions** to nutrient loads can be described with comparison to nutrient loads simulated at N911 B upstream of the WRP discharge point. The baseline scenarios simulate that the mean annual TN and NOx loads from the WRP are approximately 20% of the loads at the upstream water quality monitoring site. In the future, TN loads from the WRP increase to just over 30% of the average annual loads at N911 B. With additional treatment proposed, the **bioavailable NOx load is predicted to decrease to 8% of the load at the upstream waterway site**. For TP, loads are expected to increase from 5% to 10% relative to the load from the catchment.

The WRP discharge relative to Nepean River loads at N92 are relatively small in the future (3-6% of loads at upstream Nepean site N92). The loads of TN and TP are expected to be slightly higher in the future, while the **NOx load decreases as a proportion of the loads in the Nepean (from 10% to 4% in the future).**

The **discharge regime** modelling highlights the need for flexibility in licencing for this reuse scheme. The year to year variability in creek flows is extreme, with a four fold increase in flows in a wetter year compared to a drier year within the time series. The extremes that limit irrigation reuse result in higher water levels in the storage dams and an increasing challenge to discharge within optimal discharge rules relative to creek flow thresholds. The model predicts how often discharge needs to occur due to dam levels being elevated. The need for flexibility is identified even in the modelled ‘compliant scenario’ B, and to an increasing degree for the future scenarios with increasing occurrence of ‘Spill Prevention Discharge’.

The model scenarios provide information to support the assessment of management options at Picton and presents some insights that can improve our understanding of the complex catchment processes and operations the treatment plant to guide decision making to improve future ecological outcomes.

1 Introduction

1.1 Background and context

Sydney Water engaged Alluvium Consulting to undertake flow and water quality modelling of the Stonequarry Creek catchment, the Picton Water Recycling Plant (WRP) and the impact of discharges from the Picton WRP on both Stonequarry Creek and the Nepean River (near Maldon Weir) which was completed in November 2020. Subsequent to this work, ecological constraints limit the scenarios simulating direct discharge to the Nepean River and failure to secure reuse agreements with nearby farms requires a new ‘worst case’ scenario to be proposed without addition reuse represented in the model, and discharge maintained in Stonequarry Creek.

Sydney Water have refined the scenarios for the Licence Variation Application (LVA) and rerun the models with revised parameters to further evaluate the operation of the Picton WRP and minimise the impacts to receiving waters. The Source catchment and river network model (eWater) has been used to understand the effluent management options for the Picton WRP over different time frames, particularly understanding current and future management of effluent discharge and reuse options.

The previous modelling report described the model build, calibration and previous scenarios assessed, Picton WRP and Stonequarry Creek – Evaluating flow and water quality (Alluvium, Nov 2020). The previous modelling report is available as one of the Specialist Studies supporting Sydney Water’s Review of Environmental Factors - Picton Treatment, Reuse and Discharge (REF), (Sydney Water, Nov 2020), https://www.sydneywatertalk.com.au/pictontreatment

The previous modelling report includes description of:

- **Available data** to describe the catchment, waterways and treatment plant operation (spatial and time series information for a range of parameters like creek flow, water quality, rainfall, wastewater inflows, dam storage levels, reuse volumes, and discharge volumes)
- The **model build process** (catchment delineation, land use analysis, calibration to key creek flow and water quality monitoring locations, and representation of the Picton WRP inflows, treatment, storage, reuse and discharge)
- **Model calibration and validation** (comparison of the simulation against observed data for a calibration scenario using 2.7 ML/d inflow corresponding to inflows in the 2014-2018 period, statistical characterisation of the adequacy of the model, suitability to simulate the system).

This addendum modelling report (May 2021) considers refined scenarios due to changes since the November 2020 report (see Section 2.1). including:

- The scale of reuse has been reduced (no additional reuse on nearby farms simulated)

- An additional 'EPL compliant' baseline included, as well as the 'existing baseline' allow contrast for future scenarios with impacts permitted under the current EPL.
- Discharge is simulated only at the existing Stonequarry Creek discharge location (not directly to the Nepean River)
- Different discharge regimes are considered (varying creek flow thresholds, discharge as a proportion of creek flow and frequency of discharge)
- Refinements were made to better simulated bioavailable nutrient concentrations in Stonequarry Creek with correlation to monitored data in 2014-2020.

1.2 Purpose of this report

This report outlines the

- Updated effluent management scenarios supporting Sydney Water's Licence Variation Application and
- Model outputs and implications

The report aims to provide confidence in the appropriate use of modelling as a tool to inform management strategies and the environmental approval process to change 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 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.

1.4 Modelling limitations

The key monitoring and modelling locations for this study (Figure 1-1) are in the lower part of Stonequarry Creek near its connection to the Nepean River between Maldon Weir and Maldon Bridge. The Source model represents the processes in the upstream catchment (Figure 1-2).

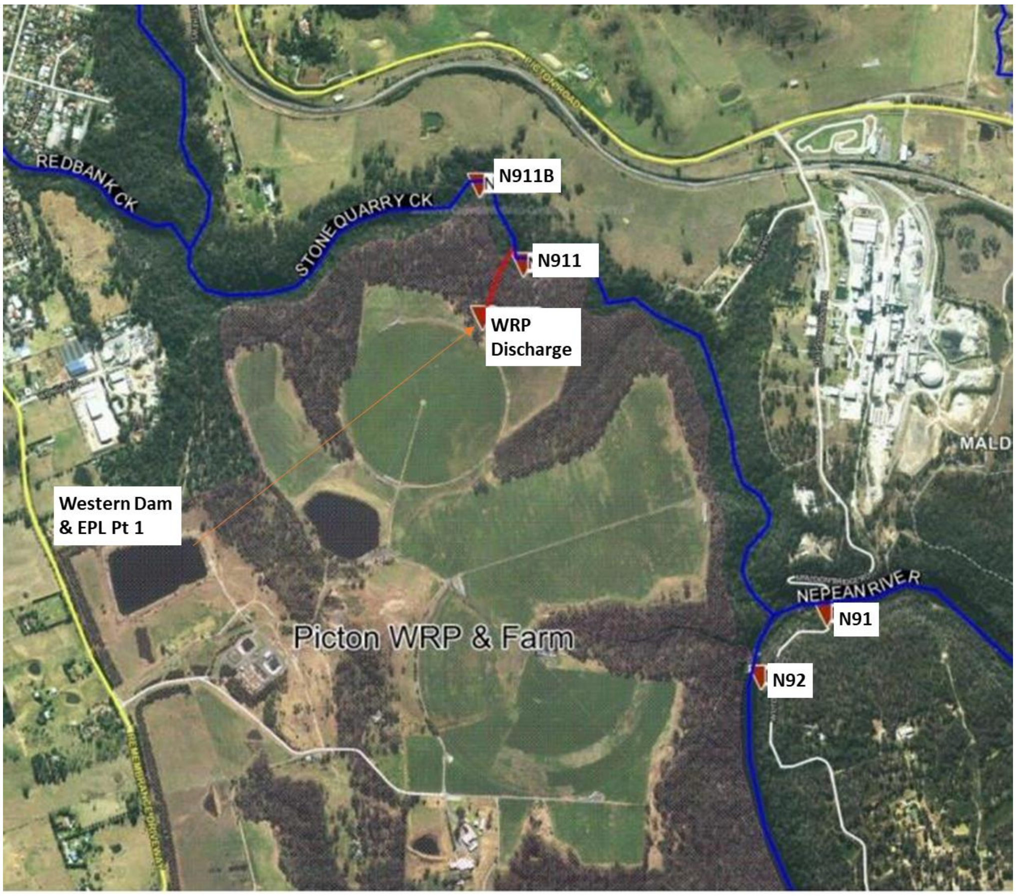

Figure 1-1 Key monitoring and modelling locations in Stonequarry Creek and Nepean River

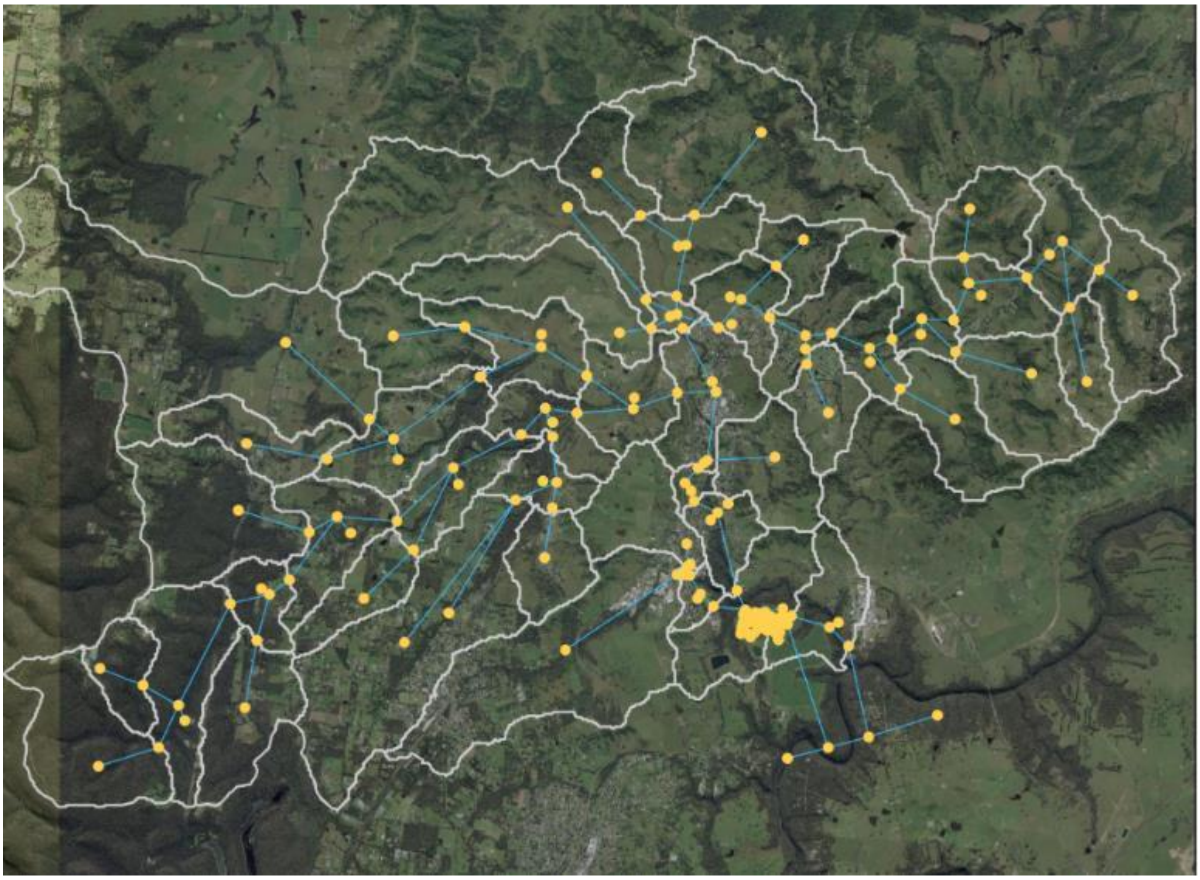

Figure 1-2 Source model Stonequarry Creek catchment representation with ‘nodes and links’

Models are, by necessity, a simplified representation of reality. Flow gauging and water quality monitoring data also have limitations with regards to representations of “points of truth” – as they can only capture conditions at the time of observation that may vary at other times (e.g. changes in flow ratings, ambient vs event sample collection). Statistics vary considerably when the time period changes (particularly when more or less wet weather periods are included).

Statistics for a model will not match statistics for monitoring data, simply because observations are usually at a much lower temporal frequency than that produced by a model, or the model simplifications cannot fully capture all of the likely variability expected in real world systems, however if the processes that the model aims to represent are adequately represented, the model can be used to predict future trends noting the assumptions and limitations of the model and data.

Table 1-1 Variety of complex processes that the model aims to simulate and indication of challenge to simulate (red-green)

Catchment	Waterway (upstream)	Treatment plant	Dams and Reuse	Discharge	Waterway downstream
Rainfall	Typical creek flows	Typical inflows	Typical irrigation rates / usage	Typical discharge	Discharge + typical creek flow
Catchment area	High creek flows	High inflows	Dam water levels	Wet weather discharge	Discharge + high creek flows
Impervious areas	Very low creek flows	Exceptional inflows	Exceptional reuse conditions	Exceptional discharge events	Discharge + very low creek flows
Soil parameters	TN concentrations	TN concentrations	Operational rules for discharge	TN concentrations	Mass balance for TN concentrations
Dams	NOx conc	NOx conc	Transfer between dams	NOx conc	Mass balance for NOx conc
Groundwater	TP conc	TP conc	Evaporation	TP conc	Mass balance for TP conc
Runoff	SRP conc	SRP conc	Seepage	SRP conc	Mass balance for SRP conc
Stormwater pollutants	Dissolved oxygen	Infrequent spikes in pollutants	Natural decay in dams		Dissolved oxygen
Sewer overflows	Temperature				Temperature
Unexpected point source contaminants	Metals, sediment and other parameters	Unexpected inflow contaminants			Metals, sediment and other parameters

The Source model aims to capture the complex and varied processes within the catchment and is a 'lumped conceptual' model, in that it 'lumps' key rainfall runoff and pollutant generation processes to the subcatchment scale, using a conceptual representation of the processes that are the major influences on these. There are multiple factors (known and unknown) that impact the flow gauge and water quality measurements. The quality of various available data sets is carefully considered but there is no 'single point of truth', in that all observations and model results are subject to limitations, assumptions and compromises around what they are intended to represent.

Ultimately, we use the models as a way of understanding the influence of the key processes, ensuring that it then can provide a representation of the observed data through calibration processes, and be used for scenario assessments where changes are made within the model to examine alternative management regimes. We therefore believe that the model results, while never able to fully replicate the observed data (because of the limitations with both the model and the data noted above), provides clear understanding in the differences between those scenarios and how we can use different management regimes to achieve the best possible outcomes for Stonequarry Creek.

Further discussion of the modelling approach and other analytes beyond those modelled in Source are described in Section 7 (Attachment 3) of this report.

2 Selecting modelling scenarios

2.1 Changes from Nov 2020 modelling report

Changes from the previous modelling (Alluvium, Nov 2020) are described below.

- **No additional reuse –** the scenarios all assume Picton Farm only (119 ha), with no additional reuse on nearby farms simulated for 'worst-case' scenarios), due to challenges in the timing to secure recycled water user agreements. Despite these challenges Sydney Water is committed to expanding reuse where feasible and cost effective (as described in the Decisions Report (Sydney Water, 2021b)).
- **Phosphorus modelling assumptions** – The discharge TP concentration was reduced to 0.05 from the 0.1 mg TP/L used in the Nov2020 model assumptions as 0.1 was found to be too conservative relative to long term trends of effluent quality. Infrequent spikes in concentration occur (below EPL concentration limits) but can't be predicted or modelled. This TP concentration is consistent across all the models. The SRP concentration in treated water from the WRP is also constant across the models (0.005 mg/L).
- **Nitrogen modelling assumptions** - The discharge TN concentration for the future scenarios was reduced to 2.5 from 3 mg TN/L, as again, 3 mg TN/L was considered too conservative relative to expected performance from new treatment infrastructure. The current scenarios (A, B) adopt 4 mg/L which is consistent with the average concentration in recent years. Future nitrate concentrations are estimated to be 0.6 mg/L given the low proportion of non-degradable TN observed in the influent to the Picton WRP. The current scenarios (A, B) use 3.2 mg/L, reflective of average concentrations in recent years. Previous modelling set NOx at 60% of TN (which would equate to 2.4 mg NOx/L for the current scenarios (slightly underestimated), and 1.8 mg NOx/L for future scenarios (overestimated) – relative to expected future treatment performance).
- **Nitrate and SRP relationships for Stonequarry Creek sites** – a regression calculation was done using flow and water quality information at N912 and N911B to better reflect the trends for bioavailable nutrients from the available information. Further details are included in 5 – Attachment 1). The functions used are:
    - N912 NO x 0.0496 * Stonequarry Creek Flow ^0.5085
    - N911 B NO x 0.0652* Stonequarry Creek Flow ^0.295
    - N912 SRP 0.0091* Stonequarry Creek Flow ^0.1777
    - N911 B SRP 0.0047* Stonequarry Creek Flow ^0.1806
- **Time series (2010-2018)** - The time series was reduced to just under 10 years (Mar 2009-2018) from the 28 year simulation run for the REF (1991 – 2018). The shorter time series results in higher average discharge than for the longer period (greater proportion of higher rainfall years in the time series). The 2010-2018 period reflects improved Nepean River water quality concentrations relative to a longer time period and prior to e-flows. The model time series duration is adequate to describe the expected variability year to year. The shorter time series allowed many more discharge regime configurations to be considered (shorter run time and data processing).

- **No scenarios discharging to Nepean River –** the scenarios all use the existing discharge location on Stonequarry Creek to mitigate potential impacts on the threatened Sydney Hawk Dragonfly (MPM, 2020).
- **Discharge regimes** – potential discharge regimes for the 'worst case' discharge volumes are proposed.

2.2 Inflows to Picton WRP

The calibrated model can be used to consider the impact of future inflows (4+ ML/d), or assess performance when inflows were less than current levels (2.25 – 2.7 ML/d). Table 2-1 provides a description of the inflows considered for the modelling scenarios. Further scenarios have considered 5.5 ML/d inflow (inflow predicted in 2046).

Table 2-1 Selecting inflow to WRP for model scenarios

WRP Inflow	Approx period	Scenario	Description
2.25 ML/d	2010 - 2014	Scenario B	'EPL compliant' baseline has lower inflow than the 'current / existing baseline'. The 'EPL compliant' baseline was included, as the 'current baseline' and assessed period of monitoring data include discharges from the Picton WRP that breach the requirements of the current EPL (discharge in lower creek flow conditions, <8 ML/d).
2.7 ML/d	2014 - 2018	Scenario A	The current calibration scenario uses 2.7 ML/d for the dry weather flow in the Picton WRP. This was the inflow for the calibrated model, and reflects the approximate inflow for the period 2014 – 2020 which is the period that also has regular water quality data available in the receiving waterways.
4 ML/d	~ 2024 - 2028	Scenario C	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.

2.3 Infrastructure to comply with current EPL when inflow is 4 ML/d

A scenario was developed to consider the infrastructure required to be compliant with the current precautionary discharge regime in EPL 10555, with 4 ML/d inflow to the WRP. To prevent breaches of the EPL (across a 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 active draw down volume available in our current dams).

- Large pump (30 ML/d capacity) to transfer water to an offsite storage (5-10 times the size of the pump proposed for the reuse scheme being designed now)
- Offsite irrigation areas (180 ha) in addition to the current irrigation area – an additional 1.5 times the irrigated area on the Picton Farm now.

A change is required to the current EPL rules that restrict discharge to Stonequarry Creek. The infrastructure requirements to comply with the current EPL when inflows are 4 ML/d are impractical to deliver (size of dam storages needed, transfer pump capacity, and irrigation area) cost-effectively.

Greater flexibility is required for discharge, with a change to the EPL. Without some flexibility - transfer from the catchment would be required to ensure compliance with the current EPL. Increasing reuse (even with a change to the EPL) will still be important to minimise risks with a 'worst case' scenario, and to reduce the nutrient and sediment loads discharged, concentrations in Stonequarry Creek and the frequency of discharge.

2.4 Additional reuse

Sydney Water has not yet secured agreements with nearby farmers for reuse, and the selected LVA scenarios are based on the assessment of 'worst case' scenarios with no additional reuse. Modelling runs below provide an indication of how discharge to the creek is expected to decrease if larger reuse areas become available. Sydney Water is continuing to pursue additional reuse.

