Picton WWTP Discharge

Review of Environmental Factors: Hydrology

Final

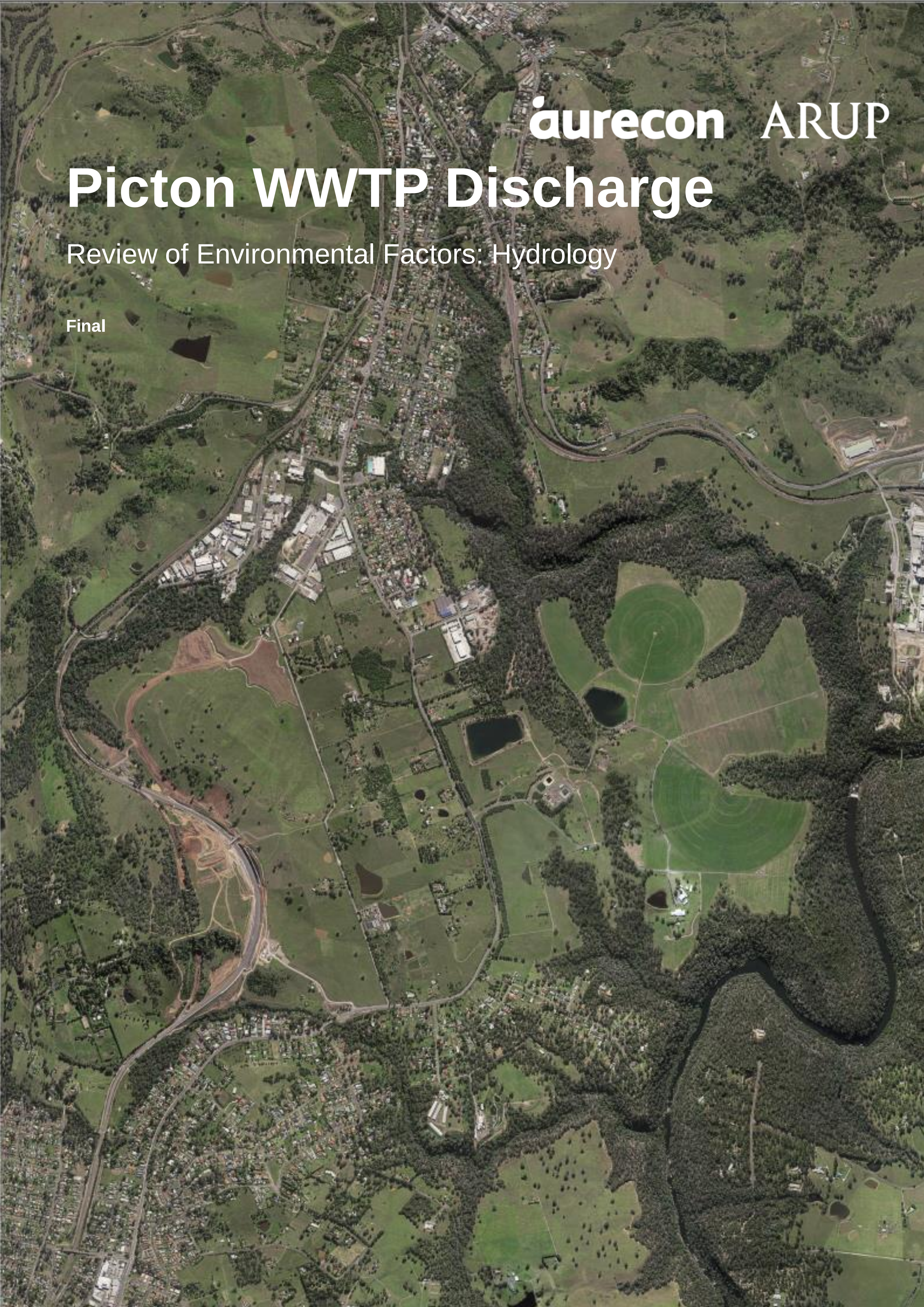

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Table of Contents

Figures

Tables

1 Introduction

1.1 Background

Sydney Water is developing a strategy to expand the Picton Wastewater Scheme to service new connections and growth in the area. This includes consulting with the Environmental Protection Agency (EPA) and Wollondilly Council as well as other stakeholders and the community to identify options that:

- enable development
- are cost effective
- maintain local waterway health.

The existing effluent management system includes effluent storage, irrigation at Picton Farm and precautionary discharges to Stonequarry Creek. Picton WRP currently has an average dry weather flow (ADWF) treatment capacity of 4 ML/d (secondary and tertiary treatment trains).

Recycled water is used to irrigate up to 119 hectares of pastureland at Picton Farm. Precautionary discharges occur when excess effluent is discharged to Stonequarry Creek via the Western Dam in accordance with flow and volume limits in EPL 10555 (known as the precautionary discharge rules). Discharges follow a drainage channel, which flows to Stonequarry Creek at a location about 1.5km upstream of the Nepean River.

Increased development in the area has led to a significant rise in wastewater coming into the Picton Water Recycling Plant. This additional wastewater means the options to use or release the water once it’s treated are at capacity, that is, the farm is unable to use any more water and the conditions of Sydney Water Environmental Protection Licence prevent discharging more treated water (Sydney Water, 2020).

Aurecon and Arup have been engaged by Sydney Water to develop the Review of Environmental Factors (REF) for the Picton Water Recycling Plant (WRP) license variation application (LVA) to assess the following three potential future discharge scenarios:

- Additional Stonequarry Creek discharge over and above the current precautionary discharge in combination with an additional 60ha of irrigable area (Scenario 2)
- New discharge location on the Nepean River, downstream of Maldon weir but upstream of the confluence with Stonequarry Creek in combination with an additional 60ha of irrigable area (Scenario 3)
- New discharge location on the Nepean River, downstream of Maldon weir but upstream of the confluence with Stonequarry Creek with no expansion to the current irrigable area (Scenario 4)

1.2 Site plan

The Picton wastewater scheme catchment is indicated in **Figure 1-1**, along with the identified growth areas and location of the WRP and associated farm.

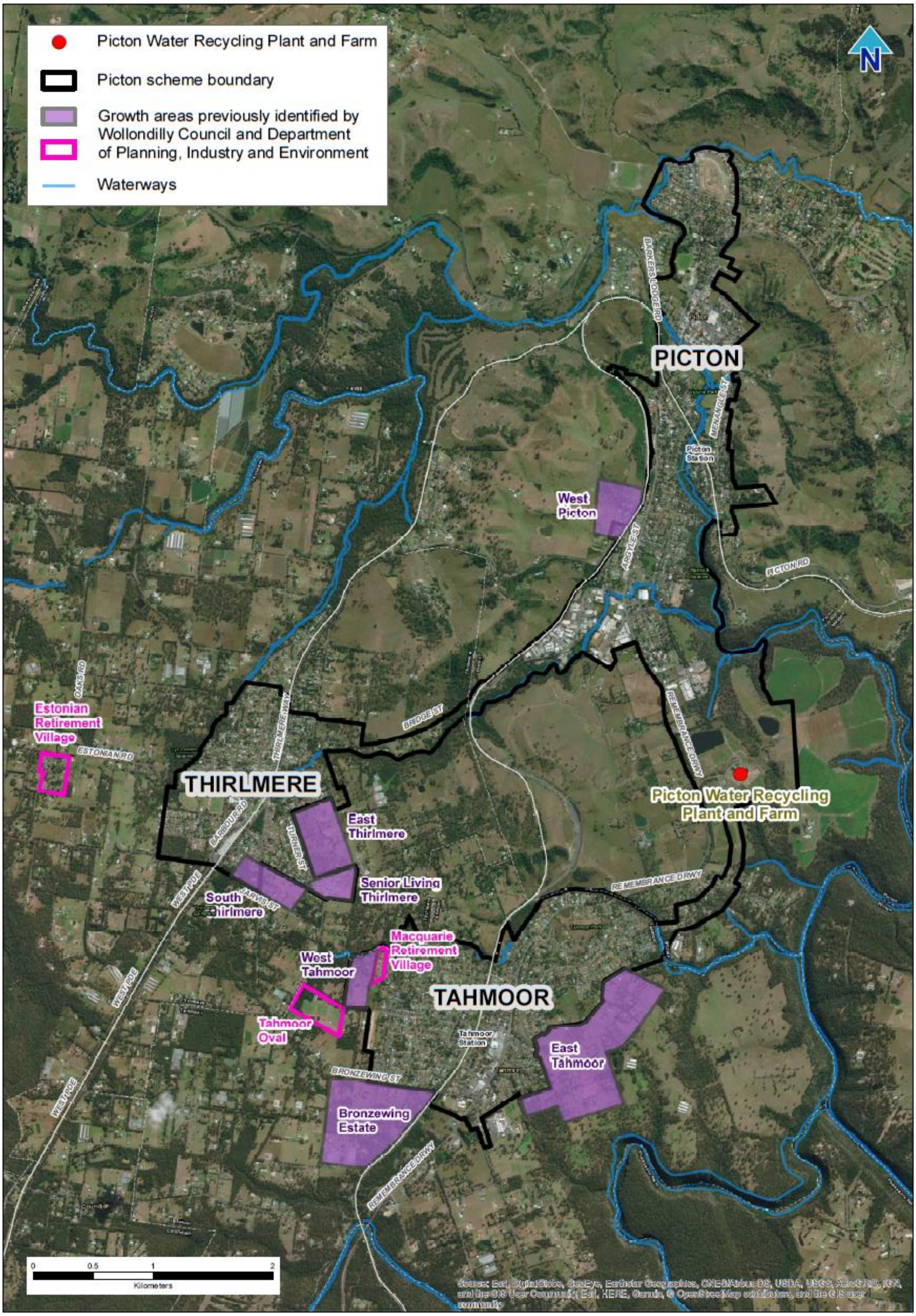


Figure 1-1 Picton wastewater scheme catchment

2 Assessment methodology

The following general tasks were carried out as part of this REF:

- Desktop review of available information and data collation
- Existing environment description
- Discharge impact to local hydrology assessment

To assess the impacts on the local hydrology, several critical flows need to be considered. In natural systems, diverse and varying flows within a river or creek support the local ecology in different ways, as shown in **Figure 1-1**.

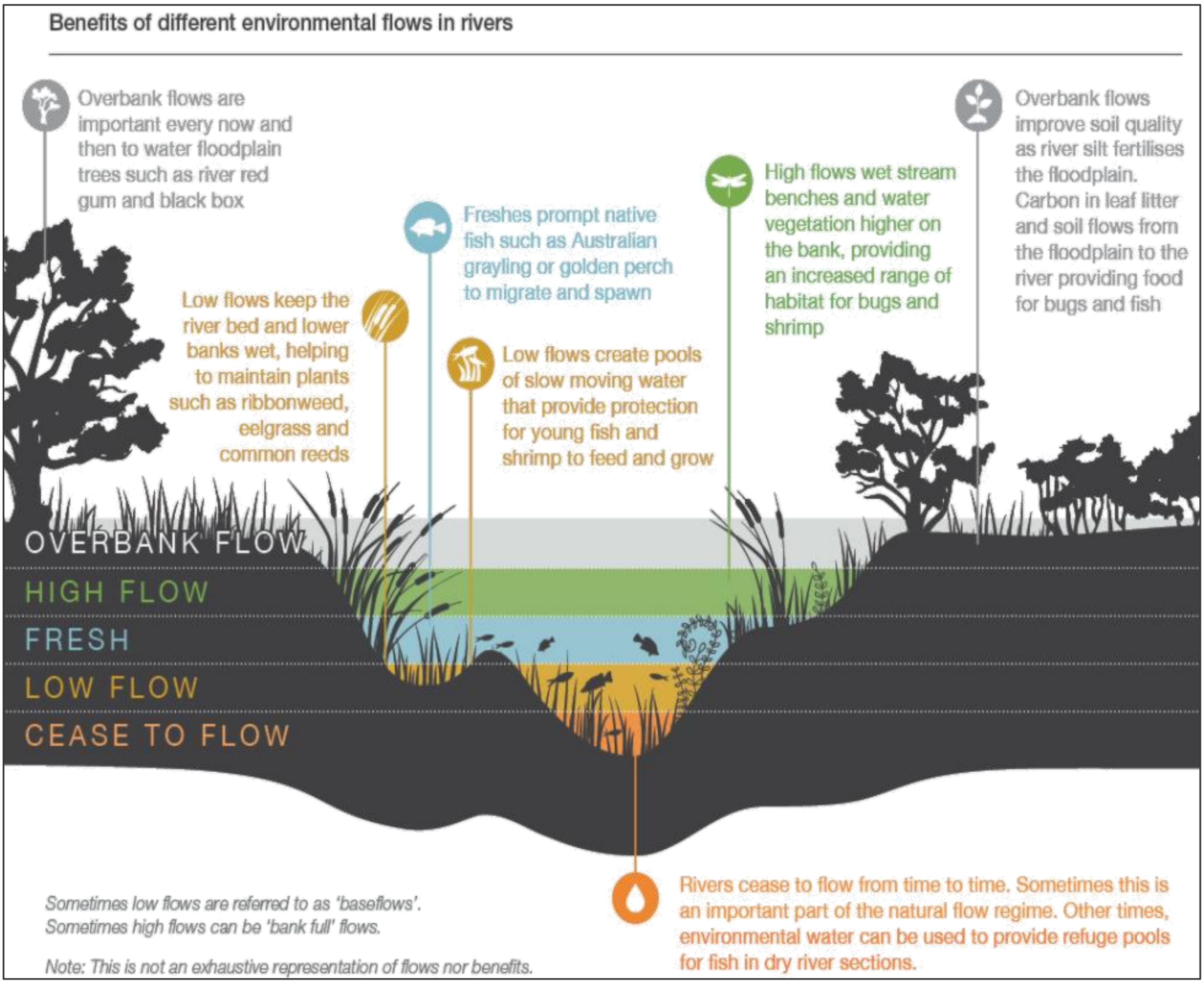


Figure 2-1 Benefits of different environmental flows in rivers (VEHW, 2020)

The proposed discharge regime is expected to result in the highest proportional changes to no-flow, low flow and freshes flow rates. Changes to high flows and overbank flows are expected to be minimal.

To ensure consideration is given to the potential impacts on the relevant flow categories the hydrologic metrics relevant to urban settings as recommended in the *Stormwater and Outflow Planning Controls for Waterway Health: Applying the Urban Streamflow Impact Assessment* (USIA) (Streamology Pty Ltd, 2019) were considered. These metrics are described in further detail in **Section 5.1.1**. As the proposed discharge will add water to the waterways, focus was given to the critical low flow regimes which could be negatively impacted.

Flow and water quality modelling for Stonequarry Creek in the broader Nepean River catchment has been undertaken. The model was developed using the eWater Source software and was calibrated to observed data prior to being used to model potential future scenarios.

For the purpose of impact assessment, four different scenarios were modelled as listed and described in **Table 2-1**.

Table 2-1 Scenarios assessed

Scenario ID	Discharge location	Avg inflow *(ML/d)	Additional irrigated area* (ha)	Estimated avg future discharge (ML/d)
1	Stonequarry Creek	2.7	0	1.35
2	Stonequarry Creek	4	60	1.66
3	Nepean River	4	60	1.75
4	Nepean River	4	0	2.35

*Scenario 1 assumed an inflow rate consistent with the baseline “2014-2019” average rates, Scenarios 2 through 4 assessed the system under expected future conditions with an average inflow rate of 4 ML/d

Simulated flow data for relevant locations up and downstream of the two considered discharge locations were generated by the model. The locations are shown in **Figure 2-2** and additional metadata for each location provided in **Table 2-2**.

Table 2-2 Modelled flow locations

Location ID	Description	Catchment area (ha)	Simulated Data Period
N911A/B	Stonequarry (SQ) Creek directly upstream of the discharge location	9,560	1991-2018
N911 (Gauge: 2122006)	Stonequarry (SQ) Creek downstream of the discharge location (SWC Gauge location)	9,600	
N92: Nepean at Maldon Weir (Gauge: 212208)	Nepean upstream of SQ and upstream of the potential discharge location (WaterNSW Gauge location)	17,320	
Nepean u/s of SQ	Nepean upstream of SQ and downstream of the potential discharge location	17,320	
N91	Nepean River downstream of Stonequarry Creek	27,080	

Figure 2-2 Location of the modelled flow

3 Existing environment

3.1 General description

The Picton Water Recycling Plant (WRP) treats wastewater from about 4,000 homes and businesses in Picton, Tahmoor, Thirlmere, Bargo and Buxton. The Picton Wastewater Scheme includes:

- Pipelines and pumping stations
- Picton Water Recycling Plant, which was originally designed to treat an average of 2.6 ML/d of dry weather flows (DWF), and has recently been upgraded to treat 4 ML/d of average DWF
- Farm – irrigating with treated effluent currently on 119 ha
- Precautionary discharge to SQ – for excess effluent under conditions by the EPA

Once wastewater is treated, it's used to irrigate 119 hectares of crops on the Sydney Water-owned Picton Farm. In limited circumstances, excess recycled water can be released into Stonequarry Creek. The frequency and amount of treated water that can be released must comply with conditions set by the NSW Environment Protection Authority.

Sydney Water has been improving the Picton Wastewater Scheme for several years. This includes:

- increasing the volume of wastewater that can be treated at the plant
- building pilot wetland cells to assess how well they remove nutrients from the treated wastewater.

3.2 Catchment description

Stonequarry Creek is a tributary of the Nepean River, and has a catchment area of approximately 84 km^2. Stonequarry Creek receives inflows from five main tributaries: Racecourse Creek from the east, Crawfords Creek from the north, and Cedar, Mathews and Redbank Creek to the west of Picton. The Stonequarry Creek catchment is characterised by grassed hills and areas of moderate to dense tree cover, with urban areas within the Picton township and parts of Thirlmere to the south.

Upstream of Picton WRP, the banks of Stonequarry Creek comprise of native and exotic vegetation, and the creek itself is a series of shallow pools. Redbank Creek (a tributary of Stonequarry Creek which discharges approximately 1.2 km upstream of the WRP discharge location) is relatively narrow, impacted by mining and urban development and natural springs were historically observed in the area. Stonequarry Creek banks are eroded and covered by much exotic vegetation. Downstream of Picton WRP, Stonequarry Creek banks are heavily disturbed, being a mix of bare earth, boulders and native and exotic vegetation. The Picton WRP precautionary discharge point is in a heavily eroded steep gully flowing into a small riffle section. Teatree Gully discharges to Stonequarry approximately 440 m downstream of the WRP discharge location. Any accidental spills from the plant's Eastern Basin will discharge via this gully.

The reach of the Nepean River between Maldon Weir and the confluence with Stonequarry Creek is a series of shallow pools and small riffles fed by the weir. Sandstone boulders dominate the banks with native and exotic vegetation. Downstream of the Stonequarry Creek and Nepean River confluence, there is a wide slow flowing deep pool used for public recreation. The eastern bank is disturbed, the western bank is less so, as it is harder to access. The banks are a mixture of sandstone outcrops with native and exotic vegetation.

Additional description of the local fluvial geomorphology is provided in **Section 3.5**.

There are two stream flow gauges recording the flow in Stonequarry Creek. Contributing catchments and land use zoning (NSW DPIE, 2020) are indicated in **Figure 3-1,** with the zone classification shown in **Table 3-1**.