Table 2-2 Model discharge from Picton WRP for scenarios with additional reuse

Metric	Scenario A 2014-2020	Future Scenario C Worst case	Future with 60 ha extra reuse	Future with 120 ha extra reuse
Volumes and Frequency		**Note ***		
Mean Annual Flow (ML/yr)	451	915	642	417
Mean Daily Flow (ML/d)	1.24	2.51	1.76	1.14
Mean Annual Discharge Frequency (% of time)	42%	70% *	44%	28%
Mean Annual Discharge Frequency (days/yr)	154	254 *	162	102
Loads				
Mean Annual TN Load (kg/yr)	1,803	2,330	1,606	1,042
Mean Annual TP Load (kg/yr)	23	47	32	21
Mean Annual NOx Load (kg/yr)	1,400	546	385	250
Mean Annual SRP Load (kg/yr)	2.3	4.7	3.2	2.1

* Note - Lower frequency of discharge possible with adjusted regime (C2)

2.5 Additional treatment

The model runs for this report (May 2021) have simulated lower TN, NOx and TP than in the previous 'conservative' simulation presented in the Nov 2020 modelling report as noted in 2.1 above. The adopted model parameters as outlined in the table below are those we anticipate can be achieved with the proposed treatment investment. These concentrations represent a **significant** reduction relative to current EPL concentration limits.

Further work is underway with a wetland trial and a macroalgae trial to understand the opportunities for even lower nutrient concentrations, and the best configuration for low energy treatment technologies that may also be able to reduce chemical use. Early results are promising, with a two-year trial underway in 2021-2023.

Table 2-3 Discharge water quality and model assumptions for additional treatment

Metric	Current requirements EPL 10555	Scenario A Existing and Scenario B 'compliant'	LVA 2021 Future Scenario C	Potential Future with low energy treatment options
Concentrations	**50%ile limit / 90%ile**			**TBC – trials in 2021-23**
Discharge TN Conc. (mg/L)	6 / 10	4	2.5	< 1.5 mg/L
Discharge TP Conc. (mg/L)	0.2 / 0.4	0.05	0.05	< 0.05
Discharge NOx Conc. (mg/L)	-	3.2	0.6	< 0.3
Discharge SRP Conc. (mg/L)	-	0.005	0.005	< 0.005

Why not Reverse Osmosis?

It would be possible to discharge lower concentrations with reverse osmosis treatment, however this technology uses more energy, produces a brine stream that can be difficult to manage (likely to require transfer out of the catchment – to the ocean - beyond 1-2 ML/d RO capacity) and is high cost. While the Stonequarry Creek waterway assessment indicates that biological indicators have not deteriorated from discharges between 2014-2020, Sydney Water aims to lower the nutrient concentrations with alternative technologies and support additional reuse where feasible to reduce the loads discharged from Picton WRP.

2.6 Discharge location

The Source model allows discharge to be simulated and the expected impact on water quality to be quantified where the model routes the flows and water quality constituents from upstream sources to the new location in the node-link hydrologic network (the network which represents the waterway within the model).

The scenarios represented in the previous 2020 modelling report (Alluvium Nov 2020) included discharge directly to the Nepean River (Figure 2-1). The refined scenarios for the Licence Variation Application - LVA (Chapter 3 of this report), represent discharge at the current location in Stonequarry Creek (with alternative regimes considered). Direct discharge to the Nepean River is not proposed at this time due to the presence of the threatened Sydney Hawk Dragonfly found in survey work in Dec 2020.

Other locations on the Nepean River were considered in refining a concept for the location downstream of Maldon Weir. A variety of challenges remain for alternative discharge locations (including swimming and other recreational values, geological stability and difficult terrain for infrastructure construction, risk to pipelines in flood conditions, impounded water upstream of Maldon Weir, indigenous heritage, ecologically sensitive sites).

Figure 2-1 Current discharge location (Stonequarry Creek) and Nepean River site considered

2.7 Discharge regimes

2.7.1 Current discharge regime

The current discharge regime consists of the EPL compliant Precautionary Discharge and an Emergency Operating Protocol that has been used as required over recent years due to challenges with increased inflows. These operating conditions were represented in the Nov 2020 modelling report in detail, demonstrating the discharge logic that determines what discharge should occur at any time based on dam levels and creek flow (Further details on Discharge rules and logic statements adopted in the model to represent them are included in Attachment 2 of this report).

- **Precautionary discharge:** The precautionary discharge in EPL 10555 allows discharge from the WRP equivalent to 25% of the creek flow (for creek flows above 8 ML/d). This allows release of water from the WRP at times when there are contributions of runoff and associated water quality constituents from the upstream catchments. Discharge in higher flows minimises the magnitude of impact on creek water quality.
- **Emergency Operating Protocol (EOP):** The Emergency Operating Protocol aims to release water from the storage dams depending on the water level in the dams, so that uncontrolled spill from the dams is avoided. At these times, the discharge does not comply with the Precautionary Discharge criteria (discharge occurs when creek flows are below the 8 ML/d flow threshold). Discharge rules are triggered by defined dam levels with discharge from the WRP equivalent to 100% of creek flow for creek flows above 2.5 ML/d. If dam levels are even higher, discharge occurs irrespective of the creek flow (and at even higher proportions of creek flow, exceeding 100% of creek flow in worst case conditions).

2.7.2 Future discharge regime options

Potential discharge regimes were assessed systematically by varying the numeric value of parameters in the same model structure developed and calibrated previously described in November 2020 report. More than 50 model runs were completed.

The key parameters that were varied included:

- Discharge as a proportion of creek flow
- Creek flow thresholds for discharge from dams and
- Dam storage level triggers for discharge.

Model outputs were compared between simulations and the parameters adjusted to optimise the resulting simulated outcomes for key waterway metrics:

- Discharge volume – minimised discharge (ML/y) for the simulation period (annual average)
- Discharge Frequency – minimised frequency of discharge (days/y) for the simulation period
- Increase in TN conc downstream – minimised increase in simulated TN concentration downstream of the discharge (mg/L) relative to upstream concentrations compared using an exceedance curve showing the proportion of time and magnitude of increase in TN
- Frequency of discharge in lower creek flows– minimise occurrence (days/y) of 'excess' discharge when dam levels are elevated occurring beyond the simulated discharge rules (Spill Prevention Discharge).

Table 2-4 Key model parameters for discharge regime selection

Discharge rule model parameters		
Description	Discharge as proportion of Stonequarry Creek flow	Creek flow threshold for discharge
Current EPL	25 %	8 ML/d
Minimum simulated	0 % (days with no discharge)	0.5 ML/d
Max simulated	200% (in storm flows)	5+ ML/, 8+ ML/d
Spill Prevention Discharge	Higher proportion than scenario discharge rules for that flow range	Discharge below the target threshold when dam water level is high. Mostly predicted in very low flows (0 – 0.5 ML/d)

Table 2-5 Key model outputs for discharge regime selection

Modelled outputs and waterway metrics				
	Discharge Volume	**Discharge Frequency**	**Increase in TN conc downstream**	**Frequency of discharge in lower creek flows**
Description	ML/y	days/y	Difference in TN (mg/L)	days/y excess discharge
Importance of metric	Volume linked to loads and relative magnitude of potential impacts	Frequency linked to temporal duration of potential impact	Concentration increases are linked to the magnitude of potential impacts	Discharge in lower creek flows increases magnitude of potential impacts
Current EPL	Limit linked to EPL load limits	Dependent rainfall etc. each year	Elevated in wet weather conditions	Not permitted in current EPL
Approach for analysis Limitations / Findings	Minimise mean annual discharge volumes Little difference even for extreme range of regimes simulated	Consider ‘book-end’ scenarios for frequency, from minimum (50% of the time) to regular (90%) for	Minimise increase in TN with exceedance curves indicating range and magnitude across the time series.	Minimise frequency of ‘spill prevention’ discharge in unfavourable creek flow conditions. Regimes were unable to completely limit discharge to the simulation ‘rule’ for the whole time series.

Further detail of the operating rule parameters that were varied:

- **Minimum creek flow** for water to be discharged
  - current EPL has 8 ML/d of flow in Stonequarry Creek threshold,
  - alternatives tested included 0.5 ML/d, 3 ML/d, 5 ML/d, 8 ML/d
- Additional **creek flow thresholds** for altered regime
  - current 'Emergency Operating Protocol' has a threshold at 2.5 ML/d and if dam storage levels are elevated, discharge at '100%' of creek flow is triggered
  - alternatives tested included 0.5 ML/d, 3 ML/d, 5 ML/d, 8 ML/d
- **Volume discharged** (fixed discharge volume or discharge proportion related to creek flow)
  - current EPL permits 25% ratio (2 ML/d discharged when creek flow is above 8 ML/d),
  - current 'Emergency Operating Protocol' discharges 100% (1:1) above 2.5 ML/d creek flow and also 200%+ at any flow range if dam levels are elevated to prevent dam spills
  - alternatives tested included 10%, 25%, 50%, 100%, 200%, 200%+ (worst case conditions) as well as scenarios with a fixed discharge volume for high dam levels: 1 - 8 ML/d.
- **Dam level triggers** for discharge to occur
  - Storage capacity in dams similar to current operation that ensures water is available for reuse, but also reserves an 'air gap' to accommodate wet weather inflows
  - Minor alterations with limited benefits in the model simulation. Operations balance the need to reserve an air gap for high inflows in wet weather and stored water available for reuse
- **Maximum** daily discharge
  - Current EPL has 14 ML/d maximum. A 15 ML/d maximum was also simulated.

The iterations aimed to capture "book-ends" that would allow the potential implications of the discharge regime to be understood through assessment of the simulated water quality impacts, hydrology, ecology and expected changes to broader waterway values.

The discharge regimes are 'intermittent' releases from the Western storage dam within the Picton treatment water recycling plant (rather than continuous discharge that occurs at most treatment plants).

Table 2-6 Rationale for selection of discharge regimes for further analysis

Scenario	Characteristics relative to other regimes simulated
'EOP like' C1 (chapter 3)	• Maintains the current EPL conditions and rules for discharge of excess treated water that are similar to those currently in place ('Emergency Operating Protocol' allows a higher proportion of discharge relative to creek flow when dam levels are elevated) • Provides comparison for other future scenarios with varying frequency of discharge (70% of the time), proportion of discharge (relative current discharge rules), increase in TN concentration downstream and occurrence of excess discharge

Minimise frequency of discharge C2 (chapter 3)	• Minimise the frequency of discharge by increasing the proportion of discharge when creek flows exceed 5 ML/d. Simulated treated water discharge as proportion of creek flow: 200% 'storm' discharge. • Frequency of discharge (on average ~ 50% of the time). Iterations showed lower frequencies of discharge did not occur – increasing restrictions on when discharge occurs resulted in more times when dam levels were elevated and 'spill prevention discharge' was required in lower creek flows. • Increase in TN concentrations downstream – iterations showed alternative discharge rules related in more periods when a greater increase in TN was observed downstream (linked to greater volumes discharged in lower creek flow conditions)
Minimise proportion of discharge C3 (chapter 3)	• Minimise the proportion of discharge (limited to 50% most of the time) by increasing the frequency of discharge. Discharge of treated water when creek flows exceed 0.5 ML/d. • Frequency of discharge (on average ~ 90% of the time). A constant discharge (with no lower bound creek threshold) was not selected as the greatest magnitude of impact on water quality occurs in very low flows conditions. With existing dam storages and 119 ha of reuse on the Picton Farm, the existing infrastructure and operations can reduce the frequency of discharge when creek flows are very low. • Simulated treated water discharge as proportion of creek flow: 50% 'regular' discharge. Iterations showed with lower proportions of creek flow (10%) the storage dam water levels were more frequently elevated and 'spill prevention discharge' occurred more often without the fixed ratio to creek flows. This results in higher TN concentrations downstream of the discharge.

3 LVA Scenarios (A, B, C1, C2, C3) and model results

3.1 Scenarios for LVA assessment

Five scenarios (A, B, C1, C2, C3) are assessed in the Licence Variation Application for Picton.

Scenario A represents the 'current' 2014-2020 modelled discharge conditions from the Picton WRP with median inflow of 2.7 ML/day to the Picton WRP, discharge to Stonequarry Creek, and a constant TN concentration of 4 mg/L and TP concentration of 0.05 mg/L.

Scenario B represents a compliant baseline – This scenario responds to concerns that the REF compared future scenarios with a baseline that was not meeting current EPL requirements. It is similar to scenario A, but with a lower inflow (2.25 ML/d) similar to conditions in 2010-2014 when the scheme was (mostly) compliant with EPL10555. "Spill prevention discharge" is still simulated to occur.

Scenario C_SQ_0 represents a worst case future outcome with no additional reuse (Picton Farm only, 119 ha) and an increase to the median inflow to the Picton WRP to 4 ML/day. Discharge is to Stonequarry Creek when dam levels are elevated under differing discharge rules for Scenario C1, Scenario C2, Scenario C3. A constant TN concentration of 2.5 mg/L is used to reflect future treatment levels, with Nitrate at 0.6 mg/L. TP is the same in each of the scenarios (and reduced from previous modelling as described in 3.2).

Table 3-1 Description of modelled scenarios

Scenario name & rationale	Scenario description
Scenario A 'existing' baseline	The 'existing' baseline (Scenario A) is the calibration model that uses 2.7 ML/d for the dry weather inflow to the Picton WRP. The calibrated model reflects the inflows, dam levels, reuse and discharge observed for the period 2014 – 2020 which also corresponds to the period that has regular water quality data available in the receiving waterways. Refer to Part A Waterway Assessment of existing conditions (Sydney Water, 2021). Discharge: precautionary and EOP.
Scenario B 'EPL compliant' baseline	'EPL compliant' baseline has lower inflow than the 'current / existing baseline'. 'EPL compliant' baseline aims to represent the period prior to discharges from the Picton WRP that breach the requirements of the current EPL (i.e. 'Emergency Operating Protocol' – EOP discharges). In the modelled timeseries there are some extreme conditions that result in 5% of the time where discharge occurs despite the significantly reduced inflow. Inflow of 2.25 ML/d occurred around the period 2010 – 2014 and did not result in discharge beyond the EPL conditions in that climatic period.

C Scenarios		*Future scenarios (for the short to medium term) which consider 4 ML/d inflow. These are the focus of this report and for the Review of Environmental Factors and Licence Variation Application. This is the expected inflow to the Picton WRP in the period from 2024 – 2028 subject to development connections and water usage / volumes discharged to the sewer.*
Future Scenarios	**Scenario C1** ‘EOP like’	Similar operational rules to the current Emergency Operating Protocol with discharge from the Western Dam when water levels are too high. Discharge rules: ‘Precautionary’ (up to 25% of the Creek flow when over 8 ML/d) plus ‘EOP’ (3 ML/d when the Creek flow exceeds 3 ML/d, ‘100%’), with additional infrequent excess at higher dam levels to prevent overtopping the dams.
	Scenario C2 ‘less frequent’	‘Storm’ discharge only in higher creek flows (above 5 ML/d) as much as possible but limited to 200% of the creek flow (10 ML/d discharge when creek flows at 5 ML/d). Some infrequent discharge at higher dam levels to prevent overtopping the dams.
	Scenario C3 ‘less proportion of SQ flows’	‘Regular’ discharge across almost all creek flow categories (except the lowest creek flows less than 0.5 ML/d). Discharge rule for up to 50% of the creek flow when creek flows are above 0.5 ML/d). Some infrequent discharge at higher dam levels to prevent overtopping the dams.

3.1.1 Modelled discharge nutrient concentrations

The key parameters used in these scenarios are summarised below.

Table 3-2 Key input parameters for the selected model scenarios

Parameter	Scenario A Current Baseline	Scenario B Compliant Baseline	Scenario C1 SQ_0 ‘EOP’	Scenario C2 SQ_0 ‘low freq’	Scenario C3 SQ_0 ‘low prop’
Wastewater inflow volume (ML/d)	2.7	2.25	4	4	4
Irrigation area (ha)	119	119	119	119	119
TN conc. WRP discharge, mg/L	4.0	4.0	2.5	2.5	2.5
NOx conc. WRP discharge, mg/L	3.2	3.2	0.6	0.6	0.6
TP conc. WRP discharge, mg/L	0.05	0.05	0.05	0.05	0.05
SRP conc. WRP discharge, mg/L	0.005	0.005	0.005	0.005	0.005

3.1.2 Modelled discharge regimes

The modelled discharge regimes are a combination of discharge rules triggered by these flow thresholds:

- Very high flows, above 8 ML/d

- High flows, between 5 – 8 ML/d
- Medium flows, 3 – 5 ML/d
- Low flows, 0.5 – 3 ML/d
- Very low flows, 0 – 0.5 ML/d

Model outputs are tabulated below. The model period uses 2009-2018 climate data, with annual statistics for full years (2010-2018), and calculations across the time series for water quality changes (excluding 3 month initialization), extending from March 2009 – 2018.

Table 3-3 Key output results for the selected model scenarios

Parameter	Scenario A Current Baseline	Scenario B Compliant Baseline	Scenario C1 SQ_0 'EOP'	Scenario C2 SQ_0 'low freq'	Scenario C3 SQ_0 'low prop'
Inflow to WRP (ML/d)	2.7	2.25	4	4	4
'Storm' discharge rule in higher flows	25% for 8+ ML/d	25% for 8+ ML/d	25% for 8+ ML/d	200% for 5+ ML/d	50% for 5+ ML/d
'Excess' discharges low to medium flows	100% for ~2.5+ ML/d	NIL	100% for 3+ ML/d	NIL	50% for 0.5+ ML/d
Discharge frequency					
Annual discharge frequency (%)	42%	30%	70%	50%	87%
Discharge proportion of inflow					
Proportion of annual inflow (%)	46%	48%	63%	64%	63%
Discharge volume					
Total discharge to Stonequarry Creek, average annual (ML/y)	451	395	915	932	926
'Excess' discharge (ML/y)	96	0	172	1	132
'Spill prevention' discharge * (ML/y)	40	13	119	79	60
Frequency- Spill Prevention	Threshold 2.5 ML/d	Threshold 8 ML/d	Threshold 3 ML/d	Threshold 5 ML/d	Threshold 0.5 ML/d
Spill prevention discharge (days/y)	27	19	91	57	50

* **Note 'Spill prevention'** is discharge that occurs outside the stated discharge operating rules (i.e. below the lowest indicated threshold for discharge to be triggered).

The average annual discharge (Figure 3-1) has a broadly similar distribution for each scenario across the selected flow categories, with most discharge occurring in the highest creek flow category (creek flows above 8 ML/d): Scenario C2 has the most discharge in the 5-8 ML/d creek flow range, but this allows less discharge in the lower flow ranges in comparison to the other future scenarios, and even in comparison to the existing scenario for low and medium creek flows.

The frequency of 'spill prevention discharge' is shown for each year of the modelled time series (Figure 3-2), with the greatest differences between scenarios with 2018 climate data where creek flows were particularly low (annual average creek flow was 1/3 of the average for the time series). The 'compliant scenario B' simulation also shows between 10-30 days per year where the discharge rules result in elevated dam levels, and a 'spill prevention discharge' is required.

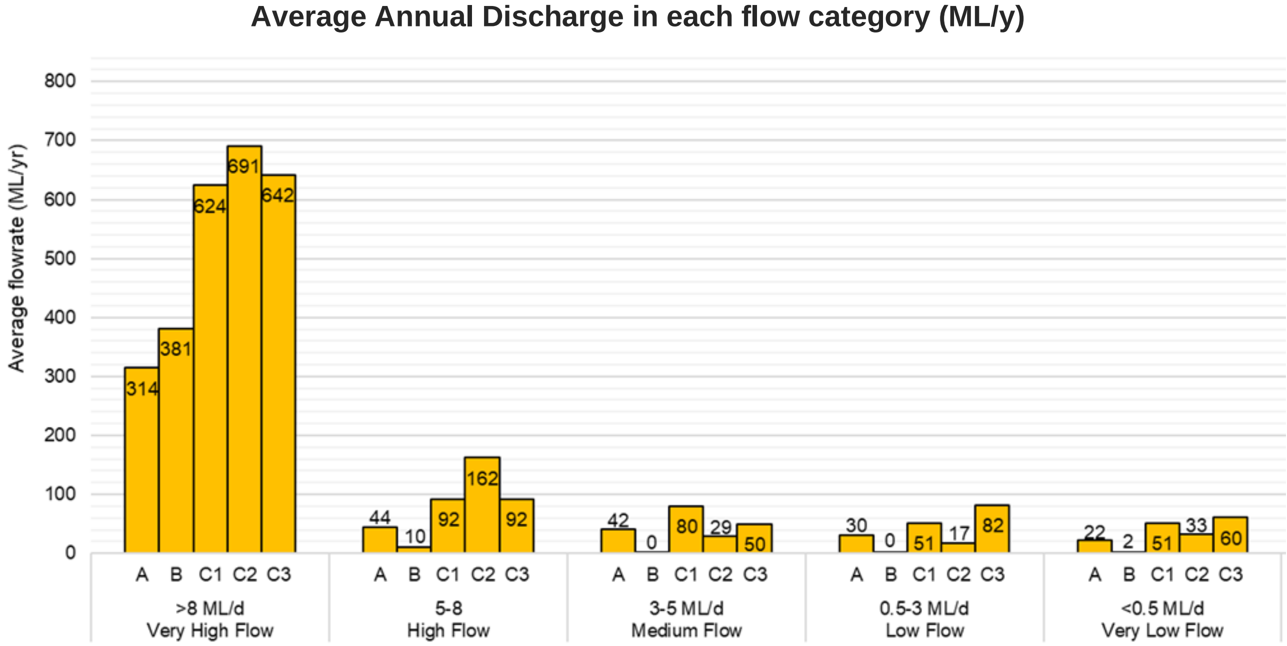

Figure 3-1 Average annual volumes discharged in each flow category for each scenario

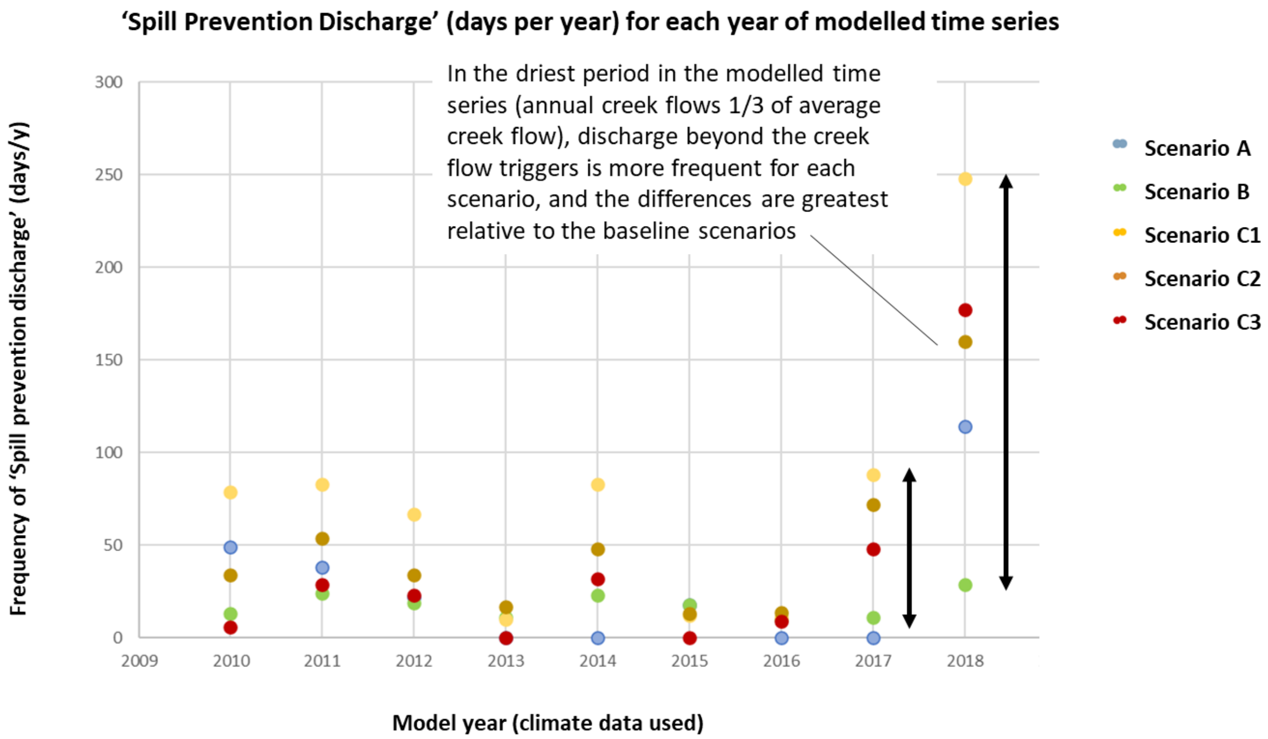

Figure 3-2 Average annual volumes discharged in each flow category for each scenario

3.2 Flows

Within the Stonequarry catchment, flows are generated upstream of the 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 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. Operation of the WRP (inflows and discharge regime) changes for each scenario run. The 'current' baseline conditions (scenario A) represent the existing case aligning to the 2014-2020 monitoring period. A 'compliant' baseline (scenario B) with lower inflow volumes and discharge under the EPL rules is also used to compare with the remaining scenarios.

Flows in the catchment are highly variable both as indicated by the observed data and replicated in the model. Discharge to Stonequarry Creek will vary according to those flows.

3.2.1 Flow - upstream of the WRP discharge point in Stonequarry Creek (N911 B)

Upstream of the WRP discharge point in Stonequarry Creek is represented by the upstream site N911B. The mean annual flow for each year of the modelled time series (2010-2018) is show in Figure 3-3. The annual flow at N911 B is described in Table 3-4 with the mean annual flow and the minimum and maximum to provide an indication of the likely variability.

A flow duration curve is also shown Figure 3-4, characterising the range and distribution of modelled flows in Stonequarry Creek.

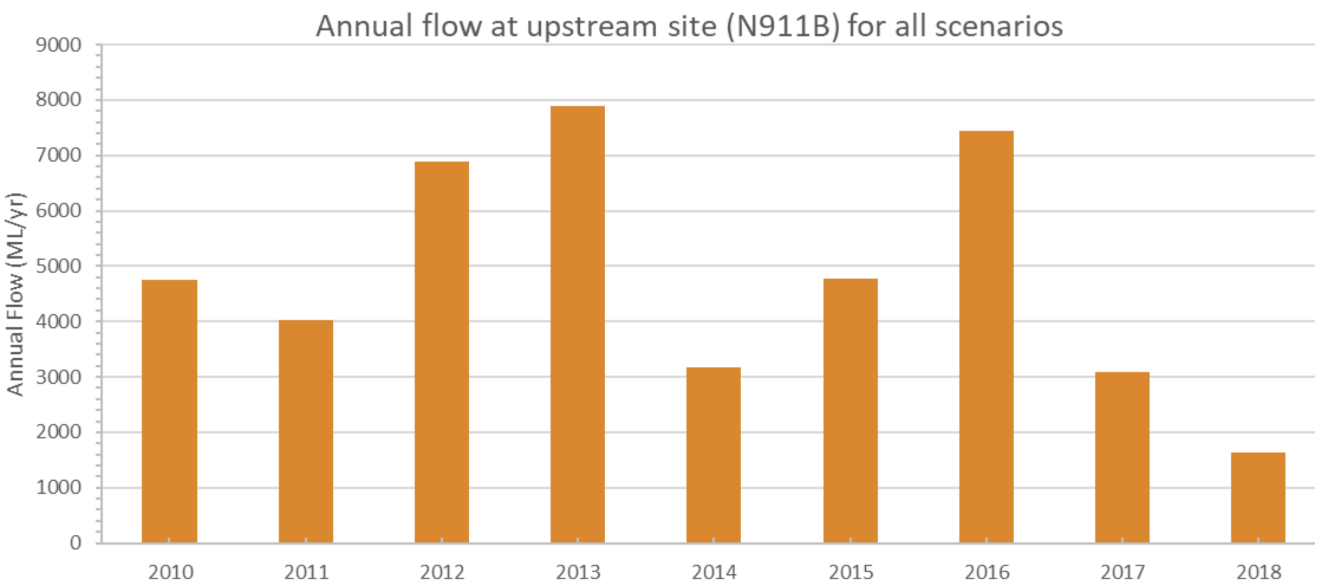

Figure 3-3 Modelled mean annual flows – N911B Stonequarry Creek Upstream of WRP discharge

Table 3-4 Modelled flows, N911B Stonequarry Creek Upstream of WRP discharge

N911B			
Metric	**All scenarios (2010-2018)**	**Lowest annual flow** (in time series)	**Highest annual flow** (in time series)
Mean Annual Flows (ML/yr)	4,848	1,634 (2018 climate data)	7,894 (2013 climate data)
Mean Annual Flow Frequency (days/yr)	365		

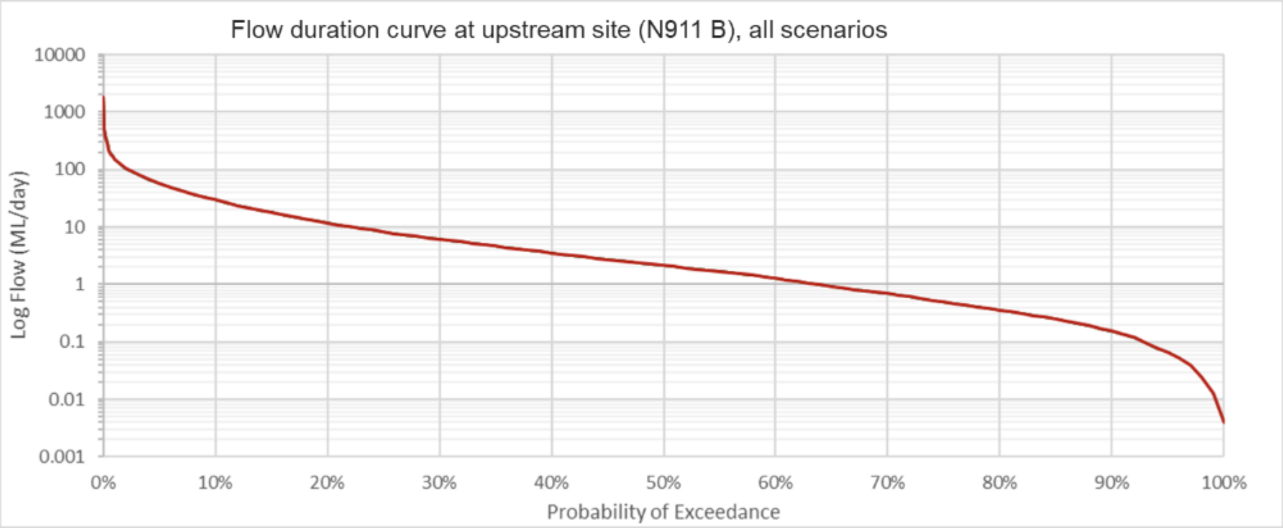

Figure 3-4 Modelled flow duration curve - N911B Stonequarry Creek Upstream of WRP discharge

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. This is to be expected given the incised nature of the stream in the lower reaches which would mean that it is likely to be intercepting groundwater seepage from the fractured rock and dominant geology and would contribute to the baseflow in the creek nearly all of the time. Annual variability is significant with wet years producing more than 4 times the annual flow of dry years (Figure 3-3, Table 3-4).

3.2.2 Flow - downstream of the WRP discharge point in Stonequarry Creek (N911)

Discharges to Stonequarry Creek from the WRP occur in all scenarios, increasing the flows observed at the point downstream of the WRP (N911). This provides an indication of the additional flow contributions to Stonequarry as a result of the WRP discharges. The monitoring location N911 is downstream of both the flow monitoring and discharge points. Comparison with the upstream results as shown above is also included for reference, Table 3-5. Year to year flow variability is illustrated in Figure 3-5 and Figure 3-6. Flow duration curves illustrate changes between scenarios across the range of flows (Figure 3-7).

Table 3-5 Modelled flows at N911 Stonequarry Creek Downstream of WRP discharge

N911 (downstream of WRP)						
Metric	**N911B All scenarios Upstream**	**Scenario A Current Baseline**	**Scenario B Compliant Baseline**	**Scenario C1 SQ_0 'EOP'**	**Scenario C2 SQ_0 'low freq'**	**Scenario C3 SQ_0 'low prop'**
Mean Annual Flows (ML/yr)	**4,848**	**5,299**	**5,243**	**5,763**	**5,780**	**5,774**
Flow Range (ML/y): min – max in 2010-2018 time series	1,634 - 7,894	1,976 – 8,383	1,875 – 8,351	2,568 – 8,847	2,523 – 8,818	2,541 – 8,834
Increase in creek flow relative to: (1) Compliant Baseline	Upstream site is the same for all scenarios	1%		10%	10%	10%
(2) Upstream site		9%	8%	19%	19%	19%
Discharge volume relative to flow range in Stonequarry		7%	6%	15%	15%	15%

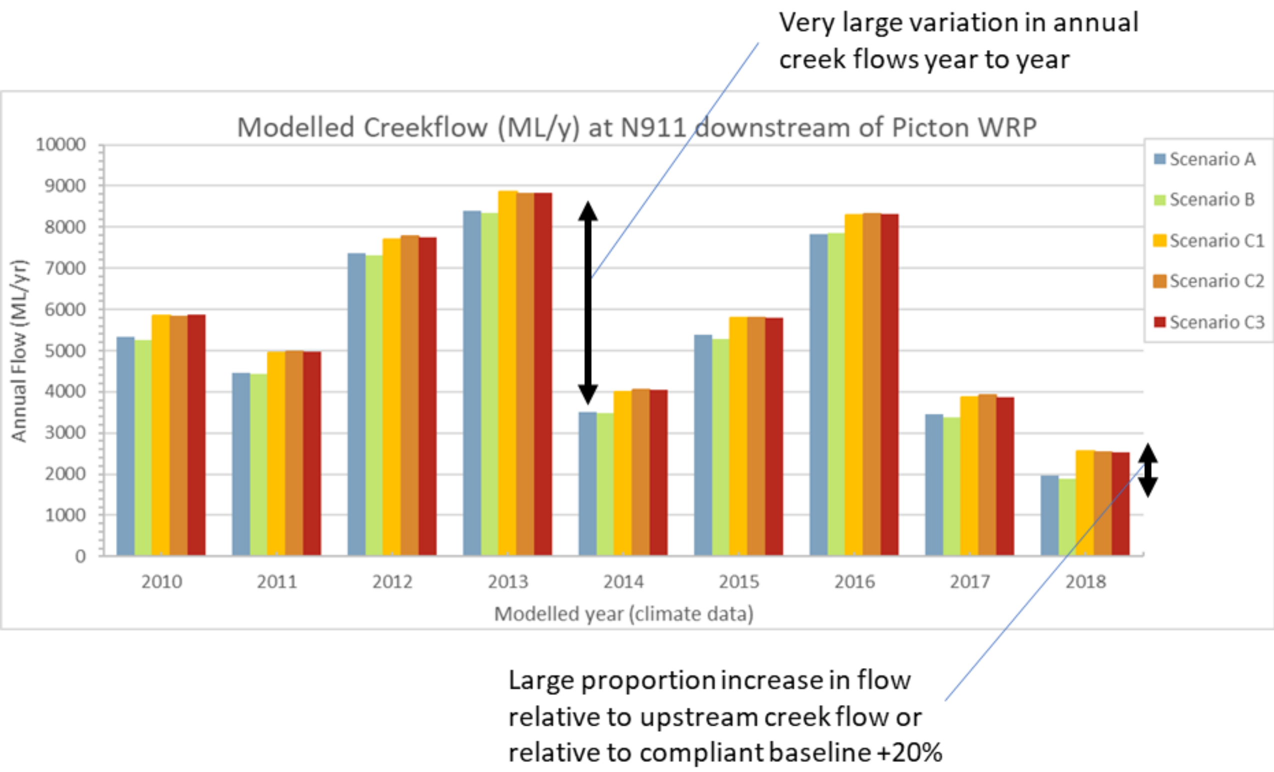

Figure 3-5 Modelled mean annual flows, N911 Stonequarry Creek Downstream of WRP discharge

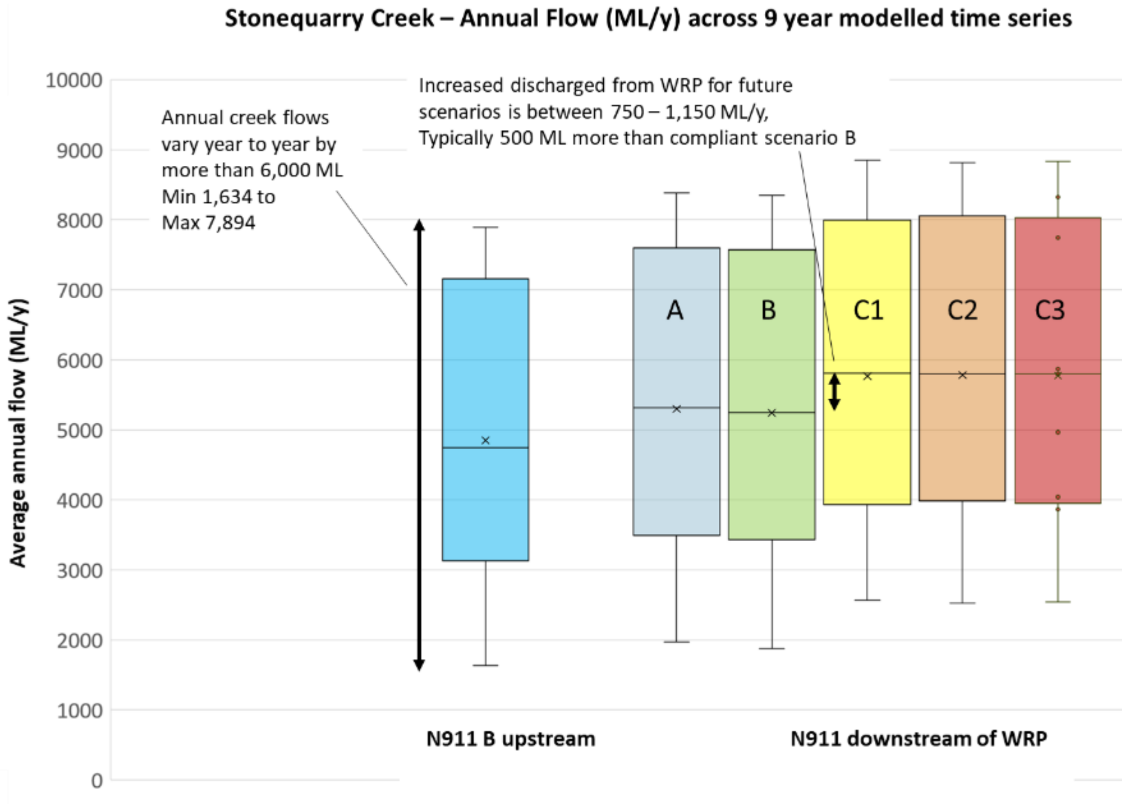

Figure 3-6 Modelled mean annual flows N911, box and whisker plots, year on year variability

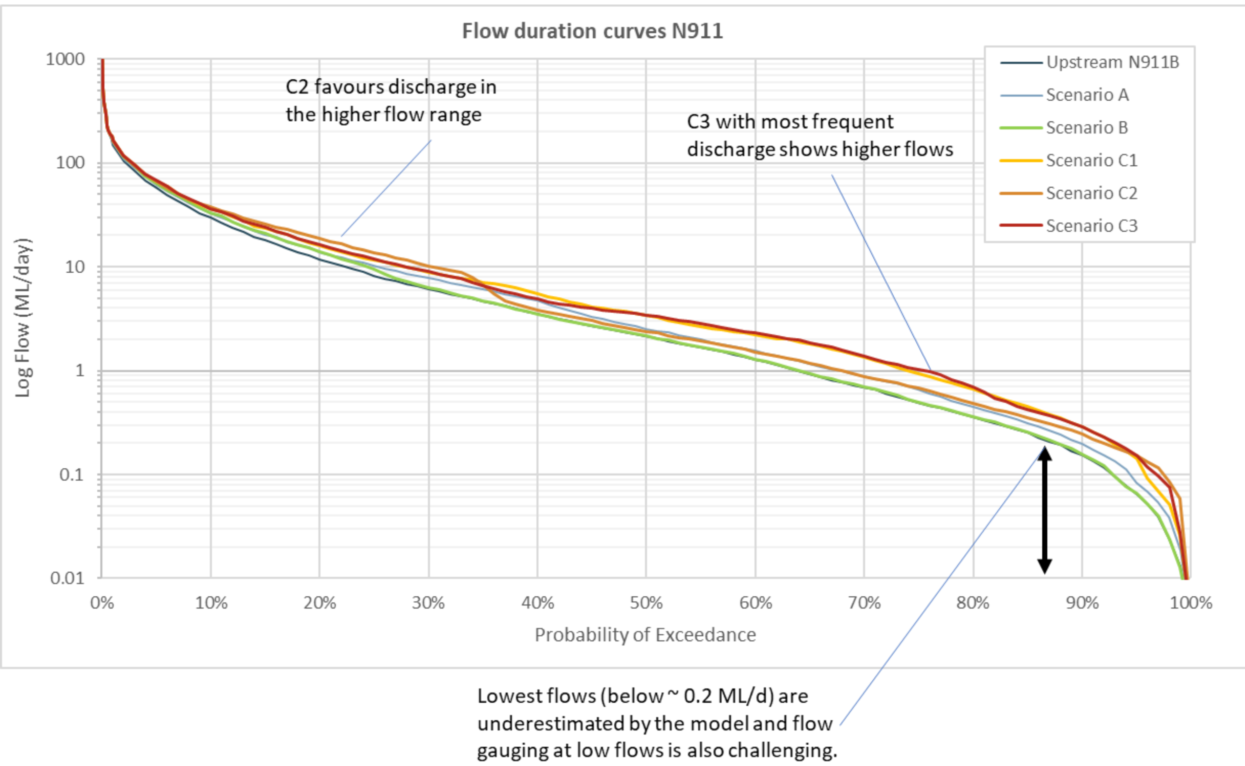

Figure 3-7 Modelled flow duration curves, N911 Stonequarry Creek Downstream of WRP

These results, and those describing the WRP discharge volumes below (Table 3-6), show that for future scenarios C1, C2 and C3 the WRP discharge is simulated as increasing mean annual flows in the creek by around 10% relative to the compliant baseline and by around 19% relative to the creek flow without discharge.