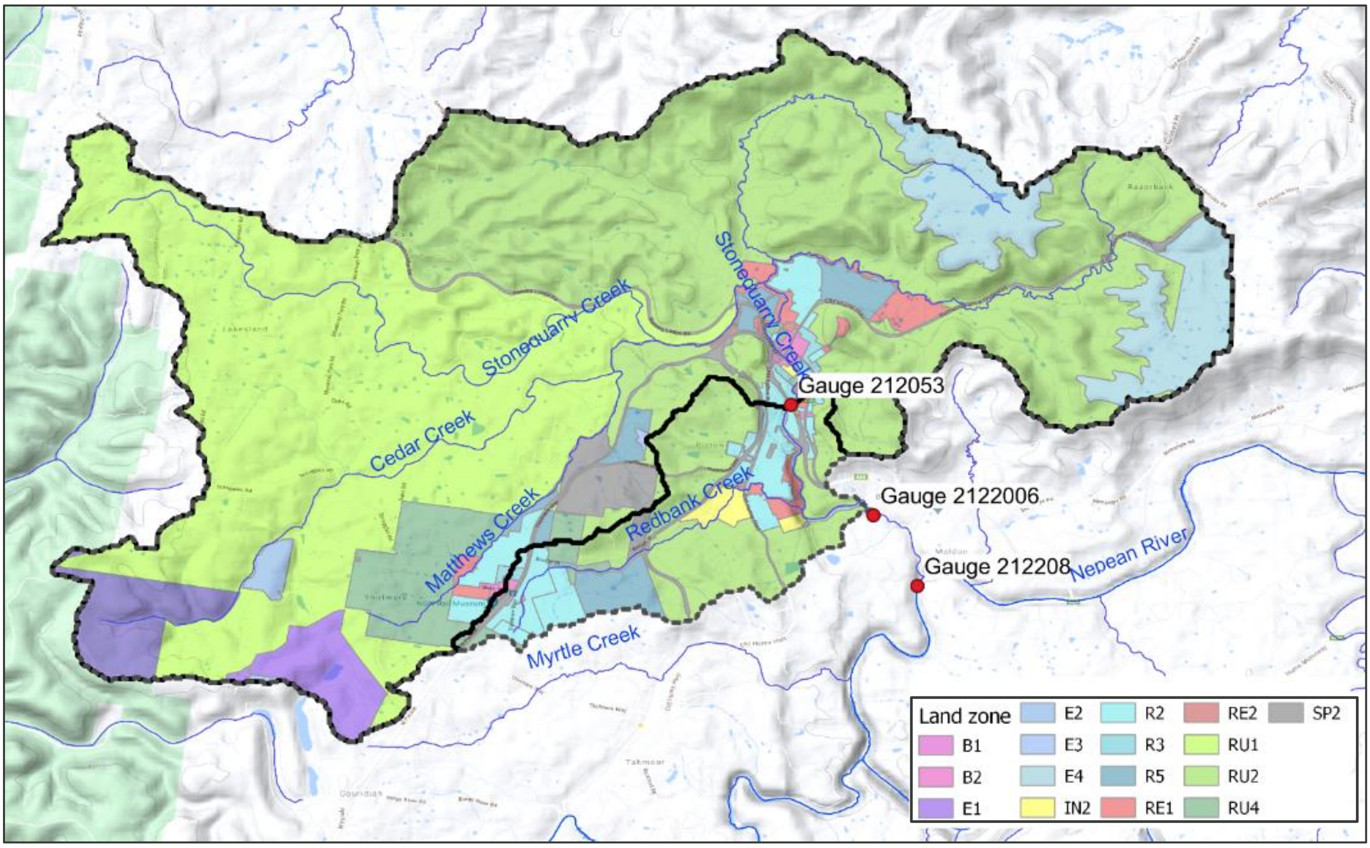


Figure 3-1 Stonequarry Creek gauged locations - Catchment delineation and land use zoning

Table 3-1 Land zone classification

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

Land zoning upstream of the Picton township is primarily classified as Primary Production and Rural landscape. Picton and Thirlmere, lower down the catchment, are urbanized zones, with a mix of residential, industrial and infrastructure classified areas.

3.3 Flow monitoring data

The details of the three local streamflow gauges (two on Stonequarry and one on the Nepean River, directly upstream of Stonequarry) are summarised in **Table 3-2**.

Data is available for streamflow gauge 212053 Stonequarry at Picton township (Webster Street) - Downstream of the weir at the Picton Baths, (approximately 3 km upstream of the WRP discharge point) from December 1990 at a sub-daily timescale (generally 10 to 15-minute intervals). Data is also available for gauge 2122006 Stonequarry Creek at Picton WRP, approximately 60 m downstream of the Picton WRP discharge point) since June 1997 at 15-minute intervals.

A second relevant WaterNSW gauge is located on the Nepean River at Maldon Weir. The gauge is directly upstream (±150m) of the confluence with Stonequarry Creek and adjacent to the proposed new discharge from the Picton WRP to the Nepean River.

Table 3-2 Local streamflow gauges

ID	Watercourse	Details
212053	**Stonequarry**	**Owner/operator:** WaterNSW **Date commenced:** November 1990 **Location:** Stonequarry at Picton township (Webster Street) - Downstream of the weir at the Picton Baths **Catchment area:** 83 km^2 **Primary land uses:** Rural and primary production (farming) **Distance upstream of the WRP discharge location:** 3.2 km
2122006	**Stonequarry**	**Owner/operator:** Sydney Water **Date commenced:** June 1997 **Location:** Stonequarry Creek at Picton WRP **Catchment area:** 96 km^2 **Primary land uses:** Rural and primary production (farming) **Distance downstream of the WRP discharge location:** 30-40 m
212208	**Nepean**	**Owner/operator:** WaterNSW **Date commenced:** April 1970 **Location:** Nepean River @ Maldon weir. Weir 100m d/s from gauge plates **Catchment area:** 865 km^2 (190km^2 below Pheasants Nest Weir which is a controlled discharge location)

The Sydney Water flow gauge (and other flow gauges in this area) are gauging natural streams and have a range of challenges with data accuracy. Erosion, sedimentation, changes to vegetation and accumulation of debris can all impact the flow gauges. Ratings are done multiple times each year to check gauge accuracy and adjust the relationship between monitored water level and flow.

At times there are discrepancies between the flows reported at the WaterNSW gauge and those reported at the Sydney Water gauge. Sydney Water's primary interest lies within the low to mid-range flows as this governs the allowable precautionary discharge volumes. Several potential reasons for the discrepancies have been noted, including that the WaterNSW gauge has been setup to accurately measure medium to high flows with less emphasis on the low flow range. Given the current understanding, the Sydney Water gauge data is suitable to define the low flow regime.

It must be noted that the challenges associated with accurately reporting flows on a continuous basis have been acknowledged during the data analysis and in the interpretation of the outcomes of this work. The dynamic nature of natural ephemeral/intermittent streams, impacts from human activities, the challenges with gauging and the natural variability in hydrology of catchments like Stonequarry Creek makes characterisation of creek flow a complex task – with care needed in interpretation of simple statistics.

3.4 Characterising the flow regime

Stonequarry Creek

The flow regime in Stonequarry Creek can be studied by plotting the flow duration curve, as shown in **Figure 3-2**. Daily average WRP discharge rates, recorded between January 2014 and July 2020, were subtracted from the average flowrates recorded at the Sydney Water flow gauge in Stonequarry Creek (2122006), to approximate the upstream flow conditions as shown.

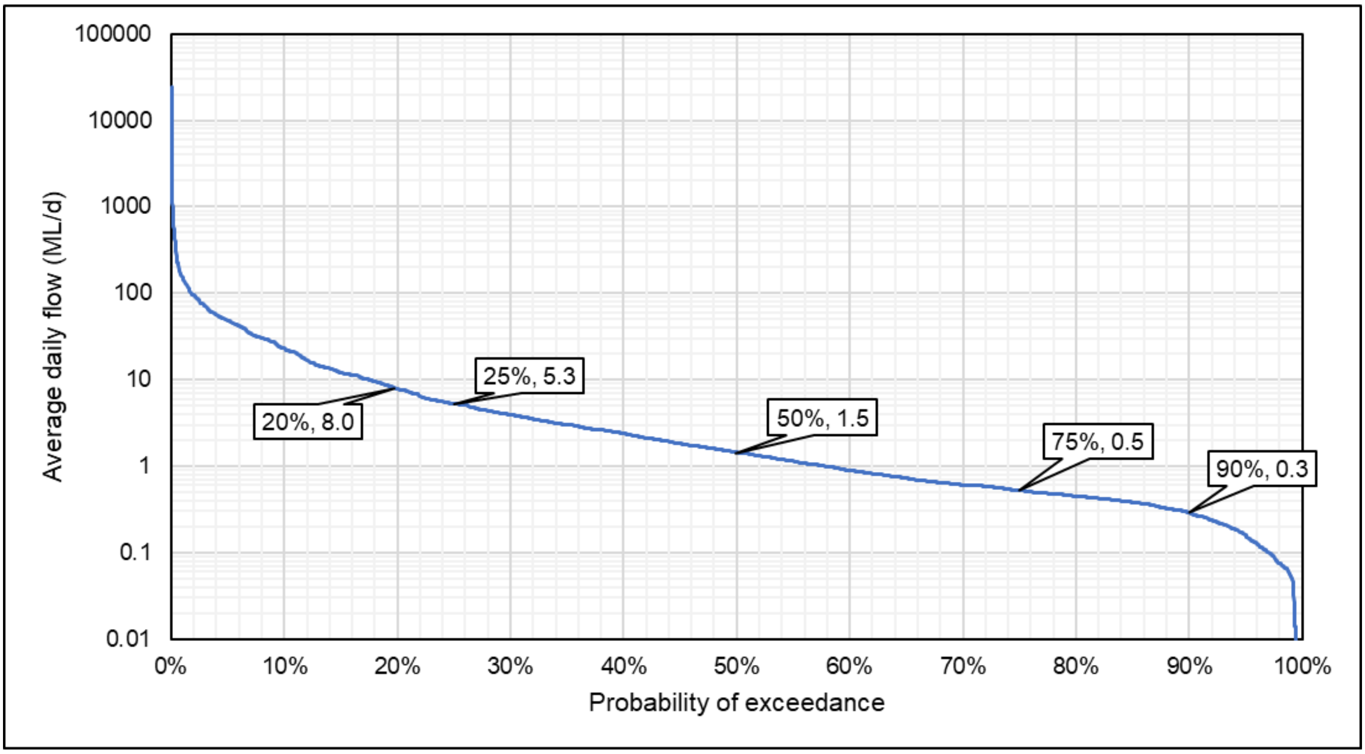


Figure 3-2 **Stonequarry Creek upstream of WRP discharge - Flow duration curve (Jan 2014 – Jul 2020)**

Key percentile values listed below are noted on the graph for the period assessed:

- 25th: Representation of high flows, 25% of the time the flowrates exceeded 5.3 ML/d
- 50th: Median flow rate of 1.5 ML/d. This is significantly different from the average flow rate of 21.7 ML/d due to rare but excessively high flood conditions influencing the average more than the median value.
- 75th: Representation of low flows, 25% of the time the flowrate is below 0.5 ML/d
- 90th: Representation of very low flows, 10% of the time the flowrate is below 0.3 ML/d
- 8 ML/d threshold value: The current EPL threshold above which discharge is allowed is 8 ML/d, over the assessed period these conditions were observed 20% of the time.

The original Picton WRP EIS (ERM Mitchell McCotter, 1996) indicated that the data available at the time (approximately 4.5 years) suggested flows in SQ were around 1 ML/ day and flood events tended to be of short duration. Flows exceeding 8 ML/d generally occurred on around 50 days per year (or 13.7% of the time). This is considerably less than the current estimate of 20%, which could indicate a change in upstream catchment or hydrology but could also purely be a result of varying climatic conditions over the short periods compared, and the challenges in flow gauging in Stonequarry Creek.

The portion of flows less than 10 ML/d for both the measured downstream and calculated upstream flow duration curves are provided in **Figure 3-3.** The curves indicate the recent impact on stream hydrology primarily due to the current Emergency Operating Protocol (EOP) currently in place. It shows a slight increase in flow rates between the 0.5 and 10 ML/d range (70th to 18th percentile), with 50th percentile flowrates increasing from 1.5 ML/d to 2.0 ML/d.

Though the proportional increase in this range is not insignificant, the resultant impacts are expected to be minimal. Instead of experiencing flows of 1.5 ML/d or less for half of the time, the creek is seeing flows of 1.5 ML/d or less for 44% of the time. A change that can easily be brought about by minimal natural fluctuations in climatic conditions, i.e. a slightly wetter period.

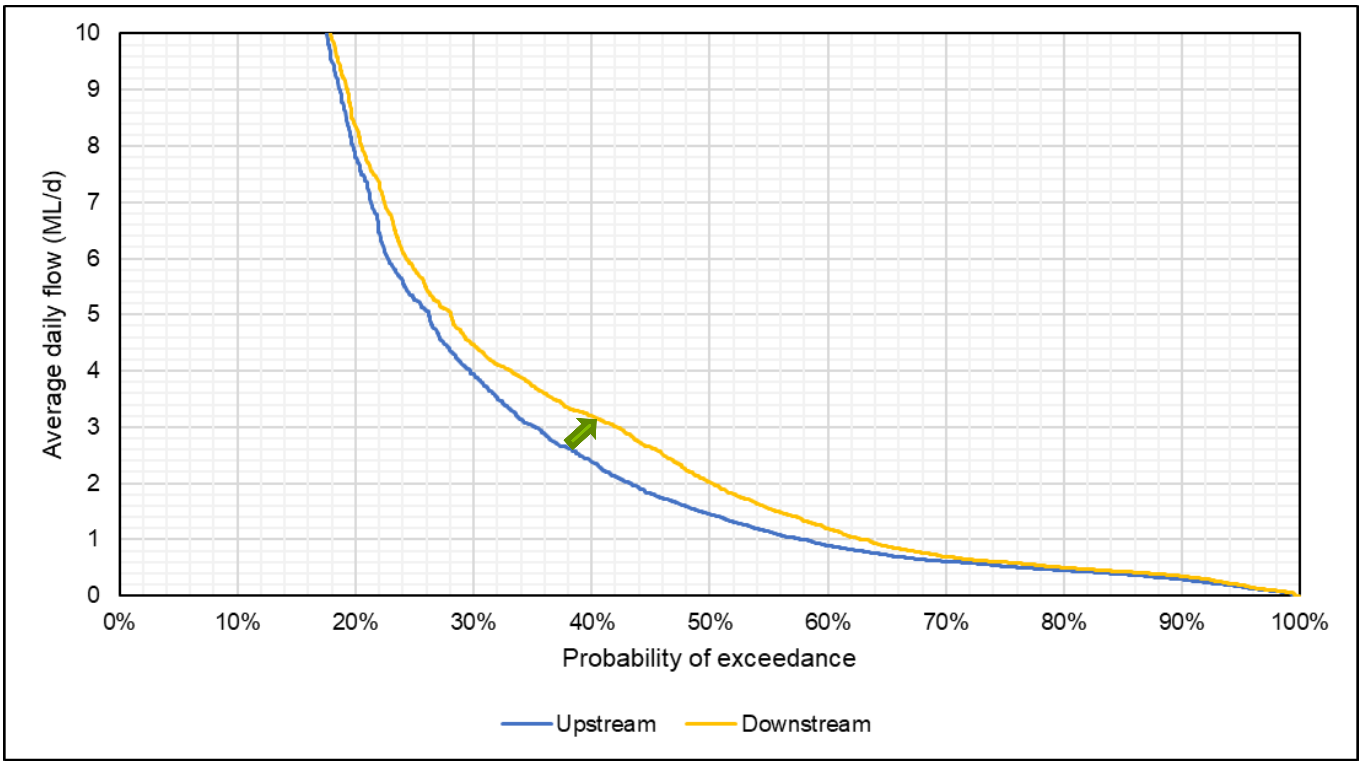


Figure 3-3 SQ upstream and downstream of WRP discharge - Flow duration curves (Jan 2014 – Jul 2020)

Monthly average flow rates are highly variable (see **Figure 3-4**), with extended periods where the monthly averages are below 1 ML/d, and also periods where the monthly average is above 10 ML/d. The major flooding events in mid-2016 and early 2017 show monthly averages above 100 ML/d.

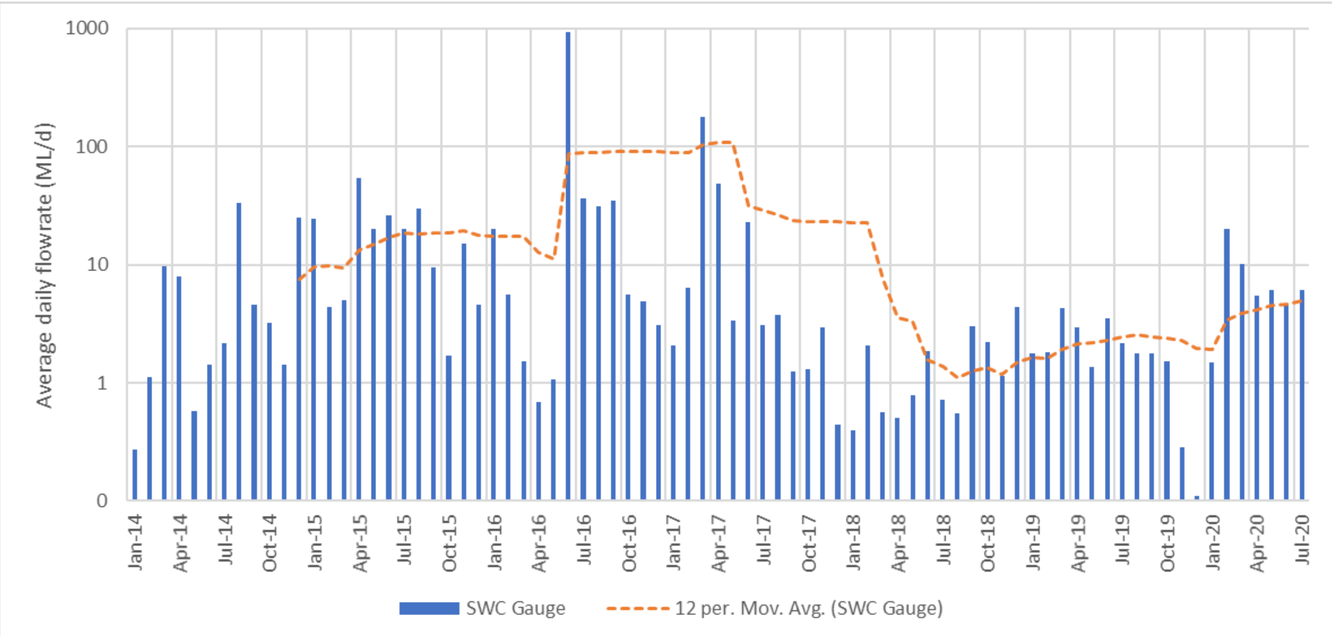


Figure 3-4 Average monthly flowrates – SWC Gauge (Jan 2014 – July 2020)

Nepean River

Flow records for the Maldon Weir gauge was obtained from the WaterNSW Real Time Data site (WaterNSW, 2020). The gauge has been active since July 1973, and the 20-year record (Aug 2000 – Jul 2020) has been assessed and compared to the corresponding period available for the SWC Stonequarry gauge (Jan 2014 – Jul 2020). The flow duration curves for both these time periods are provided in **Figure 3-5**.