The current scenario (A) is simulated to be on average around 1% higher than the compliant baseline mean annual flow, and 9% higher than the creek flow without discharge.

Given the reuse and dam storages simulated, there will be periods of time where no discharge occurs, as noted further below.

3.2.3 Discharge from the WRP

Discharge from the WRP is shown below for all scenarios with the numeric WRP discharge modelled results (Table 3-6) and graph of year to year variability in discharge (Figure 3-8). The WRP discharge in all scenarios is the surplus flow 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 in Scenario A include both precautionary and emergency discharges. Scenario B (compliant) has sufficiently low inflow to discharge under the precautionary rules (except for 1 event in the 9 year time series). For future scenario C1, C2, and C3, discharge regimes aim to release excess water to Stonequarry Creek to minimise impact (C2 – min frequency, C3 – min proportion). The discharge rules are similar to the current operation with a link to 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 for each scenario (Attachment 2 for further information).

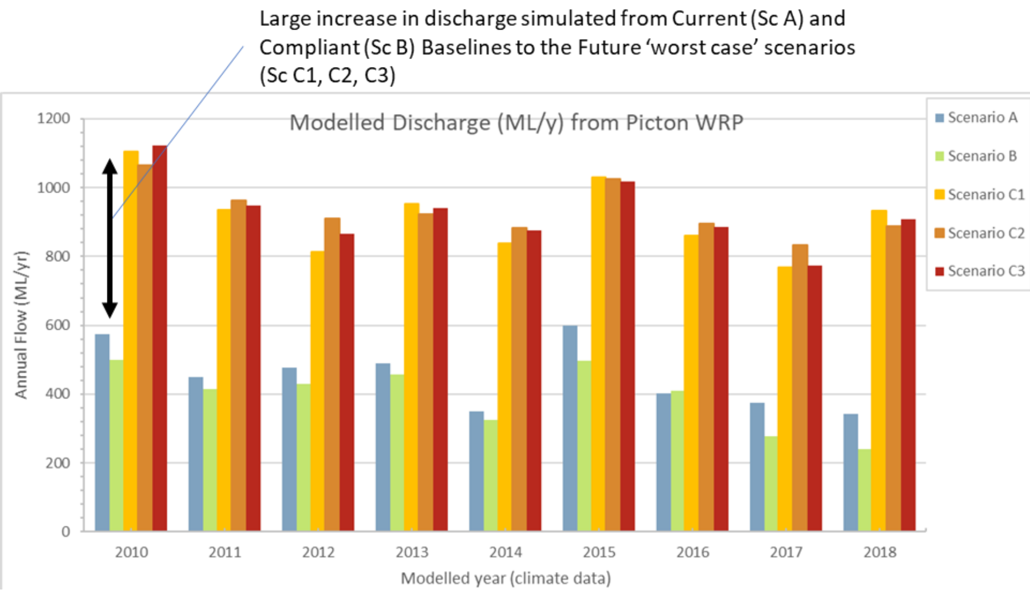

Figure 3-8 Modelled mean annual flows –WRP discharge

Table 3-6 Model outputs for scenarios – discharge volumes and loads from WRP

WRP Discharge					
Metric	**Scenario A existing**	**Scenario B compliant baseline**	**Scenario C1 EOP like**	**Scenario C2 min frequency**	**Scenario C3 min proportion**
Inflow to WRP (mean wastewater inflow)	985	820	1,460	1,460	1,460
Discharge relative to inflow (mean annual %)	46 %	48 %	63 %	64 %	63 %
Volumes and Frequency					
Mean Annual Discharge (ML/yr)	**451**	**395**	**915**	**932**	**926**
Mean Daily Discharge (ML/d)	1.24	1.08	2.51	2.55	2.54
Mean Annual Discharge Frequency (% of time)	42%	30%	70%	50%	87%
Mean Annual Discharge Frequency (days/yr)	154	111	254	181	319
Loads					
Mean Annual TN Load (kg/yr)	1803	1578	2288	2330	2316
Mean Annual TP Load (kg/yr)	23	20	46	47	46
Mean Annual NOx Load (kg/yr)	1400	1215	535	546	537
Mean Annual SRP Load (kg/yr)	2.2	1.9	4.5	4.5	4.5

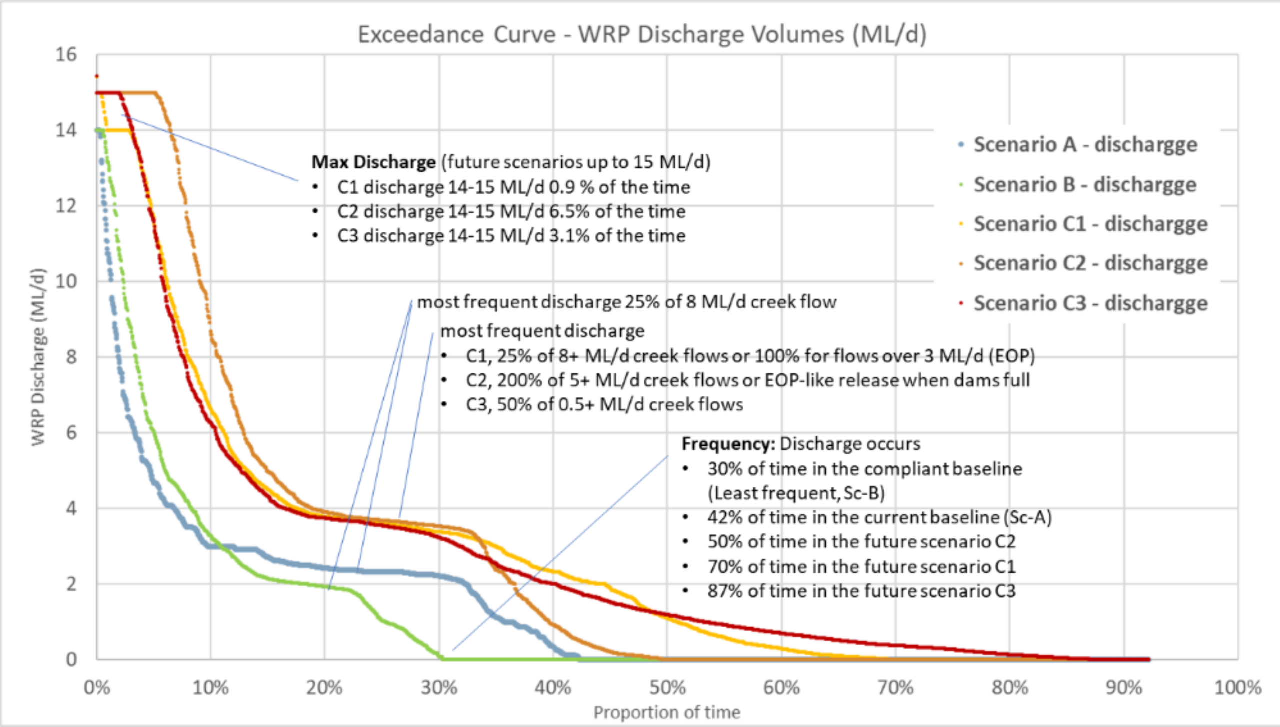

Figure 3-9 Exceedance curve modelled daily discharge from Picton WRP

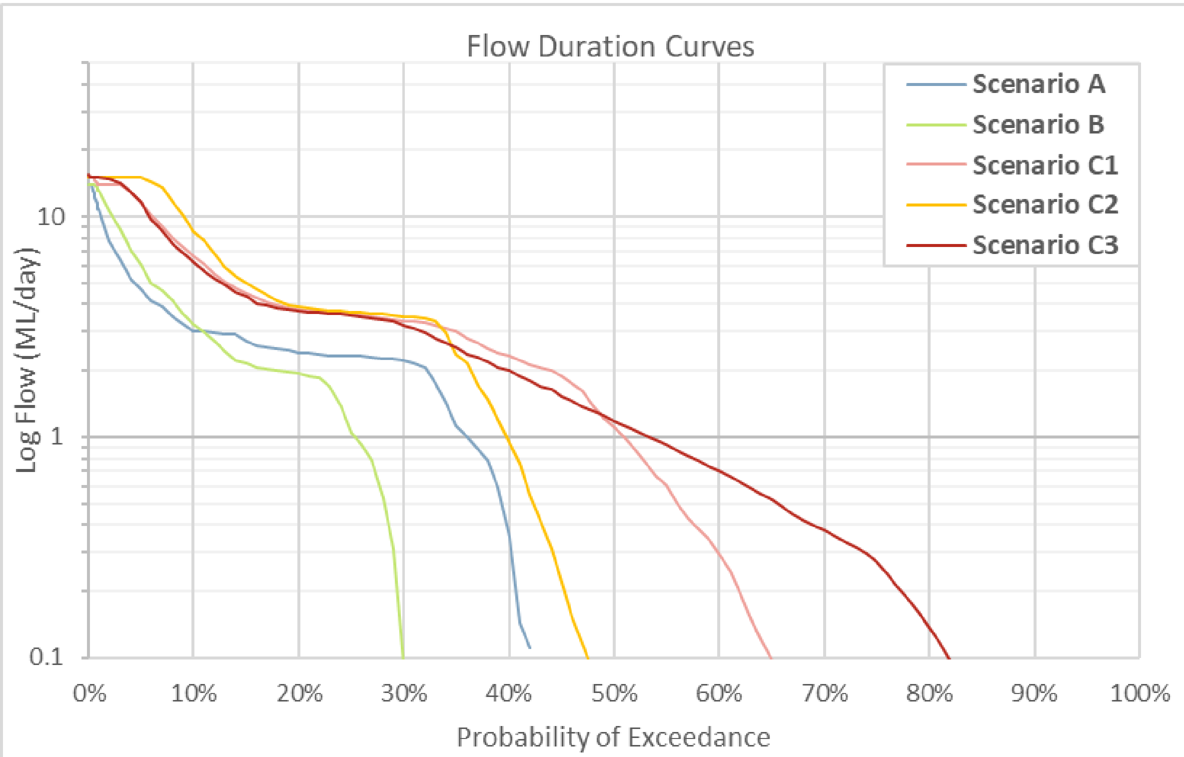

Figure 3-10 Modelled flow duration curves – WRP discharges

The exceedance curves for discharge volumes (Figure 3-9) and the flow duration curves (Figure 3-10) show that in Scenarios A and B, the amount of time that discharges occur is < 50% of the time (current – Sc A and historic – Sc B). This increases for future scenarios C1, C2, C3 where the wastewater inflow to the WRP and the discharge volumes simulated to Stonequarry Creek increase (worst case scenarios).

Discharge occurs:

- 30% of time in the compliant baseline (Least frequent, Sc-B)
- 42% of time in the current baseline (Sc-A)
- 50% of time in the future scenario C2
- 70% of time in the future scenario C1
- 87% of time in the future scenario C3

3.2.4 Nepean River – changes to flow under all scenarios

Downstream of the confluence with Stonequarry Creek at N91, the change to average annual flows for future scenarios can be compared with the current and compliant baseline scenarios (Table 3-7). The scenarios are compared over the same modelled period. The differences in discharge volumes from the WRP across the scenarios (mean annual 395 - 932 ML/y) correspond to relatively small increases in the flows downstream in the Nepean River (1% in the future scenarios compared to 0.4-0.5% in the baseline scenarios).

Table 3-7 Modelled flows summary – N91 Nepean R d/s of Stonequarry confluence

Nepean River downstream of Stonequarry Creek (N91)					
Metric	**Scenario A Existing**	**Scenario B Compliant**	**Scenario C1**	**Scenario C2**	**Scenario C3**
Nepean River (N91), downstream of SQ Creek confluence. Mean Annual Flow (ML/yr)	92,635	92,583	93,104	93,120	93,115
Difference relative to Compliant Baseline – Sc B (ML/y)	+ 52	-	+ 521	+ 537	+ 532
Modelled Mean Annual Discharge from Picton WRP Discharge (ML/yr)	451	395	915	932	926
WRP Discharge volume relative to Nepean River flow at N91 (%)	0.5%	0.4%	1.0%	1.0%	1.0%

The results show that the future 'worst-case' Scenarios C1, C2 and C3 result in a 1% increase in the flow at Maldon Bridge (N91) downstream of the Stonequarry Creek confluence (and Picton WRP) – for time series 2010-2018. This slight increase in flows in the Nepean River is 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.

3.3 Loads

The volumes discharged from the WRP will 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). The simulation of the bioavailable forms of the nutrients in Stonequarry Creek have been improved from the Nov 2020 report – now represented by a relationship related to creek flow (regression using a power formula as described in section 3.2).

A new framework for licencing will reduce the concentration limits for discharge from treatment plants with investment in new technologies to reduce bioavailable nutrients, especially Nitrate. Monitoring the performance of these new technologies in coming years will provide the information needed about what concentrations should be simulated in the model and how they vary seasonally. Without this information currently available, the simulation has adopted constant concentrations for the future discharge (Table 3-2).

There are large increases in discharge volumes for the worst case future scenarios C1 – C3 relative to the baseline, however the model indicates a **decrease in the bioavailable NOx loads** when compared to current and EPL compliant scenarios, and only moderate increases in TN loads (due to the additional treatment reducing expected discharge concentrations from 4 mg TN/L to 2.5 mg TN – or lower).

3.3.1 Annual Loads - Total Nitrogen and Oxidised Nitrogen

The predicted nitrogen loads for the modelled scenarios are indicated year to year (Figure 3-11 and Figure 3-12) and in the tabulated average annual loads (Table 3-8). The figures visually show the modelled WRP discharge and the variability in loads year to year and comparison between scenarios. The tabulated values also clearly show the predicted differences, including relative to upstream waterway sites which are 'control' sites.

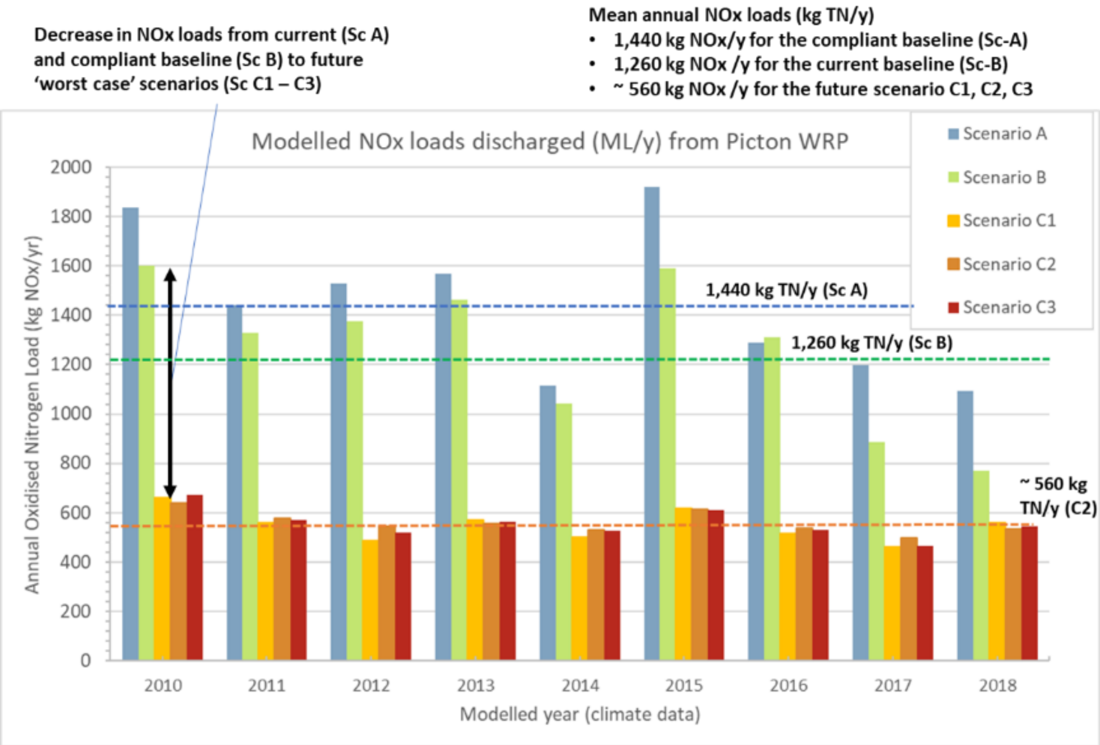

Figure 3-11 Modelled mean annual loads NOx – WRP discharge to Stonequarry Creek

Figure 3-12 Modelled mean annual loads TN – WRP discharge to Stonequarry Creek

Table 3-8 Total Nitrogen (TN) and Nitrate (NOx) loads for all scenarios (2010-2018 simulation)

Mean Annual Loads					
Metric	**Scenario A Existing**	**Scenario B Compliant**	**Scenario C1**	**Scenario C2**	**Scenario C3**
WRP discharge **TN Load** (kg/yr), Average across time series	1,803	1,578	2,288	2,330	2,316
Median across time series	1,801	1,660	2,335	2,274	2,268
WRP discharge **NOx Load** (kg/yr)	1,443	1,263	549	559	556
Change in load of bioavailable NOx (%)	Increase by 14%	Baseline	Reduce by 57% from B	Reduce by 56% from B	Reduce by 56% from B
Stonequarry Creek					
N911B u/s WRP TN Load (kg/yr)	7,327				
N911 d/s WRP TN Load (kg/yr)	8,968	8,876	9,517	9,621	9,584
N911B u/s WRP NOx Load (kg/yr	1,164				
N911 d/s WRP NOx Load (kg/yr)	2,462	2,401	1,694	1,719	1,727
Nepean River					
N92 Nepean u/s SQ confl TN Load (kg/yr)	37,714				
N91 d/s SQ confl TN Load (kg/yr)	48,402	48,197	48,898	48,928	48,926
N92 Nepean u/s NOx confl SRP Load kg/yr	14,581				
N91 d/s SQ confl SRP Load (kg/yr)	17,420	17,275	16,481	16,489	16,487

3.3.2 Annual Loads - Total Phosphorus and Soluble Reactive Phosphorus

The predicted phosphorus loads for the modelled scenarios are indicated year to year (Figure 3-13) and in the tabulated average annual loads (Table 3-9). The results are described by statistical analysis of data across the 2010-2018 time series.