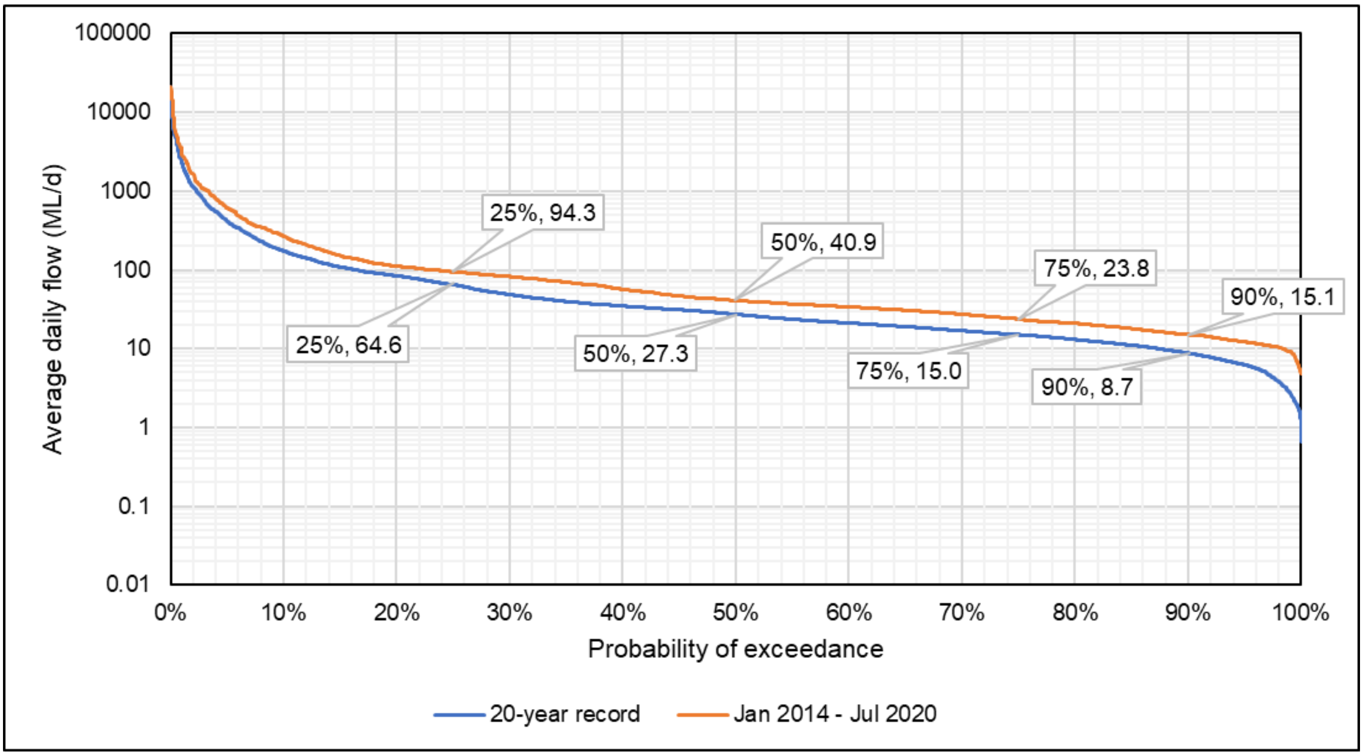


Figure 3-5 **Maldon Weir Gauge - Flow duration curves**

The curves indicate a general wetting or increase in discharge over the most recent 6.5-year period compared to the complete 20-year dataset. This is primarily attributed to the addition of environmental releases in recent years.

As per the WaterNSW environmental flows web page: *WaterNSW introduced daily variable flows from the Upper Nepean dams and water supply weirs for environmental purposes from 1 July 2010. Improvements to weirs along the Hawkesbury-Nepean River help the new flows make it downstream, with new fishways to allow fish to move more freely up and down the river to breed. At times of low flow, all inflows to the Upper Nepean dams and water supply weirs are released to the downstream river.*

Gauging stations for high and low flows have different requirements, and often need to be located within different reaches with specific geomorphic characteristics to ensure accurate readings within the targeted range. The key objective of the Maldon Weir gauge is to accurately measure high flows and thus slight inaccuracies can be expected for the very low and "zero" flows measured. Bearing this in mind the key percentile values of the available dataset are noted on the graph and the 6.5-year record comparative values are listed below:

- 25th: Representation of high flows, 25% of the time the flowrates exceeded 94 ML/d
- 50th: Median flow rate of 41 ML/d. This is significantly different from the average flow rate of 193 ML/d due to rare but excessively high flood conditions influencing the average more than the median value.
- 75th: Representation of low flows, 25% of the time the flowrate is below 24 ML/d
- 90th: Representation of very low flows, 10% of the time the flowrate is below 8.7 ML/d

The monthly average flow rates are somewhat variable (see **Figure 3-4**), with most months recorded average flow rates of between 10 and 100 ML/d. Generally, the annual average tracks above 100 ML/d however following the dry spell in mid July 2017 through Jan 2020, this average dropped below 100 ML/d.

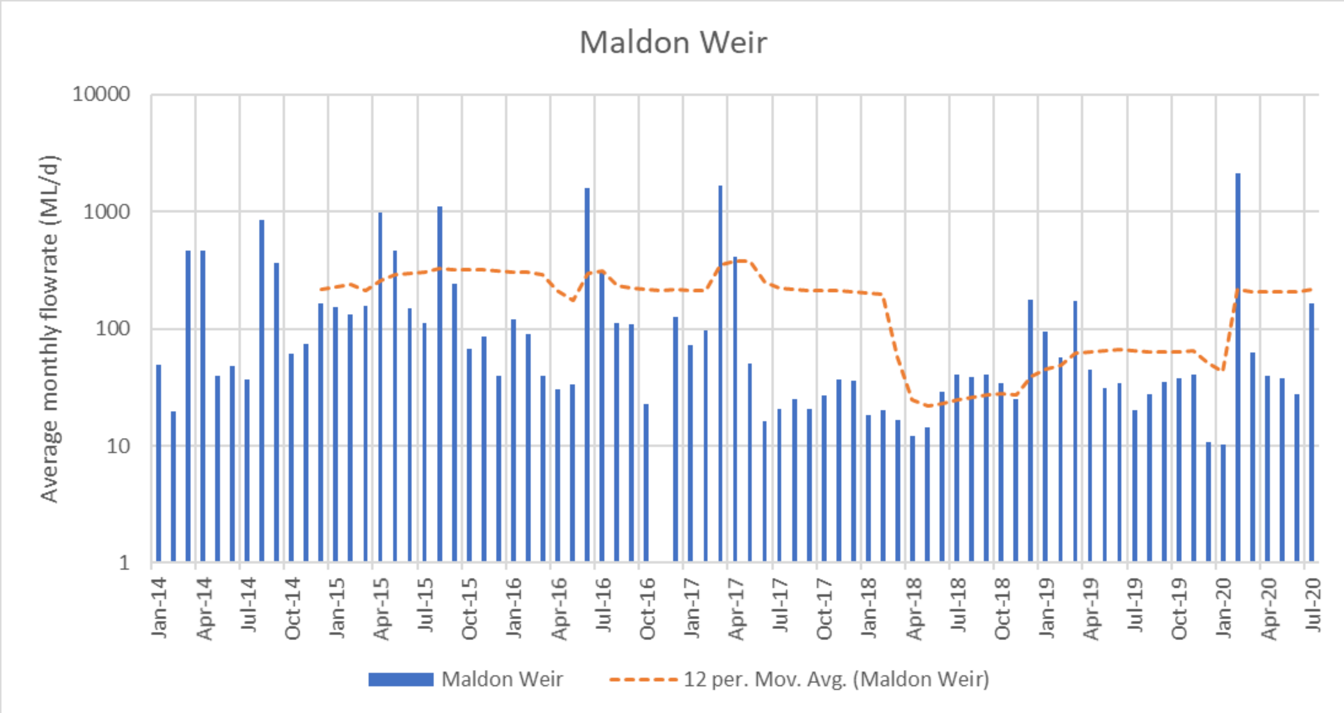


Figure 3-6 **Average monthly flowrates – Maldon Weir Gauge (Jan 2014 – July 2020)**

3.5 Fluvial geomorphology

This sub-section describes the physical form and functioning of the Stonequarry Creek and Nepean River.

Regional geology and soils

The area is located on the south-western edge of the Sydney Basin, which is dominated by sedimentary geology with some later (Tertiary) volcanic activity. Most geological units in the Picton area belong to the Triassic (225 to 180 million years ago) Sydney Basin Sequence. The higher ground consists of the Liverpool SubGroup of the Wianamatta Group. This subgroup consists mainly of shale with some sandstone beds and forms residual cappings on some hilltops.

Low lying areas are composed of Hawkesbury Sandstone which underlies the Wianamatta Group. The Hawkesbury Sandstone is a thick, uniform quartzose sandstone with occasional shale lenses. It is more resistant to erosion than the overlying Wianamatta Group. River downcutting through the Hawkesbury Sandstone has created the majority of the gorges in the Sydney region.

Local conditions

Geomorphological classification

The River Styles Framework was used in this assessment to form a description of rivers channel forms and processes and to incorporate the condition of the river reach and its likely recovery potential, based on the fragility of the river and its geomorphic condition (after Brierley and Fryirs 2005).

The River Styles classification is based on valley setting, level of floodplain development, bed materials and geomorphic units. Characterisation of the fluvial geomorphology of the study area was approached at reach scale (10s to 100s of m). The River Styles framework has provided a consistent way to define river character and behaviour (**Table 3-3**).

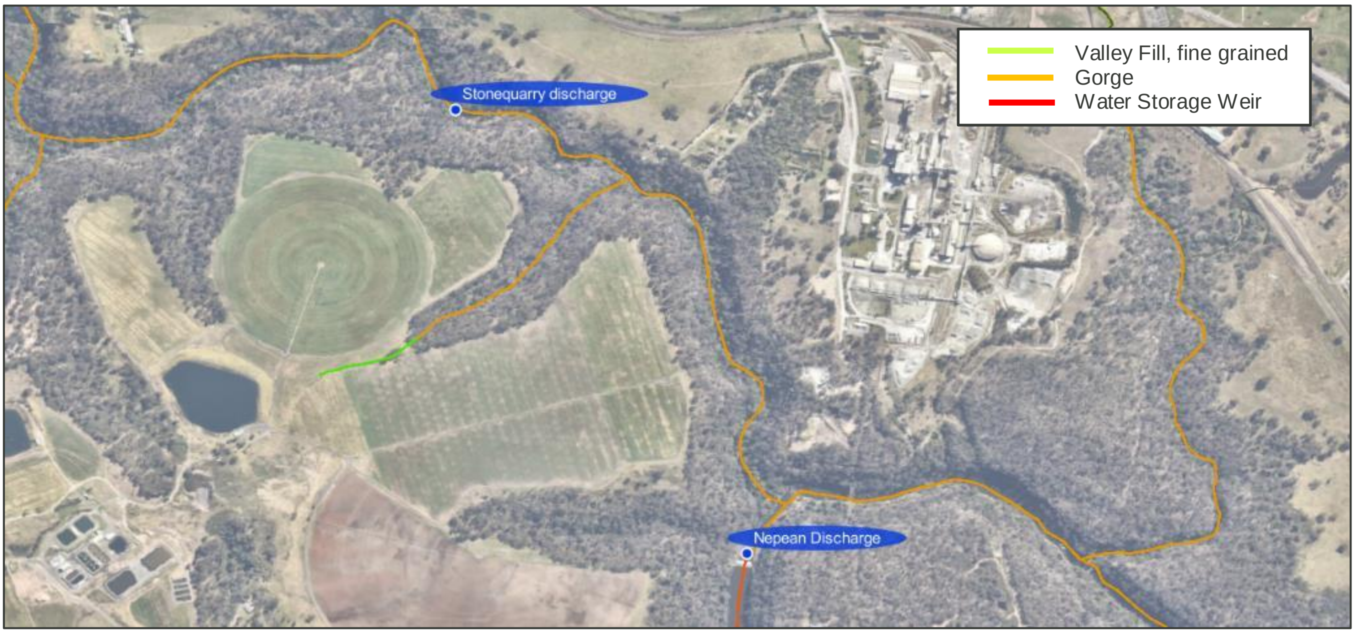


Figure 3-7 **Geomorphological classification at discharge locations (NSW DPIE, 2020)**