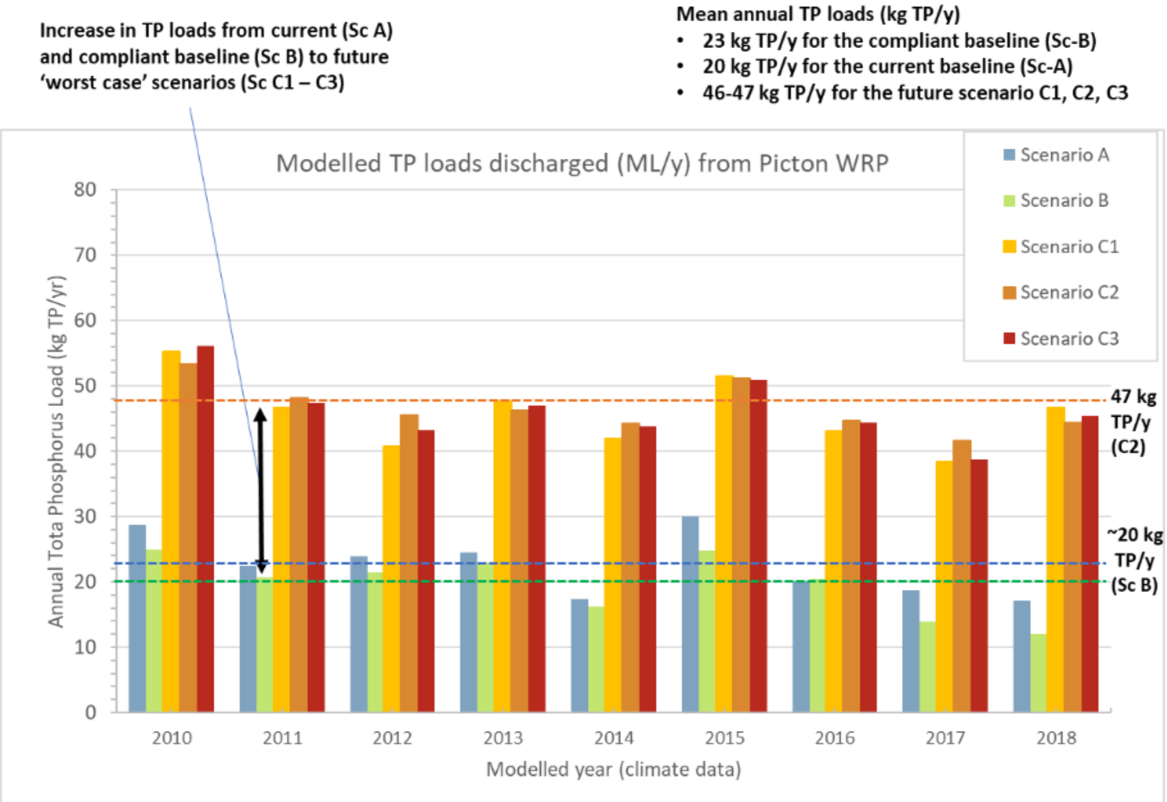

Figure 3-13 Modelled mean annual loads TP – WRP discharge to Stonequarry Creek

Table 3-9 Modelled Total Phosphorus (TP) and Soluble Reactive Phosphorus (SRP) loads

Mean Annual Loads					
Metric	**Scenario A Existing**	**Scenario B Compliant**	**Scenario C1**	**Scenario C2**	**Scenario C3**
WRP discharge **TP Load** (kg/yr), Average across time series	23	20	46	47	46
WRP discharge **SRP Load** (kg/yr)	2.3	2.0	4.6	4.7	4.5
Stonequarry Creek					
N911B u/s WRP TP Load (kg/yr)	434				
N911 d/s WRP TP Load (kg/yr)	456	454	477	479	478
N911B u/s WRP SRP Load (kg/yr	49				
N911 d/s WRP SRP Load (kg/yr)	51	51	54	54	54
Nepean River					
N92 Nepean u/s SQ confl TP Load (kg/yr)	1,645				
N91 d/s SQ confl TP Load (kg/yr)	2,187	2,183	2,210	2,210	2,211
N92 Nepean u/s SRP confl SRP Load kg/yr	952				
N91 d/s SQ confl SRP Load (kg/yr)	1,007	1,007	1,009	1,010	1,010

The key model outputs, related to nutrient loads, show:

- Bioavailable NOx loads are significantly reduced in the future scenarios due to additional treatment proposed.
    - 1,440 kg NOx/y for the compliant baseline (Sc-A)
    - 1,260 kg NOx /y for the current baseline (Sc-B)
    - ~ 560 kg NOx /y for the future scenario C1, C2, C3, approx. half baseline loads

- TN loads increase in the future scenarios due to the increase in volume discharged, but the increase is moderated by the additional treatment. TN loads are mostly within the range that is simulated for the current baseline.
    - 1,580 kg TN/y for the compliant baseline (Sc-B), range 960 – 2,000 kg TN/y (dry-wet years)
    - 1,800 kg TN/y for the current baseline (Sc-A)
    - 2,290 kg TN/y for the future scenario C1
- TP (and SRP) loads increase in the future scenarios due to the increase in volume discharged. TP concentrations are expected to be similar to current levels in future years, and no change in concentration was simulated.
    - 23 kg TN/y for the compliant baseline (Sc-B)
    - 20 kg TN/y for the current baseline (Sc-A)
    - 46-47 kg TN/y for the future scenario C1, C2, C3, approx. twice baseline loads

- There is high modelled variability year to year is due to changes in rainfall, inflows and reuse.
    - Scenario A loads range from 1,365 – 2,400 kg TN/y in the modelled time series variability.
    - There is less variability predicted in the 'worst case' future scenarios where no additional reuse is simulated and expected discharge relative to inflows increases.

- Discharge loads (from WRP) relative to load at the upstream waterway site (N911 B).
    - WRP discharge relative to Stonequarry Creek loads at N911B are:
        - Increasing for TN from baseline (22-25%) to future (~ 32%)
        - Decreasing for NOx from baseline (17-20%) to future (~ 8%)
        - Increasing for TP and SRP from baseline (~ 5%) to future (~ 10%)
    - WRP discharge relative to Nepean River loads at N92 are:
        - Increasing for TN from baseline (4 - 5%) to future (~ 6%)
        - Decreasing for NOx from baseline (~ 10%) to future (~ 4%)
        - Increasing for TP and SRP from baseline (~ 1.2 – 1.4 %) to future (~ 2.8 %)

Further points related to loads include:

- **Licenced load limits** (current / future) - All scenarios (including the modelled 'compliant' baseline) exceed the current EPL (1,460 kg TN/y), but loads are well below the Hawkesbury Nepean Framework load allocation for Picton WRP (approximately 4,000 kg TN/y). Additional reuse at Picton has the potential to reduce the quantum of future investment across the Yarramundi Zone 1 bubble in the Hawkesbury Nepean Nutrient Framework

- **Opportunity for 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 loads at the upstream water quality monitoring site, between 20 – 25% for NOx and TN for the baseline and approx. 8% NOx in the future, and 32% for TN. Stormwater in the catchment is largely untreated (minimal infrastructure for stormwater quality management) and there are many onsite sewage systems. There are opportunities to reduce catchment loads. Collaboration is underway with Council on a nutrient offset project at the Sportsground, and native riparian planting initiatives.

3.4 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.

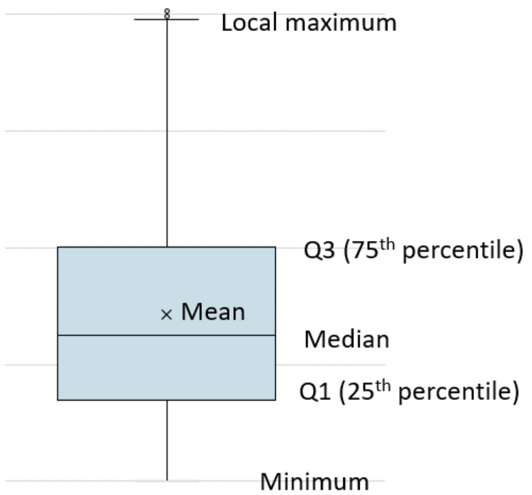

Figure 3-14 Box and whisker plot interpretation

3.4.1 Stonequarry Creek concentrations

The baseline scenario (A) has been modelled to reflect the existing conditions, and Scenario B reflects a compliant baseline. Scenarios C1, C2, C3 reflects increased discharge to Stonequarry Creek for a future configuration with 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 plots below show the results for both the upstream and the two relevant discharge scenarios for bioavailable NOx, TN and TP, Figure 3-15, Figure 3-16 and Figure 3-17.

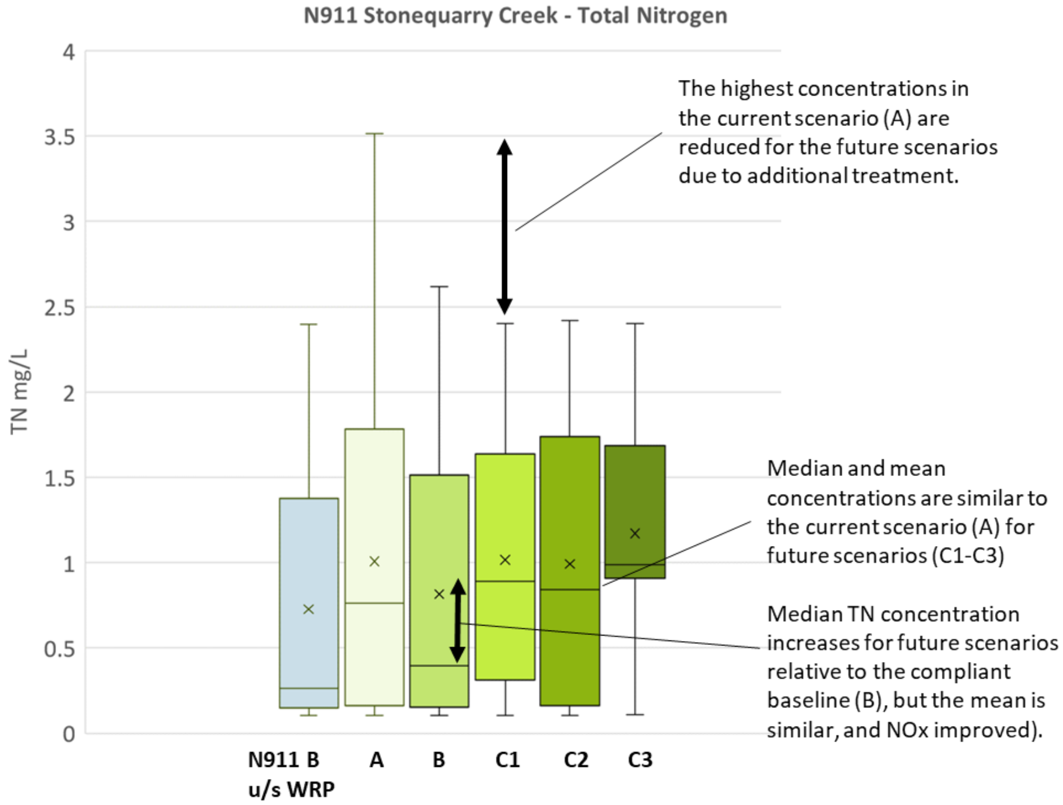

Figure 3-15 TN concentrations in Stonequarry Creek relative to upstream concentrations

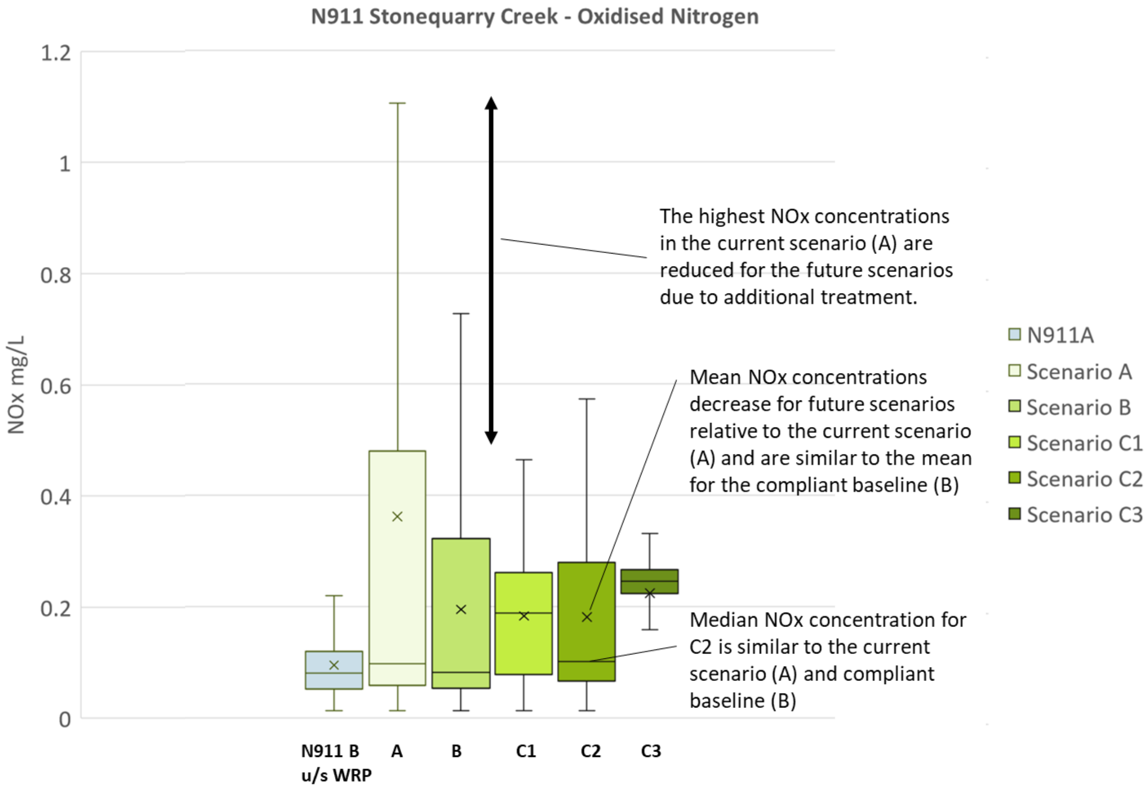

Figure 3-16 NOx concentrations in Stonequarry Creek relative to upstream concentrations

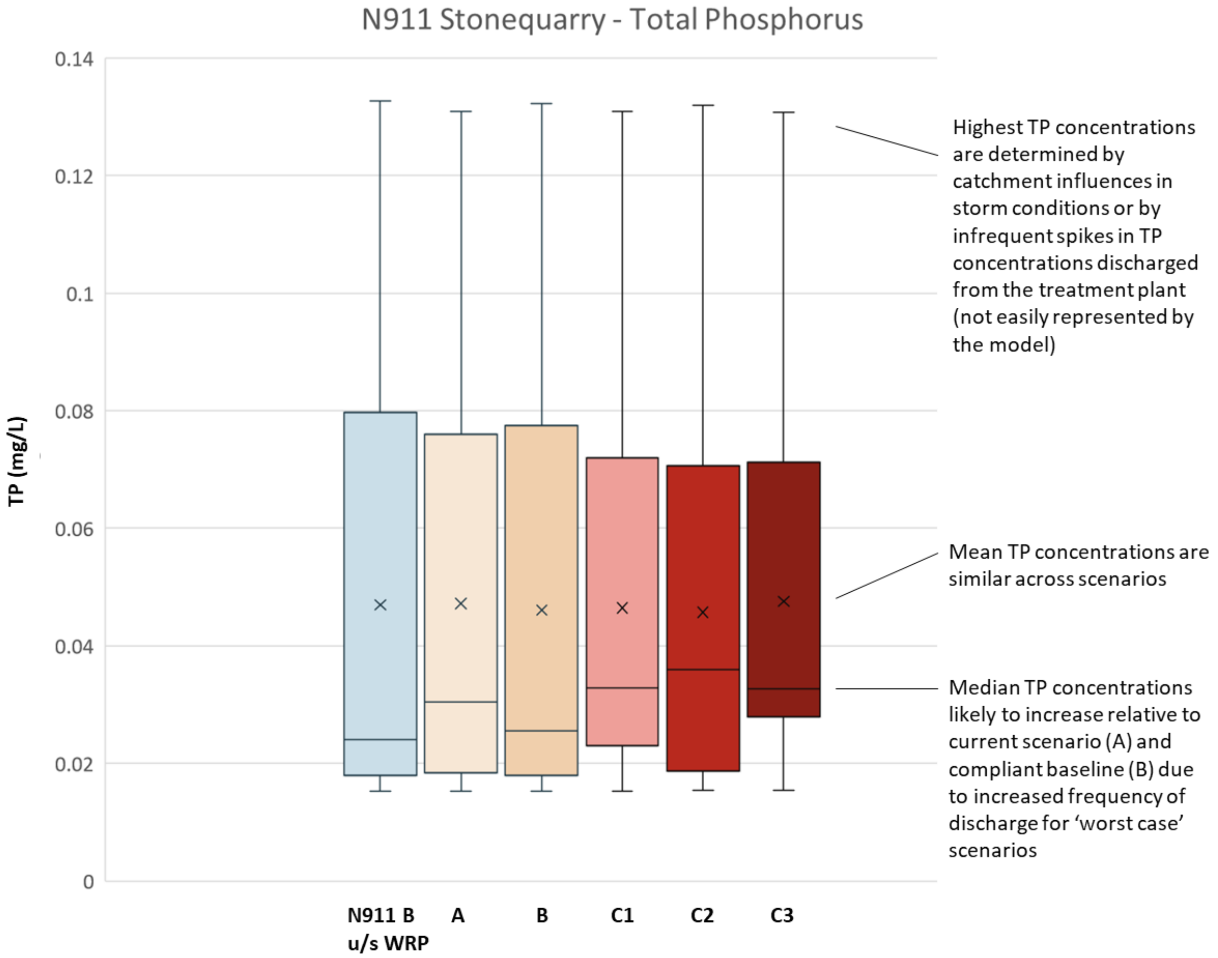

Figure 3-17 TP concentrations in Stonequarry Creek relative to upstream concentrations

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.

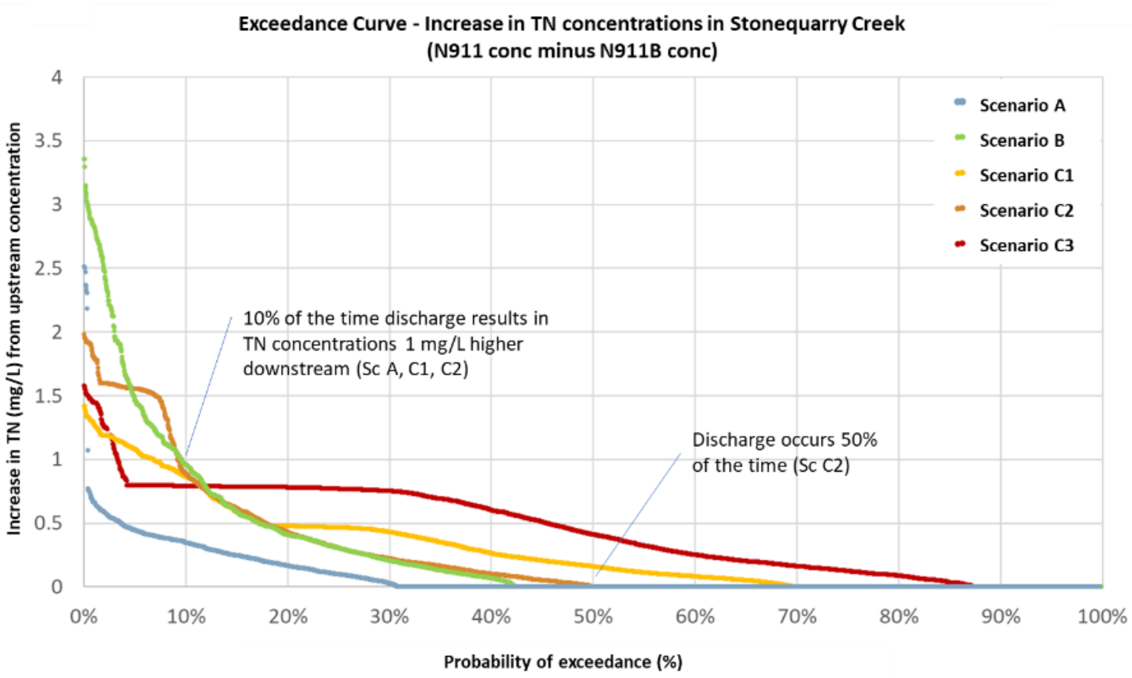

Figure 3-18 Exceedance curves, modelled daily TN concentrations in Stonequarry Creek

The modelled concentrations in Stonequarry Creek indicate that:

- 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.