Table 3-3 **Geomorphological classification of project watercourses**

Watercourse	River Style	Confinement level	Margin control	Planform descriptor	Floodplain	Full bed matrix	Stream condition
Stonequarry Creek	CVS-Gorge	Confined valley setting-continuous	Bedrock	Low sinuosity	None	Bedrock	Good
Nepean River u/s of discharge point	Water storage - dam or weir pool	None	Bedrock or cohesive terrace	N/A	N/A	N/A	None
Nepean River d/s of discharge point	CVS-Gorge	Confined valley setting-continuous	Bedrock	Low sinuosity	None	Bedrock	Good
Teatree Gully Upstream	Valley Fill, fine grained	Laterally Unconfined Valley Setting - Discontinuous	Unconfined	None	Valley fill	Fine grained	Poor
Teatree Gully Downstream	CVS-Gorge	Confined valley setting-continuous	Bedrock	Low sinuosity	None	Bedrock	Good

The Nepean River downstream from the discharge point, Stonequarry Creek and Teatree Gully downstream are classified in the River Styles Framework as being in a confined valley setting with bedrock margin control and channel (NSW DPIE, 2020). Teatree Gully Upstream, however, has a laterally unconfined setting with fine-grained channel material. The Nepean River upstream from the discharge point is classified as a water storage pool because of the Maldon Weir instream structure.

Channel planform structure

Satellite imagery over the Upper Nepean is poor with low resolution and short-period records. Acknowledging this, aerial images of key selected watercourse sections (approximately 200 m length) were captured using the NearMap Vertical Historical Imagery Tool with the following criteria:

- Clearest images on record
- The most current image
- The oldest image

For completeness, historic aerial images of selected sites are provided in **Appendix A**. Due to the limitations of these images, no further analysis such as channel planform movements or lateral accretion (e.g. approach advocated by Downward *et al.* 1994) has been performed.

Site observations

Site observations support the River Styles Classification (see earlier 'Geomorphological Classification' text) but there are additional superficial deposits of fine-grained material present on terraces within both Stonequarry Creek and the Nepean River channel.

There are signs of active erosion along the section of Stonequarry Creek in the vicinity of the WRP, both up and downstream of the discharge location. The extent is generally minor and is mainly confined to about 0.5 to 1m above waterline. There is also evidence of some erosion in flood runners due to higher flows (AAJV, 2015).

(a) Bank erosion and establishment of riparian vegetation from the 2016 flood

(b) Bedrock pool at the end of a bedrock run showing some transitory sediment deposits

Figure 3-8 Stonequarry Creek typical channel structure (E2Designlab, 2019)

At the confluence of Stonequarry Creek and the Nepean River, there are exposed alluvial deposits on both banks, however, any erosion here could be caused by flows from either the Nepean River or Stonequarry Creek (AAJV, 2015).

(c) Maldon Weir with boulder / bedrock channel and occasional pools

(d) Maldon Bridge showing forested catchment, confined channel and bedrock outcrops

Figure 3-9 Nepean River typical channel structure (E2Designlab, 2019)

Stream orders

Stream ordering provides an indication of the relative size of a watercourse. Strahler's Stream order system, as prescribed by NSW DPI (2018a), is a simple method of classifying stream segments based on the number of contributing tributaries.

It is only necessary to determine the stream order of enough tributaries to identify if the stream at the location being assessed is greater than third order. If the stream at this location is greater than third order, this means the exemptions which only apply to first, second or third order streams will not be applicable. (NSW DPI, 2018a).

The Strahler stream orders for both Stonequarry Creek and the Nepean River at the assessed discharge locations were determined using the available NSW Hydro Line spatial data (NSW DPI, 2018b). Both watercourses have a order higher than five at the assessed locations.

3.6 Land use

Impacts from mining activities

Based on the available exploration and mining titles data (State of NSW, 2020), two coal mining leases have been registered within the catchment upstream of the Picton WRP discharge location. The extent of these leases is indicated in **Figure 3-10**. Both titles are held by Tahmoor Coal Pty Ltd and only ML1539 is currently active. The Tahmoor Coking Coal mine is an underground mining infrastructure that has been in operation since 1979, with longwall mining in the Bulli coal seam.

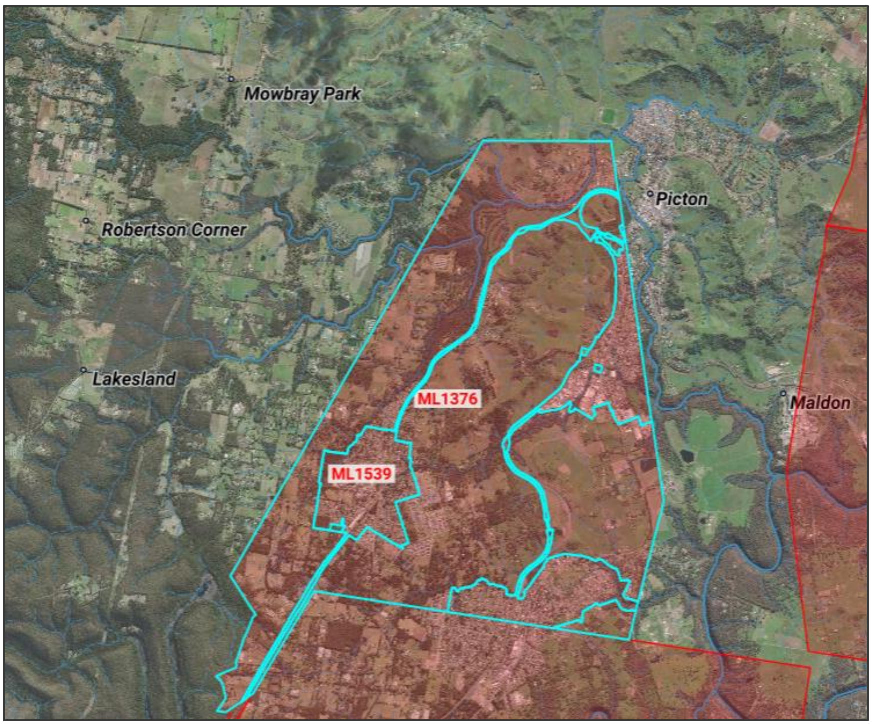


Figure 3-10 Coal mining leases (State of NSW, 2020)

The areas above and surrounding these mined sections have been classified as "Mine Subsistence Districts", the local extent of which is shown in in **Figure 3-11**. Mine Subsidence Districts define the area of control of the Mine Subsidence Board, which administers the Mine Subsidence Compensation Act, 1961. Districts are proclaimed in areas where there are potential subsidence risks from underground coal mining that has occurred or may take place in the future.

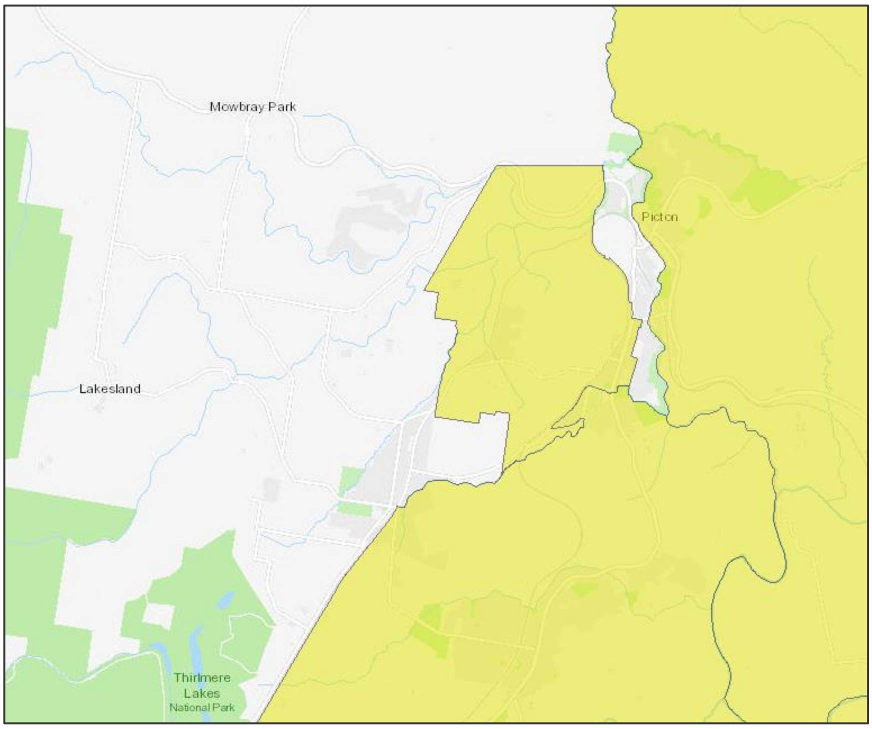


Figure 3-11 Mine Subsidence District (DFSI, 2020)

Localised subsistence in excess of 1.3 m has been observed in the Redbank Creek catchment (Sydney Water, 2020b). Sections of the creek bed and bank have been reported as fractured, buckled and broken. These conditions inhibited the natural flow and conveyance of water in the creek and could lead to loss of stream flow and unnatural pools forming and impacts on water quality. Subsidence-induced cracks occurring beneath a stream or other surface water body may result in the loss of water to near-surface groundwater flows or even leakage into the mined voids. These geomorphic changes in the sandstone can lead to reduced pH conditions, subsequently resulting in increased dissolved metal concentrations.