- At N911 downstream of the discharge there is an expected increase in concentration from the compliant baseline (B) to the existing scenario (A) as inflows increased from 2.25 to 2.7 ML/d. The greatest increases were in TN concentrations with similar smaller increases for NOx and TP.
    - TN mean at N911 increased from 0.8 to 1.0, median increased from 0.4 to 0.8, and maximum concentrations were higher and more frequent (10% of the time series)
    - NOx mean at N911 increased from 0.2 to 0.4, median increased from 0.08 to 0.10, and maximum concentrations were higher and more frequent (10% of the time series)
    - TP mean at N911 were similar at 0.05 and median similar at 0.03.
    - Note - despite these increases, deterioration in biological indicators has not been observed (Part A technical report, Sydney Water Feb 2021)

- From the **compliant baseline (B)** similar increases are expected for the future scenarios (C1, C2, C3)
    - TN mean at N911 expected to increase from 0.8 to 1.0, median increase from 0.4 to 0.84 (C2), 0.89 (C1) and 0.99 (C3). Maximum concentrations are expected to be

    - higher than the compliant baseline for 10% of the time series – but not as elevated as for the existing scenario
    - NOx mean at N911 is expected to be similar at 0.2, and median increase from 0.08 to 0.10 (C2), 0.19 (C1) and 0.25 (C3). Maximum concentrations are expected to be higher than the compliant baseline for 10% of the time series – but not as elevated as for the existing scenario.
    - TP mean at N911 is expected to be similar at 0.05 and median similar at 0.03 – 0.04.

- From the **existing scenario (A)**
    - TN mean at N911 expected to be similar at 1.0, and median increase from 0.76 to 0.84 (C2), 0.89 (C1) and 0.99 (C3). Maximum concentrations are expected to be lower with additional treatment reducing the 4+ mg/L TN concentrations discharged by the treatment plant currently
    - NOx mean at N911 is expected to decrease from 0.36 to 0.18, and median similar or increase from 0.10 to 0.10 (C2), 0.19 (C1) and 0.25 (C3). Maximum concentrations are expected to be decrease relative to the existing scenario.
    - TP mean at N911 is expected to be similar at 0.05 and median similar at 0.03 – 0.04.

- For most analytes the interquartile range doesn't change significantly between the upstream and both downstream scenarios – however further discussion of each of the future discharge regimes and water quality changes is provided in *Picton LVA Water quality report – Part B Proposed discharge regimes and their potential impacts on waterway health (Sydney Water, 2021).*

- TP concentrations have been reduced from the conservative assumptions used in the Nov 2020 report (to 0.05 for all scenarios from 0.1 mg/L). We expect concentrations at 0.1 to occur 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 concentrations are well below the current EPL limit of 0.2 mg/L.

- Sydney Water's 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) with increasing focus across multiple trophic levels.

- Trials into low energy 'nutrient polishing' with wetlands and macroalgae will continue and provide greater confidence in the lower end concentrations that can be discharged in the future.

3.4.2 Nepean River concentrations (N92)

For the Nepean River simulations, the model uses a fixed boundary condition of observed flows and concentrations in the Nepean River at Maldon Weir (N92), rather than simulating the entire catchment. Water quality changes with e-flows and other factors saw an improving trend in TN from 2010 – 2018, as documented in Sydney Water's Sewage Treatment System Impact Monitoring Program. The modelling assumptions for Maldon Weir (made in 2019) aimed to reflect the water quality from the 2010-2018 period, rather than the earlier historic data prior to 2012 that showed poorer water quality and had the potential to under estimate the impact of future changes due to increasing discharge from Picton WRP. For a conservative approach, historical data prior to 2012, was replaced with a constant monthly concentration based on the more recent water quality trends.

This approach impacts the median and interquartile ranges, for longer model time series of TN and NOx concentrations. There were also periods of no flow records that influence concentration statistics.

Further, water quality changes have shown a significant declining trend in 2018 – 2020 compared to the preceding decade (STSIMP, Vol 1 Data report 2019-2020). Refinement of modelling assumptions over time will be necessary, and the relative impact of discharges from Picton WRP will be less where the models reflect the observed decline in water quality in the Nepean River.

The representations of modelled scenarios from this Source modeling work are valid even though future simulations of the upstream Nepean River concentrations are likely to use different concentration assumptions.

3.4.3 Nepean River concentrations (N91) – downstream of Stonequarry Creek confluence

The Nepean River monitoring site at Maldon Bridge (N91) is downstream of the Stonequarry Creek confluence (conveying both catchment runoff and WRP discharge). Concentrations at N91 are primarily influenced by the larger catchment flows where dilution moderates the increase in concentrations.

The box and whisker plots have been constrained to the period 1/3/2009 – 31/12/2018 to show the changes to TN and TP concentrations in the Nepean River where we have greater confidence in the observed data. 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.

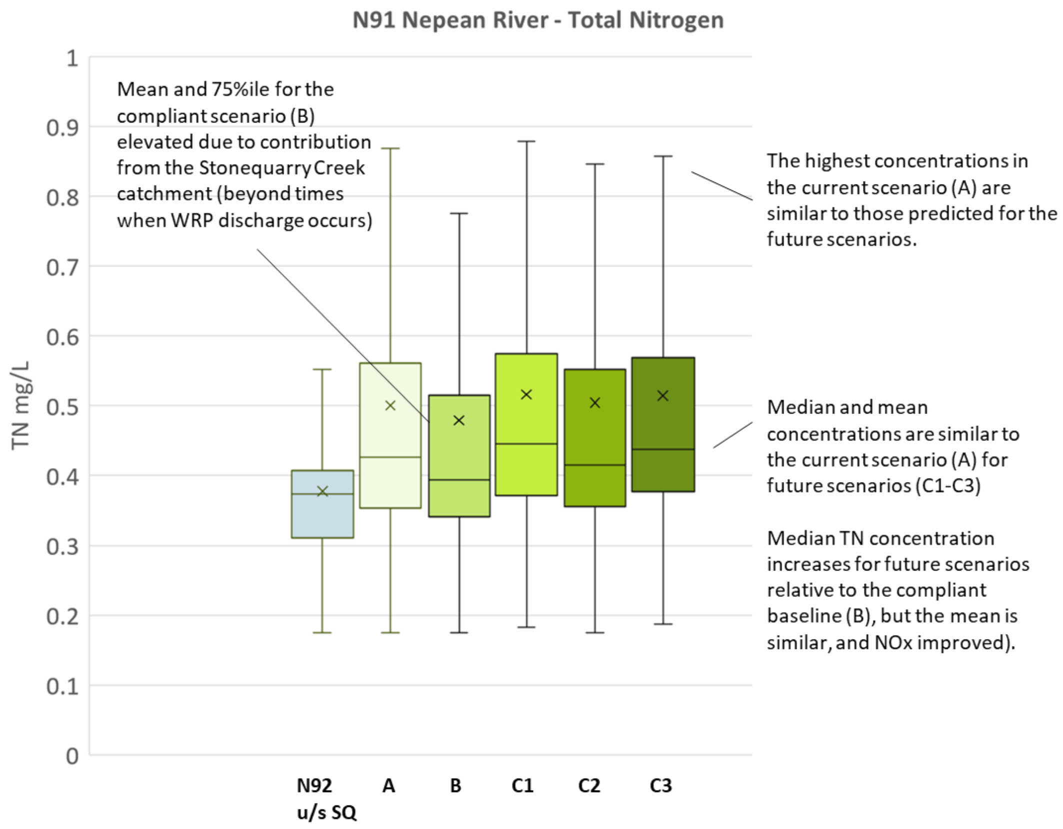

Figure 3-19 TN concentrations in the Nepean River – N91 downstream of SQ

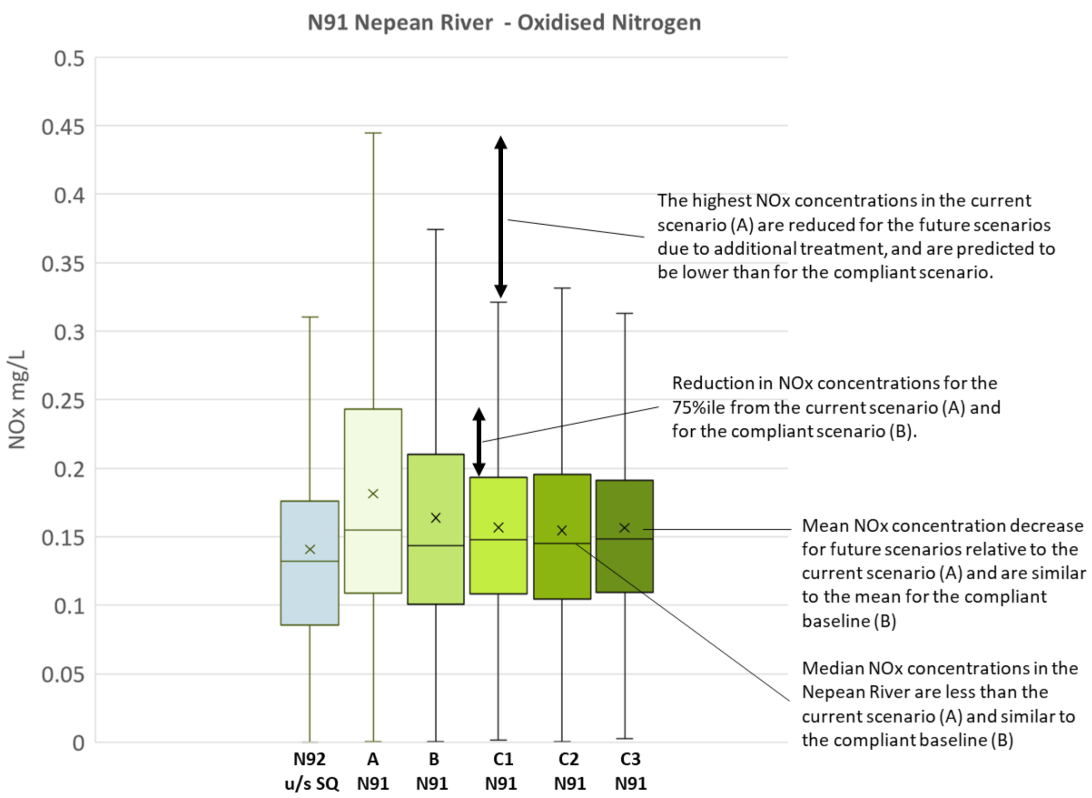

Figure 3-20 NOx concentrations in the Nepean River – N91 downstream of SQ

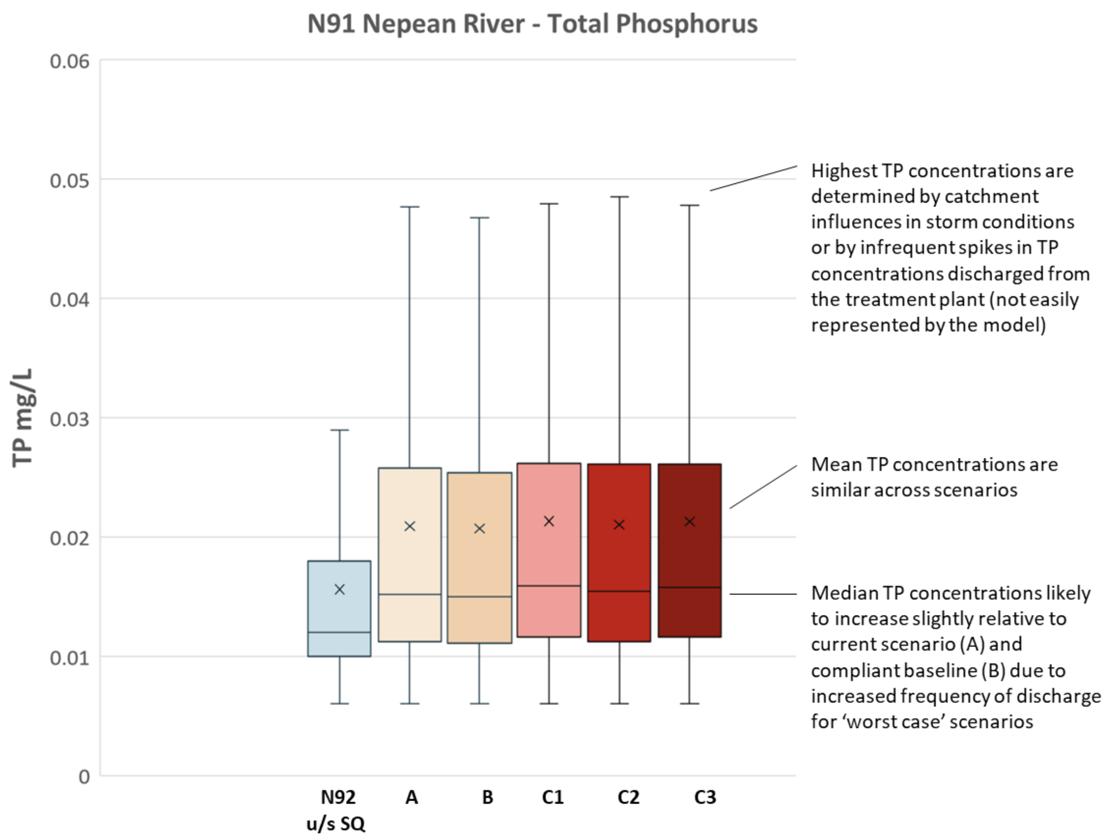

Figure 3-21 TP concentrations in the Nepean River – N91 downstream of SQ

The N91 results show that the future scenarios are expected to result in only small changes in the Nepean River water quality. These small increases are predicted either from comparison of the compliant baseline modelled water quality (scenario A), or from the existing scenario (B).

- The N92 (Maldon Weir) monitoring site on the Nepean River is considered a 'control' site as it is upstream of the Stonequarry Creek confluence (N92) and the WRP discharge. It has:
  - a median TN concentration of 0.37 mg TN/L, and a mean of 0.38 mg TN/L. This just exceeds the ANZG (0.35 mg/L) and reference site objectives (Nepean River – 0.31 mg/L).
  - a median NOx concentration of 0.13 mg NOx/L, and a mean of 0.14 mg NOx/L. This exceeds the ANZG (0.04 mg/L) but is the same as the reference site objectives (Nepean River – 0.14 mg/L).
  - a median TP concentration of 0.012 mg TP/L, and a mean of 0.016 mg TP/L. This is below the ANZG (0.025 mg/L) but above the reference site objectives (Nepean River – 0.010 mg/L).

- The N91 (Maldon Bridge) monitoring site is downstream of the confluence with Stonequarry Creek, the WRP discharge and runoff from the urban and rural areas. There is an expected increase in waterway concentrations and statistics. The concentrations simulated increase at N91 when comparing the modelled compliant baseline (B) to the existing scenario (A):

  - TN mean at N91 increased from 0.48 to 0.50, median increased from 0.47 to 0.48
  - NOx mean at N91 increased from 0.16 to 0.18, median increased from 0.17 to 0.18
  - TP mean at N91 were similar at 0.021 and median increased from 0.019 to 0.020.

- From the **compliant baseline (B)** similar increases are expected for the future scenarios (C1, C2, C3)
  - TN mean at N91 expected to increase from 0.48 to 0.50-0.52, median increase from 0.47 to 0.49 (C2), 0.51 (C1) and 0.52 (C3).
  - NOx mean at N91 is expected to be similar at 0.16, and median slightly decrease from 0.18 to 0.15 (C2), 0.16 (C1) and 0.16 (C3).
  - TP mean at N91 is expected to be similar at 0.021 and median slightly increase from 0.019 to 0.020 – 0.021.

- From the **existing scenario (A)**
  - TN mean at N91 expected to increase from 0.50 to 0.50-0.52, median increase from 0.48 to 0.49 (C2), 0.51 (C1) and 0.52 (C3).
  - NOx mean at N91 is expected to decrease from 0.18 to 0.15-0.16, and median slightly decrease from 0.18 to 0.15 (C2), 0.16 (C1) and 0.16 (C3).
  - TP mean at N91 is expected to be similar at 0.021 and median be similar / slightly increase from 0.020 to 0.020 – 0.021.

3.4.4 Nepean River concentrations (beyond N91)

The changes predicted at N91 are small, however further detail on the far field impacts is being considered through the Hawkesbury Nepean Modelling project. Modelling of the Nepean River with greater capability in nutrient cycling processes and recent calibration refinements should enhance simulation and understanding across the broader spatial scale, though it is noted that the Picton WRP contributions are relatively minimal compared to overall flows and model resolution may constrain the ability to evaluate any potential effects. This modelling is being done in combination with planning for the Wilton Growth Centre on the eastern side of the river and development across the Macarthur region, South Creek catchment and beyond. The management of stormwater, wastewater and recycled water for the Wilton area and broader Macarthur region is being considered in broader planning with stakeholders and regulators.

3.5 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 persistent with minimal cease to flow periods.

The 'existing' scenario (A) provides an adequate correlation with the existing conditions to allow the model to be used for predictions of future outcomes under alternative future scenarios (C1, C2 and C3).

Changes from compliant baseline

The compliant baseline scenario (B) characterises the changes as inflows to the WRP have increased from 2.25 ML/d to 2.7+ ML/d. The contrast between the compliant (B) and existing (A) scenarios highlights increases particularly in Stonequarry Creek (N911 downstream of the WRP discharge) in TN and NOx.

- TN mean at N911 increased from 0.8 to 1.0, median increased from 0.4 to 0.8, and maximum concentrations were higher and more frequent (10% of the time series)
- NOx mean at N911 increased from 0.2 to 0.4, median increased from 0.08 to 0.10, and maximum concentrations were higher and more frequent (10% of the time series)

Future scenarios to mitigate impacts

Future increases in WRP inflows are expected due to population growth and new connections to the wastewater network. Efforts to expand reuse to 2 nearby farms have been unsuccessful to date, but discussions are continuing. The scenarios assessed are 'worst case' future scenarios (no additional reuse simulated). When reuse agreements are secured, the risk of potential impact from increasing loads and concentrations will be reduced.

Sydney Water is seeking to maintain waterway values despite increasing discharges. The treatment infrastructure proposed will substantially reduce bioavailable nitrate concentrations and reduce total nitrogen concentrations. Additional low energy treatment strategies are also being trialled. Opportunities also exist to reduce pollutant sources from across the catchment.

The model predicts a range of changes from the existing (A) to future 'worst case' scenario (C2):

- Average volume of treated wastewater discharged expected to increase from 450 ML/y to 930 ML/y
- TN loads discharged to Stonequarry Creek expected to increase from an average of 1,800 kg TN/ year (existing scenario A) to 2,330 kg TN/ year.
- TP loads discharged to Stonequarry Creek expected to increase from an average of 20 kg TP/ year (existing scenario A) to 47 kg TN/ year.
- Median TP concentrations in Stonequarry Creek (N911) are expected to increase from baseline 0.026-0.03 to 0.036. Mean concentrations are expected to remain similar at 0.046 mg TP/L.
- Frequency of discharge to increase from 150 days per year (average) to more than 180 days per year.
- Discharge as a proportion of creek flow to increase from 25% for flows over 8 ML/d (discharge 1/5 of downstream waterway flow) to 200% for flows over 5 ML/d (discharge up to 2/3 of downstream waterway flow).

Despite increased discharge volumes, frequency and some loads and concentrations, there are aspects where water quality is expected to improve, with potential to contribute to improvements in waterway values.

- Bioavailable NOx loads discharged to Stonequarry Creek are expected to decrease from an average of 1,800 kg TN/ year (existing scenario A) to an average of only 550 kg TN/ y.
- Mean bioavailable NOx concentrations in Stonequarry Creek (N911) are expected to decrease from baseline (0.20-0.36) to 0.18 mg NOx/L. Median NOx to remain similar to existing scenario (A) at 0.1 mg/L in future scenario C2.
- NOx concentrations in both in Stonequarry Creek (N911) and in the Nepean River (N91) are reduced in future scenario C2 from existing scenario A, and are even lower than for the compliant baseline (scenario B)
- TN concentrations (median and mean) in Stonequarry Creek (N911) and in the Nepean River (N91) are similar in future scenario C2 to existing scenario A, and maximum TN concentrations are reduced
- TP concentrations in Nepean River (N91) are similar across both baselines and future scenarios

Discharge Regimes C1, C2, C3

The alternative discharge regimes highlights opportunities to minimise changes to median concentrations by increasing discharge a higher flows, however the proportion of discharge relative to creek flows is greater at these times. The differences between scenarios in terms of water quality is described below, Table 3-10.

Table 3-10 Characteristics of discharge regimes considered

Scenario	Characteristics
C1 – EOP like	• More frequent discharge relative to existing scenario A (on average ~70% of the time) • Higher median NOx concentration than C2 • Often increased TN concentration downstream (50% of the time increase is 0 – 0.5 mg TN/L, 20% of the time greater than 0.5 mg TN/L)
C2 – less frequent discharge 200_5	• Least frequency of discharge (on average ~ 50% of the time) • Most similar concentration changes to current discharge simulation (Existing scenario A) • Higher concentration changes occur very infrequently (maximum concentrations reduced by new treatment despite increased discharge volumes)
C3 – less proportion discharge 50_0.5	• Highest frequency of discharge (on average ~ 87% of the time) • Higher median NOx concentration than C2 • Often large difference in TN concentrations from upstream to downstream (45% of the time downstream TN concentrations are increased by more than 0.5 mg TN/L) • Lower maximum TN concentration changes, and less frequently more than 1 mg/L increase d/s

Scenario C2 is favoured due to the greater proportion of time that discharge can be avoided, however the preferred approach will be determined following further assessment of the alternative discharge regimes will be undertaken in supporting technical reports:

- Water quality - Picton LVA Water quality report - Part B | Proposed discharge regimes and their potential impacts on waterway health
- Hydrology – potential impacts on sensitive reaches
- Waterway values

Conclusions

The future scenarios result in increases in flows, loads and concentrations in Stonequarry Creek for both TN and TP, but reductions for NOx. Changes in the 1.3 km reach of Stonequarry Creek, from the WRP to the confluence with the Nepean River will occur with increased discharge, but there is potential to protect waterway values. Efforts to avoid the changes associated with the worst-case scenarios will continue.

In the Nepean River, future scenarios result in minor increases in flows, loads and concentrations. Proportionally these increases are smaller in magnitude compared to the of change in waterway concentrations predicted in Stonequarry Creek, due to the higher river flows.

4 References

Alluvium, 2020. *Summary Modelling Report: Picton WRP and Stonequarry Creek – Evaluating flow and water quality*. November 2020

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Aurecon Arup (2020). Picton WWTP Discharge - Review of Environmental Factors: Hydrology, November 2020

Aurecon Arup (2021), *Picton WRP LVA, Hydrological Impact Study*

CTEnvironmental (2021) *Assessment of Potential Hydraulic Driven Impacts to Ecological Values of Stonequarry Creek,* May 2021

MPM (2020), *Picton WRP Upgrade Discharge Options – Assessment of Dragonfly Habitats at Proposed Discharge Sites*, Marine Pollution Research, December 2020

MPM (2021), *Picton WRP Upgrade Discharge Options – Assessment of Significance for Sydney Hawk Dragonfly (7 Part Test),* Marine Pollution Research, February 2021

Sydney Water (2020), *Review of Environmental Factors Picton Treatment, Reuse and Discharge*, November 2020

Sydney Water (2021), *Licence Variation – Waterway Assessment, Part A current impacts*, February 2021

Sydney Water (2021a), *Picton Licence Variation – Water quality assessment, Part B Proposed discharge regimes and their potential impacts on water quality.*

Sydney Water (2021b), Decision Report - Picton Treatment, Reuse and Discharge, May 2021

5 Attachment 1 – Stonequarry Creek relationships for bioavailable nutrients

For the Licence Variation Application scenarios (May 2021), improvements were made to the Nov2020 simulation of Oxidised Nitrogen and Soluble Reactive Phosphorus concentrations in Stonequarry Creek.

For the Nepean River the simulation of bioavailable nutrient concentrations focused on correlation to seasonality and the regression was linked to the months of the year. For Stonequarry Creek the flow and water quality characteristics are very different from the Nepean River and the optimum regression was linked to flow with a power relationship. This form of regression has been successful in simulation of similar catchments.

Sites: The key sites of interest are shown (Figure 5-1) with the approach to simulating water quality described.

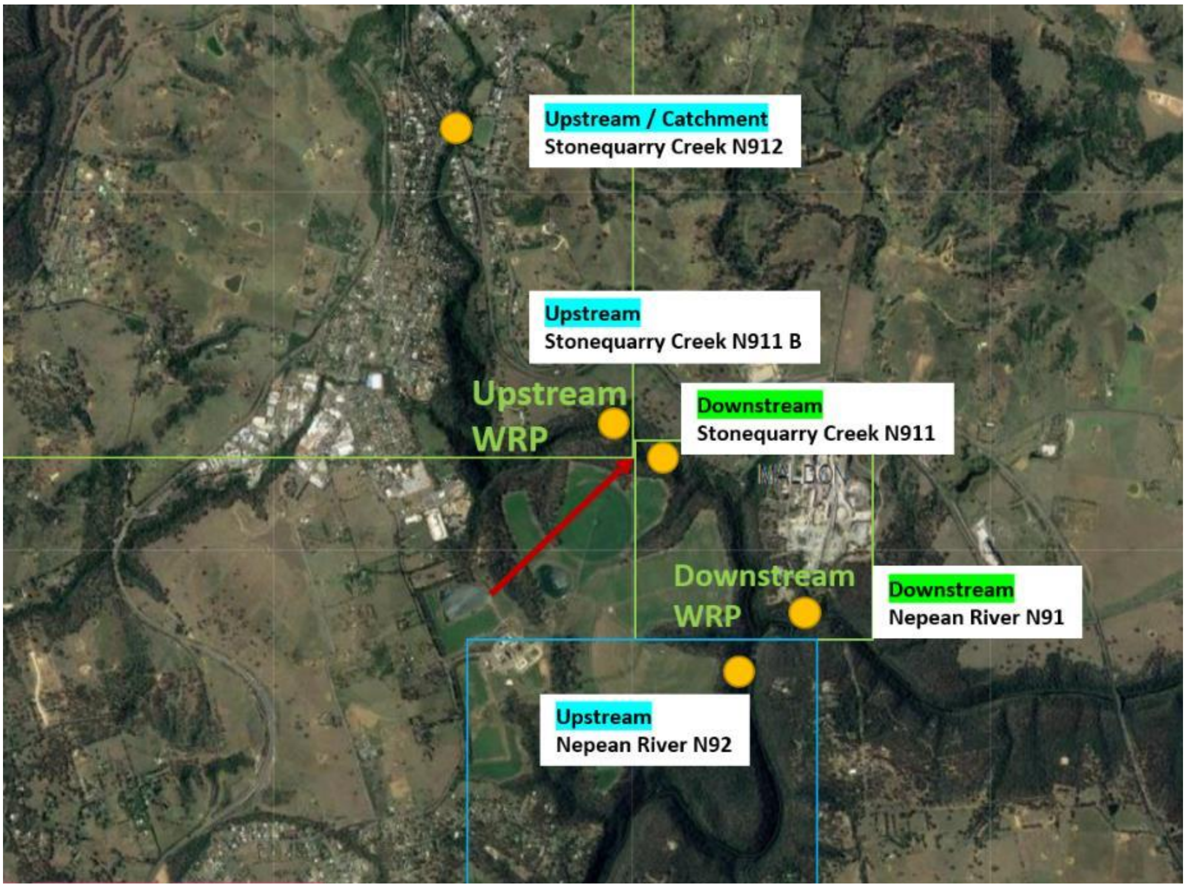

Figure 5-1 Key waterway sites (monitoring and modelling locations)

- N912 – upstream site at Picton township with TN and TP generated by the catchment model, NOx and SRP correlated to flow with a power trendline generated from observed data (flow gauging and water quality monitoring 2014-2020)

- N911 B – upstream of the Picton WRP discharge point. Pollutants simulated as for N912, but with different water quality characteristics. Despite being downstream of Redbank Creek, substantial water quality improvements occur in between N912 and N911 B. This is attributed to in stream processes and other factors (Sydney Water, 2021, Part A)
- N911 – mass balance combining hourly data for the upstream flows (modelled site N911B) and discharge from the WRP. Outputs from the model are typically average daily data, but are developed from simulations at a subdaily timestep.
- N92 – upstream Nepean River site. Data source input from available water quality data. Adjustment to data prior to 2012 to best reflect expected future water quality with the e-flows regime (in place since mid-2010). Potential to update in the future with calibrated Hawkesbury Nepean Model data.
- N91 – mass balance combining hourly data for the upstream Nepean River flows (N92) and data for the Stonequarry Creek catchment including discharge from the WRP.

Process

Generating a relationship between flow and the bioavailable nutrient concentrations involved:

- Considering available data
    - flow gauge information
        - Picton Township - 212053 (near N912))
        - Upstream of the WRP discharge - 2122006 U (near N911 B)
        - Downstream of the WRP discharge - 2122006 (near N911)
    - Modelled flow (calibrated source model)
        - Picton Township – near 212053 and N912
        - Upstream of the WRP discharge - 2122006 U (near N911 B)
        - Downstream of the WRP discharge - 2122006 (near N911)
    - Water quality monitoring data (2014-2020, upto 180 data points at each site including Ammonia NH3-N Filtered Total Phosphorus (soluble reactive phosphorus), Ortho Phosphorus, Oxidised Nitrogen, Temperature, Total Kjedahl Nitrogen, Total Nitrogen, Total Phosphorus)

- Correlating available flow gauge data with dates from water quality monitoring
    - Table with approx. 160 data points at each site for each analyte
    - Graphing water quality (Y-axis) vs Flow (X-axis)
    - Trendline (power option in Excel) and Power Equation and R-squared value

- Consideration of flow thresholds where a better correlation to higher flows may exist
    - Reducing data set to only include flows above 4 ML/d or 8 ML/d
    - Repeating graphing and trendlines
    - Comparing R-squared values and best options for simulation of the complex water quality data set

Results

The regression calculation using flow and water quality information better reflects the trends for bioavailable nutrients at N912 (Figure 5-2 and Figure 5-3) and N911B (
Figure 5-4 and Figure 5-5). The functions used are:

- N912 NO x 0.0496 * Stonequarry Creek Flow ^0.5085
- N911 B NO x 0.0652* Stonequarry Creek Flow ^0.295
- N912 SRP 0.0091* Stonequarry Creek Flow ^0.1777
- N911 B SRP 0.0047* Stonequarry Creek Flow ^0.1806

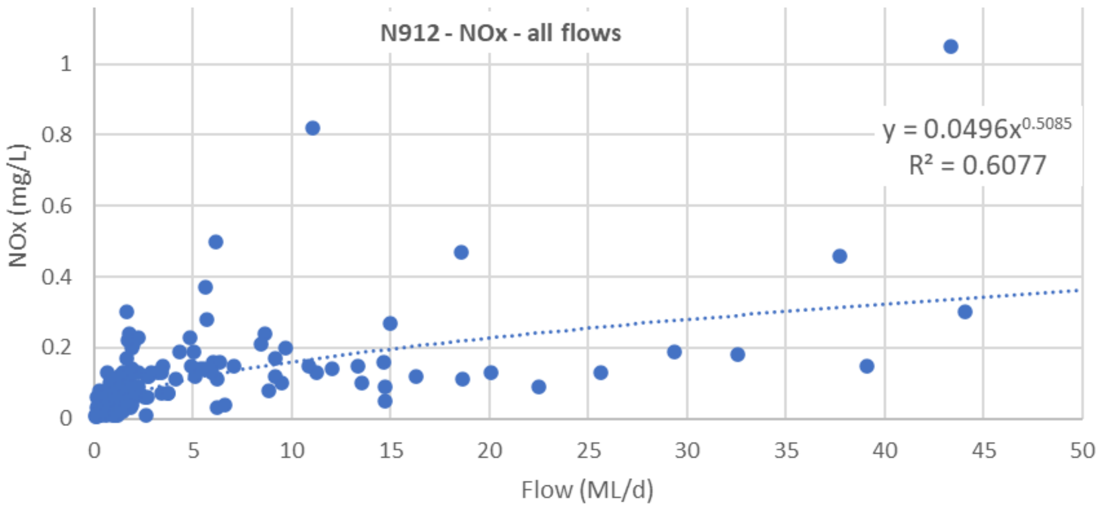

Figure 5-2 NOx concentrations in Stonequarry Creek (N912) with flow regression relationship

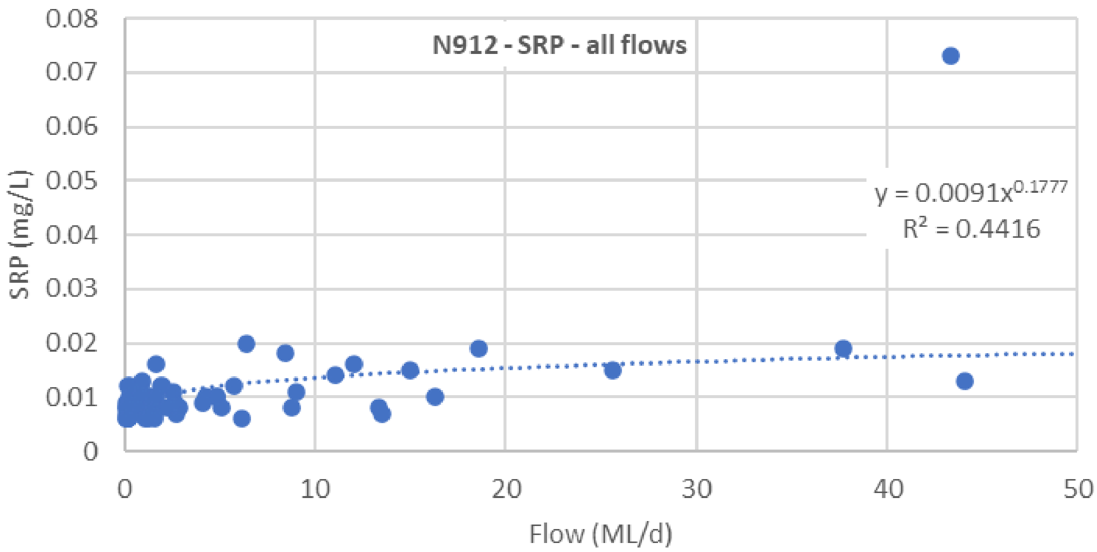

Figure 5-3 SRP concentrations in Stonequarry Creek (N912) with flow regression relationship

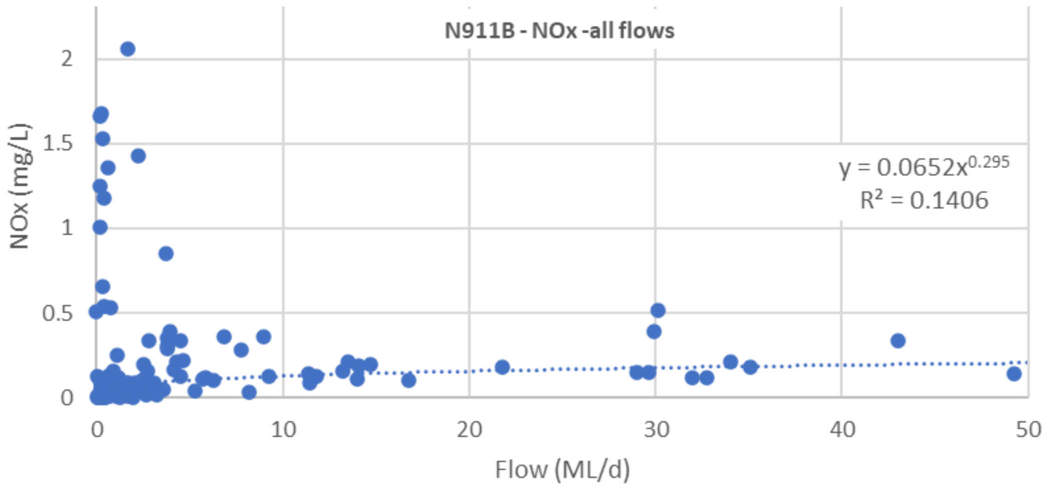

Figure 5-4 NOx concentrations in Stonequarry Creek (N911 B) with flow regression relationship

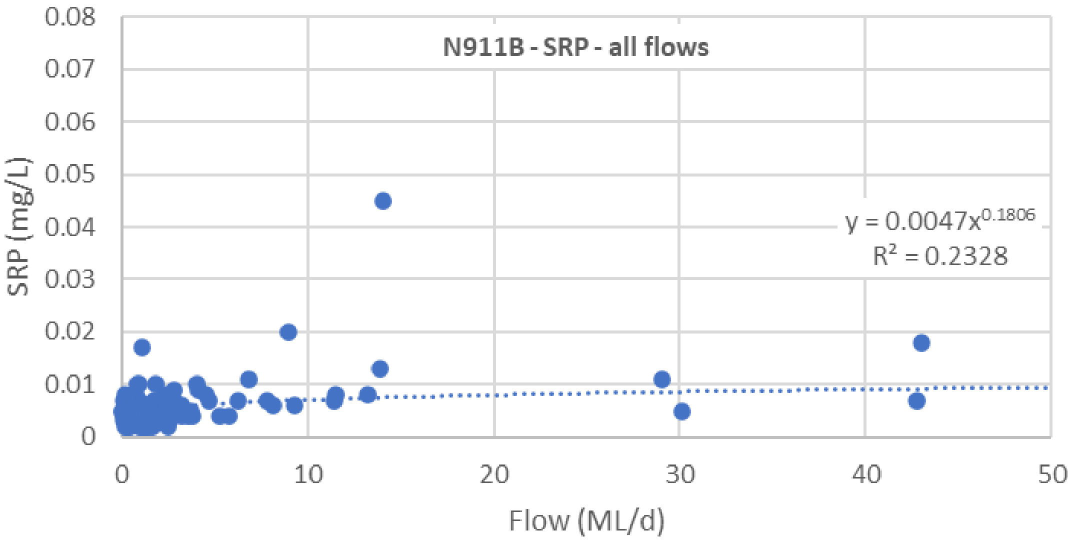

Figure 5-5 SRP concentrations in Stonequarry Creek (N911 B) with flow regression relationship

6 Attachment 2 - Discharge rules

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

6.1.1 A2.1 Precautionary Discharge Rule

The objective of the Precautionary Discharge is to maintain the storage volume of the Western Dam below a set level in the dam (e.g. 213.1 mAHD). If the storage level of the Western Dam is below that level there is no required discharge – and the water is reserved for reuse. If the storage level is above that level (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)

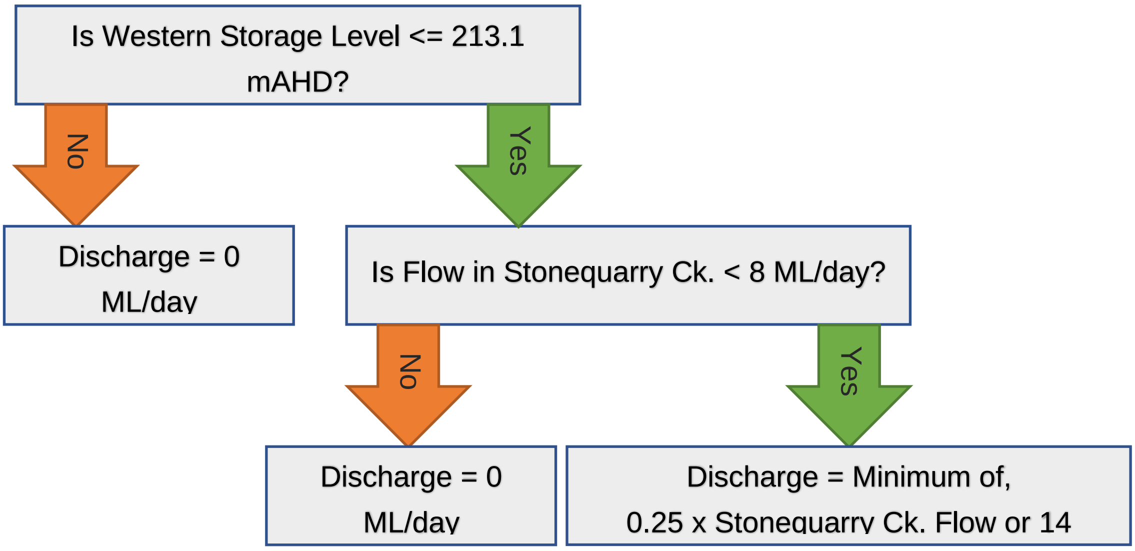

Figure 6-1 Logic rules for model simulation of Precautionary Discharge

A2.2 Storm discharge

A new configuration has been proposed for the Licence Variation Application, a ‘storm’ discharge, configured in the same way as the precautionary discharge but with adjustments to the

- Storage **dam operational levels** (elevation m AHD)

    - 213.1 m AHD was used in the calibration to reflect the current operations as much as possible.
    - Future scenarios considered adjusting the dam level triggers (ie increasing the buffer storage to reduce spills from the dam that nay occur in extreme wet weather events)
- **Volume discharged** (fixed discharge volume or discharge proportion related to creek flow)
    - current EPL permits 25% ratio (2 ML/d discharged when creek flow is above 8 ML/d),
    - current 'Emergency Operating Protocol' discharges 100% (1:1) above 2.5 ML/d creek flow and also 200%+ in worst case conditions
    - alternatives tested included 10%, 25%, 50%, 100%, 200%, 200%+ (worst case conditions) as well as scenarios with a fixed discharge when dam levels are high: 1 ML/d, 3 ML/d, 4 ML/d
- **Dam level triggers** for discharge to occur
    - Storage capacity in dams similar to current operation that ensures water is available for reuse, but also reserves an 'air gap' to accommodate wet weather inflows
    - Minor alterations with limited benefits.
- **Maximum** daily discharge
    - Current EPL has 14 ML/d maximum. A 15 ML/d maximum was also simulated.