The Redbank Creek hydrology has been impacted by subsidence historically and given the ongoing expected changes in surface topography, may continue to change in the future. These changes are most likely to lead to reduced average discharge from this catchment, countering potential increases resulting from urbanization.

The Redbank Creek total catchment covers an area of approximately 8 km^2 and incorporates areas of both Thirlmere and Picton townships. Proportionally this catchment is less than 10% of the total catchment discharging to Stonequarry Creek in the vicinity of the current discharge location.

4 The proposed activity

The current allowable precautionary discharge from Sydney Water's Picton Water Recycling Plant (WRP) to Stonequarry Creek is governed by the observed flow rates within the creek.

The system operating rules associated with the current approved water use is shown in **Figure 4-1**. This shows that discharges should only take place when the flows in Stonequarry are above 8 ML/d and then only up to a maximum rate of 0.25 x the flow in Stonequarry Creek or 14 ML/d (whichever is smaller).

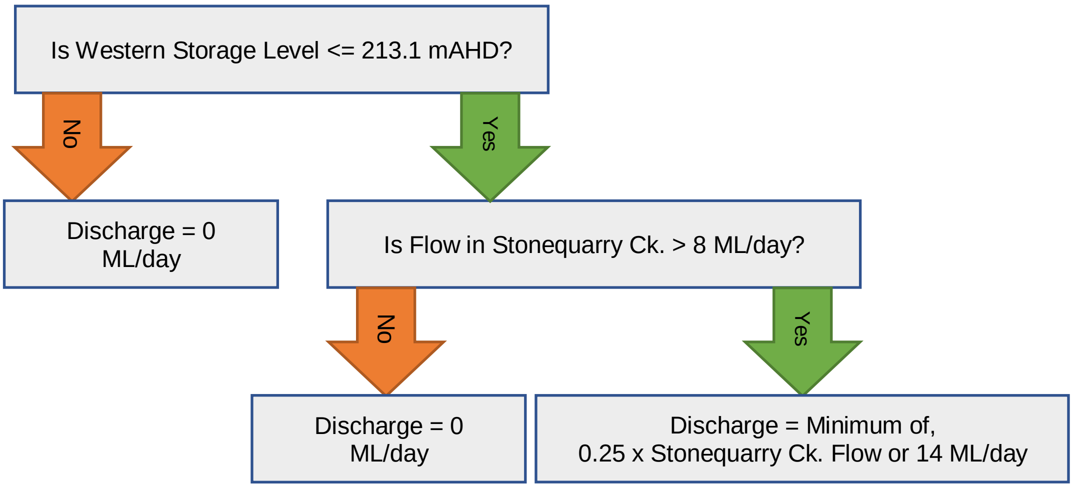


Figure 4-1 Precautionary Discharge operating rules (Alluvium, 2020)

Sydney Water are in the process of evaluating reuse and discharge options given the need to expand the capacity of the plant. A new discharge regime to Stonequarry Creek will seek to minimise concentration impacts in low flow conditions, but also seek greater flexibility than under the current precautionary protocol. The system schematic showing the two discharge options assessed as part of this study is indicated in **Figure 4-2**. The primary evaluation points of the potential impacts are also indicated.

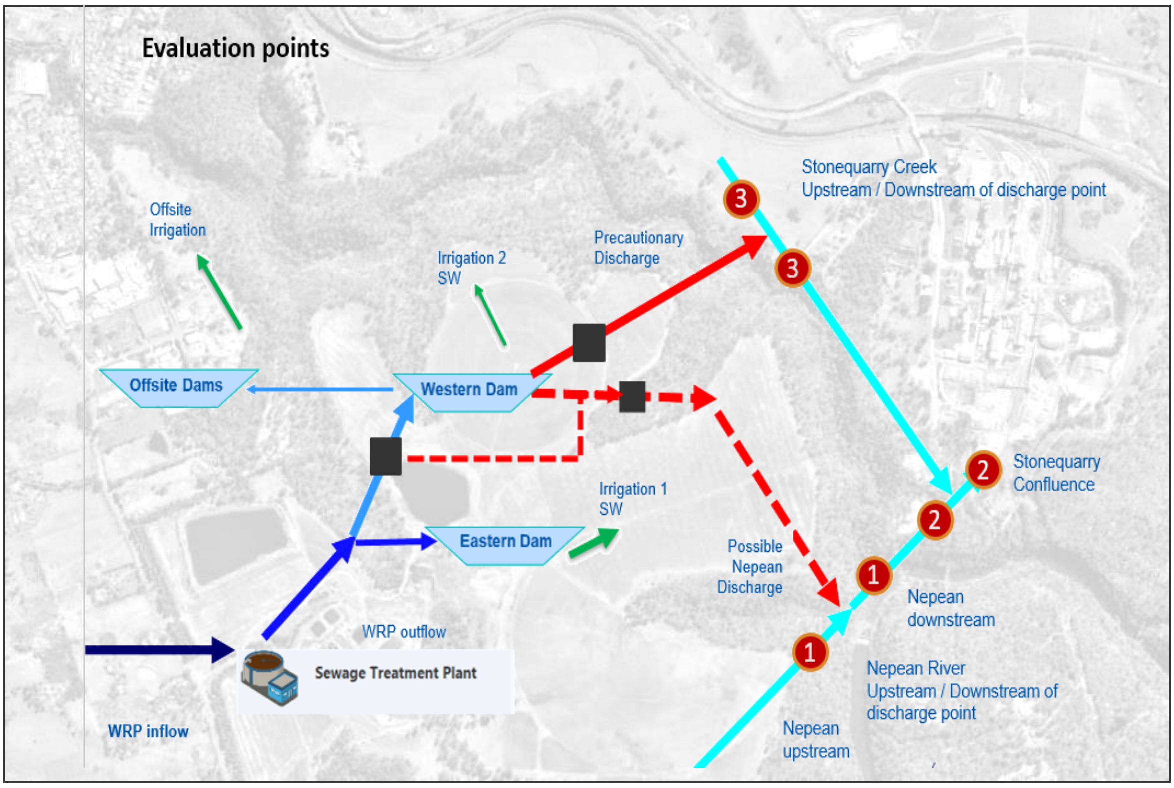


Figure 4-2 System schematic

The adjusted operating procedures which are currently being assessed (to inform Scenario 1 & 2) include an Excess (or Emergency Operating Protocol (EOP)) Discharge Rule. The objective of this operating procedure is to control the discharge from the Western Dam as the storage level approaches the maximum level to avoid uncontrolled spill over the embankment wall that would destabilise the dam. This operating rule includes 'ON' and 'OFF' operating criteria which continuously assesses the storage level of the Western Dam to determine if the Excess Discharge needs to continue, as indicated in **Figure 4-3**.

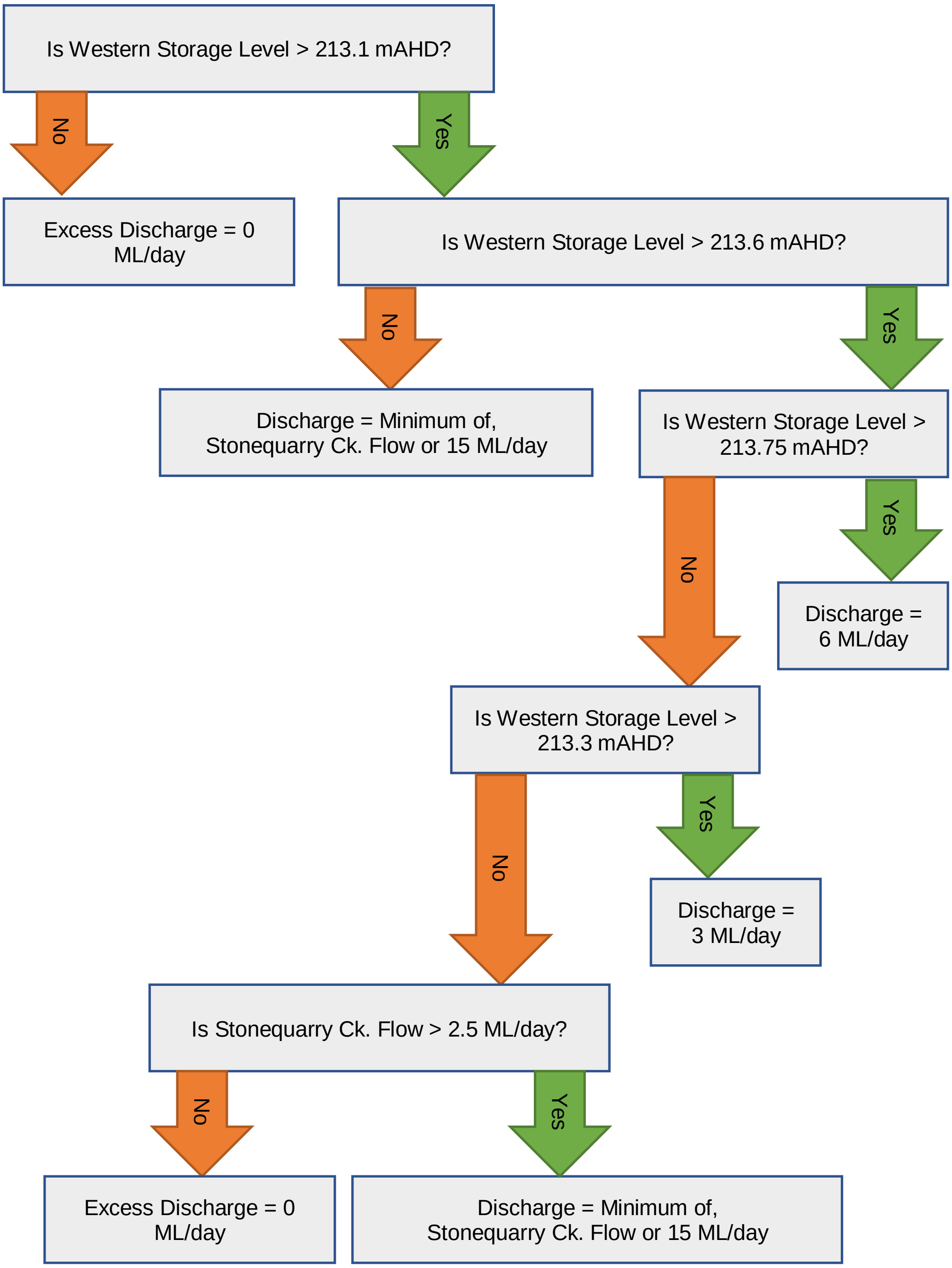


Figure 4-3 Precautionary Discharge operating rules (Alluvium, 2020)

For Scenario 3 and 4, discharges to the Nepean River have been modelled to maintain target water levels in the storage dams at the farm to allow water to be reserved for reuse, but also provide sufficient freeboard in these dams to limit the risk of spill from the dams in extreme storm events (Alluvium, 2020). This is done by operating the dams at a slightly lower lever to further reduce the probability of spilling during wet conditions.