6.1.2 A2.3 Emergency Operating Protocol 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 6-1), 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 6-2.

Table 6-1 Rule for Emergency Operating Protocol for discharge of excess effluent

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

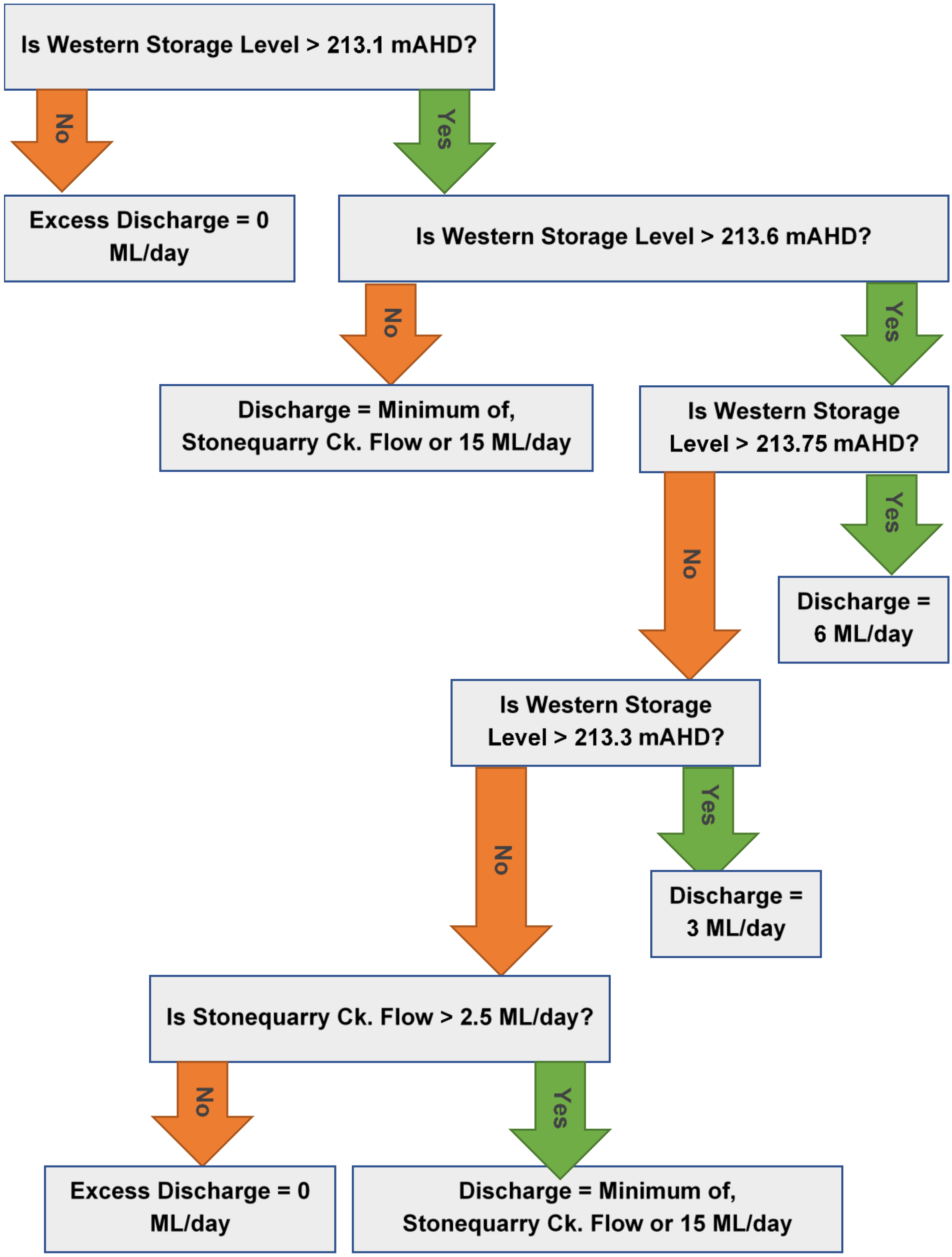

Figure 6-2 Rule for Emergency Operating Protocol for discharge of excess effluent

EOP Discharges 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 Flow at current timestep (ML/day)

A2.4 Infrequent excess discharge

A new configuration has been proposed for the Licence Variation Application, an ‘infrequent excess discharge, configured in the same way as the Emergency Operating Protocol but with adjustments to the

- Storage **dam operational levels** (elevation m AHD)
  - 213.1 m AHD was used in the calibration to reflect the current operations as much as possible.
  - Future scenarios considered adjusting the dam level triggers (ie increasing the buffer storage to reduce spills from the dam that nay occur in extreme wet weather events)
- **Minimum creek flow** for water to be discharged
  - current EPL has 8 ML/d threshold,
  - current ‘Emergency Operating Protocol’ has a threshold at 2.5 ML/d and if required discharge at any creek flow ‘0 ML/d’ in worst case conditions
  - alternatives tested included 0.5 ML/d, 3 ML/d, 5 ML/d, 8 ML/d
- Additional **creek flow thresholds** for altered regime
  - alternatives tested included 3 ML/d, 5 ML/d, 8 ML/d
- **Volume discharged** (fixed discharge volume or discharge proportion related to creek flow)
  - current EPL permits 25% ratio (2 ML/d discharged when creek flow is above 8 ML/d),
  - current ‘Emergency Operating Protocol’ discharges 100% (1:1) above 2.5 ML/d creek flow and also 200%+ in worst case conditions
  - alternatives tested included 10%, 25%, 50%, 100%, 200%, 200%+ (worst case conditions) as well as scenarios with a fixed discharge when dam levels are high: 1 ML/d, 3 ML/d, 4 ML/d
- **Dam level triggers** for discharge to occur
  - Storage capacity in dams similar to current operation that ensures water is available for reuse, but also reserves an ‘air gap’ to accommodate wet weather inflows
  - Minor alterations with limited benefits.
- **Maximum** daily discharge
  - Current EPL has 14 ML/d maximum. A 15 ML/d maximum was also simulated.

A2.4 LVA scenarios - discharge rules

In line with the approaches described above, the following rules were simulated for the LVA future scenarios C1, C2 and C3.

Table 6-2 Rule for Emergency Operating Protocol for discharge of excess effluent

Model	Code for simulation of discharge regime

C1 – EOP like	**Precautionary discharge**
	IF($mvWD_StorageLevel<=210.1, IF($SQ_US_WRP<8,0,MIN(0.25*$SQ_US_WRP,15)),0)
	
	Excess (spilling 100% when creek above 3 ML/d, then 4 ML/d or 8 ML/d if dam level gets too high)
	IF($mvWD_StorageLevel>210.1, IF($mvWD_StorageLevel>212.6,
	IF($mvWD_StorageLevel>213.7,8, IF($mvWD_StorageLevel>212.5,4,
	IF($SQ_US_WRP>3,MIN($SQ_US_WRP,15),0))),
	IF($SQ_US_WRP>3,MIN($SQ_US_WRP,15),0)),0)
	
	MAX
	IF($mvWD_StorageLevel<210.1,IF($SQ_US_WRP<8,0,MIN(0.25*$SQ_US_WRP,15)),
	IF($mvWD_StorageLevel<212.6,IF($SQ_US_WRP<2.5,0,MIN($SQ_US_WRP,15)),
	IF($mvWD_StorageLevel<213.7,IF($mvWD_StorageLevel>212.1,4,
	IF($SQ_US_WRP<3,0,MIN($SQ_US_WRP,15))),
	IF($mvWD_StorageLevel>212.6,8,MIN($SQ_US_WRP,15)))))

C2 – less frequent discharge
 	
200_5
	'Storm' discharge
	IF($mvWD_StorageLevel<=210.1, IF($SQ_US_WRP<5,0,MIN(**2***$SQ_US_WRP,**15**)),0)
	
	Excess
	IF($mvWD_StorageLevel>210.1,IF($mvWD_StorageLevel>213.1,
	IF($mvWD_StorageLevel>213.7,8,IF($mvWD_StorageLevel>212.1,2*$SQ_US_WRP,
	IF($SQ_US_WRP>5,MIN(2*$SQ_US_WRP,15),0))),IF($SQ_US_WRP>5,MIN(2*$SQ_US_WRP,15),0)),0)
	
	MAX
	IF($mvWD_StorageLevel<210.1,IF($SQ_US_WRP<5,0,MIN(2*$SQ_US_WRP,15)),
	IF($mvWD_StorageLevel<213.1,IF($SQ_US_WRP<5,0,MIN(2*$SQ_US_WRP,15)),
	IF($mvWD_StorageLevel<213.7,IF($mvWD_StorageLevel>212.1,2*$SQ_US_WRP,
	IF($SQ_US_WRP<5,0,MIN(2*$SQ_US_WRP,15))),
	IF($mvWD_StorageLevel>212.6,8,MIN(2*$SQ_US_WRP,15)))))

C3 – less proportion discharge
 	
50_0.5
	Regular Release
	IF($mvWD_StorageLevel<=210.1, IF($SQ_US_WRP<0.5,0,MIN(0.5*$SQ_US_WRP,15)),0)
	
	Excess
	IF($mvWD_StorageLevel>212.1, IF($mvWD_StorageLevel>212.6,
	IF($mvWD_StorageLevel>213.5,6, IF($mvWD_StorageLevel>212.5,3,
	IF($SQ_US_WRP>0.5,MIN(0.5*$SQ_US_WRP,15),0))),
	IF($SQ_US_WRP>0.5,MIN(0.5*$SQ_US_WRP,15),0)),0)
	
	MAX
	IF($mvWD_StorageLevel<212.1,IF($SQ_US_WRP<0.5,0,MIN(0.5*$SQ_US_WRP,15)),
	IF($mvWD_StorageLevel<212.6,IF($SQ_US_WRP<0.5,0,MIN(0.5*$SQ_US_WRP,15)),
	IF($mvWD_StorageLevel<213.5,IF($mvWD_StorageLevel>212.5,4,
	IF($SQ_US_WRP<0.5,0,MIN(0.5*$SQ_US_WRP,15))),
	IF($mvWD_StorageLevel>212.6,8,MIN(0.5*$SQ_US_WRP,15)))))

7 Attachment 3 – Other analytes

The Source modelling simulates only flow, TN, TP, NOx and SRP, however:

- **our monitoring data provides analysis for a broad range of analytes** for the 2014-2020 period. Where elevated concentrations have been observed, they have not been at levels known to cause toxicity **and have not resulted in deterioration of biological indicators**. The Part A report (Sydney Water, 2021):
    - confirms the importance of the key analytes used in the modelling: *"Of the key parameters, total nitrogen, total phosphorus and chlorophyll-a have been evaluated in greater detail. This is because these analytes were determined to be the main drivers of stream quality, were monitored routinely and most frequently (enabling more statistical power), and are known to be elevated in wastewater discharges."*
    - focuses on Total nitrogen (TN), Total phosphorus (TP) and bioavailable forms Oxidised nitrogen (NOx-N) and Soluble reactive phosphorus (SRP) but considers trends, analysis and interpretation of the waterway concentrations observed for Ammonia (Amm-N), Conductivity, Dissolved oxygen saturation (DOsat), Faecal coliforms (FC), pH, Turbidity/Total Suspended Solids (TSS), Temperature, Total metals – aluminium, arsenic, boron, copper, lead, manganese, nickel and zinc.
- The **analytes monitored at Picton are extensive.** In addition to the analysis provided in our Part A report, monitoring data provided to the EPA includes a broad range of non-trivial pollutants, with regular monitoring particularly since 2014:

Enterococci	Total Chlorine	Total Aluminium
Faecal Coliform	Chloride	Filtered Aluminium
	Fluoride in solids	Total Antimony
Ammonia NH3-N		Filterable Antimony
Total Kjedahl Nitrogen	Field dissolved oxygen	Arsenic
Total Nitrogen	Percent Dissolved Oxygen	Filterable Arsenic
Oxidised Nitrogen	pH	Barium
Total Phosphorus	Temperature	Filterable Barium
Ortho Phosphorus		Total Beryllium
Filtered Total Phosphorus	Conductivity	Filterable Beryllium
	Total Dissolved Solids	
Total Suspended Solids	Alkalinity (Bicarbonate)	Total Calcium
Turbidity	Alkalinity (Carbonate)	Soluble Calcium
Total Organic Carbon	Alkalinity (Total)	Total Cadmium
	Sulphate	Filterable Cadmium
Chlorophyll – a		Total Chromium
Total Algal Count	Boron *	Filterable Chromium
Total Biovol	Filterable Boron *	Total Cobalt
Total Cyanobacteria	Molybdenum *	Filterable Cobalt
Potentially Toxic Algae	Filterable Molybdenum *	Total Copper
Potentially Toxic Biovol	Total Nickel *	Filterable Copper
Potentially Toxic Cyanobacteria	Filterable Nickel *	Total Iron
Cyanobacteria Biovolume	Zinc *	Filtered Iron
Total Colonies	Filterable Zinc *	**Continues next page**

Total Lead	Selenium	Total Sulphur
Filterable Lead	Filterable Selenium	Filterable Sulphur
Total Lithium	Total Silicon dilution	Total Thallium dilution
Filterable Lithium	Filterable Silicon	Filterable Thallium
Total Magnesium	Silver	Total Tin dilution
Soluble Magnesium	Filterable Silver	Filterable Tin
Total Manganese	Total Sodium	Total Titanium dilution
Filterable Manganese	Filterable Sodium	Filterable Titanium
Total Potassium	Total Strontium dilution	Total Vanadium dilution
Filterable Potassium	Filterable Strontium	Filterable Vanadium

** Metals such as boron, molybdenum, zinc and nickel were marginally elevated downstream of the discharge. These levels were well below concentrations that are toxic to aquatic organisms*. Section 5 of the Part A Waterway Assessment report

- **Limitations of both modelling and monitoring make it impossible to '100%' accurately simulate** current and future conditions - particularly the variable discharge concentrations and the potential changes in complex ecological environments like Stonequarry Creek.
    - The Source model does not simulate all processes across a catchment perfectly. The assumed baseflow concentrations lead to a more constant concentration than is observed in reality for some sites. The assumed stormflow characteristics do not perfectly match the trends observed in monthly sampling data. The differences may be both in model limitations and in water quality sampling resolution.
    - Comparison of the modelled and monitoring statistics cannot be expected to be perfect across all monitored sites in a catchment, for all analytes. Whilst imperfect, these modelling tools are the best tools available, and provide greater insights than from simplistic mass balance simulations.
    - The model calibration does not use any observed data as a single point of truth to "match" – but rather as information that can assist in setting the parameters in the model that are trying to represent the complex processes across the catchment.
    - The value of the calibrated Source model is in testing a range of management configurations (treatment, reuse, discharge) across many years of climate data, for current or future inflow conditions. In these cases the comparison between scenarios is the most useful insight. Again the individual concentration statistics are not predictive, but a scenario with higher modelled concentrations reflects mechanisms that are likely to occur in reality and result in higher concentrations if the scenario was implemented compared with an alternative lower concentration scenario.
    - The model can also help us understand the predicted variability year to year (across our time series from 1991 – 2018) and characterise a range of other factors that change as we change management approaches.
    - Sensitivity testing of the many assumptions in the model ensures confidence in the outputs, and the suitability of the model to test future flow scenarios and compare management options. For the current and future scenarios considered, there are

notable differences in concentrations, volumes and discharge regimes. These differences can help guide a preferred management approach, despite the model assumptions and imperfect data inputs.

- **Additional analytes in the model presents further challenges.**
    - There are models that can simulate additional processes and analytes; however many more inputs are then needed to provide sufficient information to calibrate how analytes vary in a complex and dynamic environment. Models that are successful in simulating a broader array of analytes require extensive survey and monitoring information to represent the environment and processes that the model tries to describe.
    - The principle of parsimony in a modelling context suggests that the most acceptable simulation will be achieved with a model that involves only as many parameters and assumptions as is required to represent the system satisfactorily. Where additional analytes are represented, many more parameters are needed to describe how these analytes vary. There is a risk that the complexity results in multiple confounding factors that may distort the differences between scenarios in ways that are not expected and they may not confidently simulate the processes as intended.
    - The modelling parameters and assumptions need to be robustly represented by processes with a solid line of evidence to support them. Stretching the model capabilities may weaken the lines of evidence that support the simulation of the analytes.
    - The modelling tools are ultimately intended to help make management decisions – in highly dynamic environments. We can understand straight forward changes (increased reuse, increased treatment, changes to discharge rules), The more complex aspects of ecosystem processes are much more challenging to simulate, particularly in waterways with highly variable flow and water quality.

- **Catchment impacts are known to occur** (upstream of our discharge), highlighting the risk to waterway health from untreated stormwater across the catchment and further complexity and variability that may not be able to be simulated in model representations of the catchment (or monitored with regular monthly sampling of waterway concentrations). This is relevant for all analytes, including toxicants. In addition to investigating nutrient offset projects to reduce impacts from stormwater and other sources, our monitoring approaches are seeking to provide a better understanding of ecological health, to guide further interventions.

- Our **monitoring approached are being refined, with greater focus on biological indicators** at multiple trophic levels. Indicator organisms are a better way to assess whether fluxes in water quality are having a detrimental impact to waterway health. Monitoring of additional sites downstream of our discharge point has commenced with a range of opportunities to strengthen insights through our monitoring plans for 2021-22, and subsequent years.