5 Impact Assessment

5.1 USIA assessment

5.1.1 Description of metrics

To inform the waterway health assessment several of the hydrologic metrics relevant to urban settings as recommended in the *Stormwater and Outflow Planning Controls for Waterway Health: Applying the Urban Streamflow Impact Assessment* (USIA) (Streamology *et al*., 2019) were considered, these include:

- USIA1 Mean annual flow volume (MARV)
- USIA2 Mean duration of zero flow periods (average over all zero flow events) *
- USIA3 Total duration of zero flow periods (as a portion of the total flow period assessed) *
- USIA4 Baseflow index (ratio of baseflow to total flow volume) (flows < top 20th percentile) **
- USIA5 Frequency of freshes (flows > 3 times median flow)
- USIA6 Total duration of freshes (flows > 3 times median flow)

* Zero flows have been classified as any average daily flow rates less than 0.001 ML/d

** The USIA4 metric (Baseflow index) was replaced with a more comprehensive analysis approach by filtering the hydrograph data to separate baseflow from quick flow and not relying on a static threshold value. The Lyne and Hollick (1979) method, as currently endorsed by NSW EES, proposed a recursive digital filter for baseflow separation. The basic filter equation is as below:

$$q_f(i) = \begin{cases} \alpha q_f(i-1) + \frac{(1+\alpha)}{2}[q(i) - (q(i-1)] & for\ q_f(i) > 0 \\ 0 & otherwise \end{cases}$$

and

$$q_b(i) = q(i) - q_f(i)$$

Where q_f is the quick flow response, q is the original streamflow and q_b is the baseflow at each time step. The generally accepted default value of 0.975 was adopted for α . It needs to be acknowledged that the derived series does not reflect any underlying physical processes in shape, timing or quantum of streamflow.

The proposed metrics are applied by considering the proportional change due to the proposed activity (i.e. increase in discharge of treated effluent). The following generic impact classes have been defined based on the percentage of change from the current condition and corresponding risk of degrading or losing creek value:

- Low risk: <20% change
- Moderate risk: 20-50% change
- High risk: >50% change

5.1.2 Stonequarry Creek

Gauge data

The current assessed risk levels associated with potential creek devaluing due to the discharges that took place between Jan 2014 and July 2020 are indicated in **Table 5-1**. The “SQ upstream” dataset represents the estimated flows upstream of the WRP discharge point, whereas the “SQ downstream” represents the measured N911 dataset is representative of the flows downstream of the discharge locations. To determine SQ upstream, the measured discharge rates were subtracted from the measured downstream flowrates.

The assessment indicates a moderate risk level due to alterations in the observed zero flow frequencies and durations. The average portion of time with zero flow has reduced slightly due to the discharges, the mean duration shows an increase as the shorter zero flow periods are lost due to discharges.

These indicated changes in zero flow occurrences should be considered in the context of the accuracy of the gauge to correctly identify actual zero flow conditions. A zero-flow gauging would need to have been measured, and even with the available datapoint, several other factors could influence the precision of the readings at this point on the curve.

Table 5-1 USIA Metrics Comparison – Stonequarry Creek gauge data (Jan 2014 – July 2020)

Metric		Units	SQ upstream	SQ downstream
USIA1	Mean Annual Flow Volume	ML/yr ML/d	7,926 21.7	8,324 22.8
USIA2	Mean duration of zero flow periods (<0.001 ML/d)	days	3	4
USIA3	Percent duration of zero flow periods	%	0.4	0.3
Baseflow*	Baseflow index (ratio of baseflow to total flow)	%	5.2	5.3
	3 x median flow (freshes threshold)	*ML/d*	*4.35*	
USIA5	Frequency of freshes (flows > 3 times median)	events/yr	13.7	15.4
USIA6	Total duration of freshes (Percentage of time > 3 x median)	%	28.0	30.7
Low risk of degrading or losing creek value **Moderate** risk of degrading or losing creek value **High** risk of degrading or losing creek value				

*The USIA4 metric, which considers baseflow frequency based on a static threshold value, was replaced with a more comprehensive analysis as described in **Section 5.1.1**

Source model simulated scenarios

The baseflow hydrograph was developed using the Lyne and Hollick recursive digital filter, as described in **Section 5.1.1**. Both the total streamflow and the estimated baseflow hydrographs are indicated in **Figure 5-1.** *Note that the baseflow hydrograph is plot using an enlarged scale (secondary y-axis).* The results of the baseflow analysis in terms of portion of total flow contribution for the assessed scenarios are indicated in **Table 5-2**.

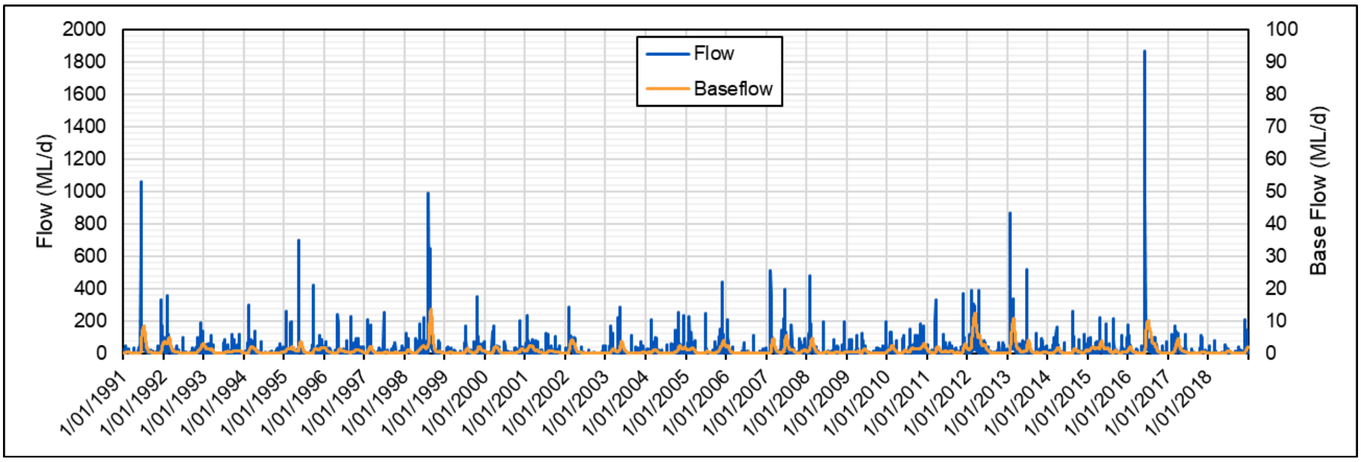


Figure 5-1 Baseflow filter results - Stonequarry Creek (N911)

The predicted risk levels related to potential creek devaluing due to the historic discharges (Scenario 1) and the proposed discharges (Scenario 2) are indicated in **Table 5-2**. The proportional change from no discharge (upstream WRP) to Scenario 1 (current baseline) is assessed and indicated via the cell colouring, the same was done comparing Scenario 2 to Scenario 1 (current baseline).

Initial application of the USIA flow metrics indicated that the change in zero flow frequency and duration (USIA 2 & 3) are the only metrics indicating a high risk for potentially degrading or losing creek value when comparing the upstream conditions to the baseline (Scenario 1). This is due to a single simulated zero flow event lasting 8 days, during which time an EOP discharge took place. Given the rarity of such an event within the simulated upstream conditions, as well as the potential minor inaccuracies for modelling such conditions, this risk has been downgraded to a low rating, as it is not expected to cause any significant resultant impacts on creek value.

Relative changes of between 3 and 12 % were associated with the other metrics indicating a low risk for potentially degrading or losing creek value.

Table 5-2 USIA Metrics Comparison – Stonequarry Creek assessment

Metric		Units	SQ upstream	SQ downstream	
				Scenario 1	Scenario 2
USIA1	Mean Annual Flow Volume	ML/yr ML/d	4,086 11.19	4,578 12.53	4,691 12.84
USIA2	Mean duration of zero flow periods (<0.001 ML/d)	days	8 (1 event in 28 yrs)	none	none
USIA3	Percent duration of zero flow periods	%	0.08	none	none
Baseflow*	Baseflow index (ratio of baseflow to total flow)	%	7.9	7.4	8.0
	3 x median flow (freshes threshold)	*ML/d*	*5.8*		
USIA5	Frequency of freshes (flows > 3 times median)	events/yr	18.8	19.4	19.8
USIA6	Total duration of freshes (Percentage of time > 3 x median)	%	28.4	29.8	31.2

Low risk of degrading or losing creek value
Moderate risk of degrading or losing creek value
High risk of degrading or losing creek value

*The USIA4 metric, which considers baseflow frequency based on a static threshold value, was replaced with a more comprehensive analysis as described in **Section 5.1.1**

5.1.3 Nepean River

The baseflow hydrograph for the Nepean River was developed using the Lyne and Hollick recursive digital filter, as described in **Section 5.1.1**. Both the total streamflow and the estimated baseflow hydrographs are indicated in **Figure 5-2**. *Note that the baseflow hydrograph is plot using an enlarged scale (secondary y-axis).* The results of the baseflow analysis in terms of portion of total flow contribution for the assessed scenarios are indicated in **Table 5-2**.

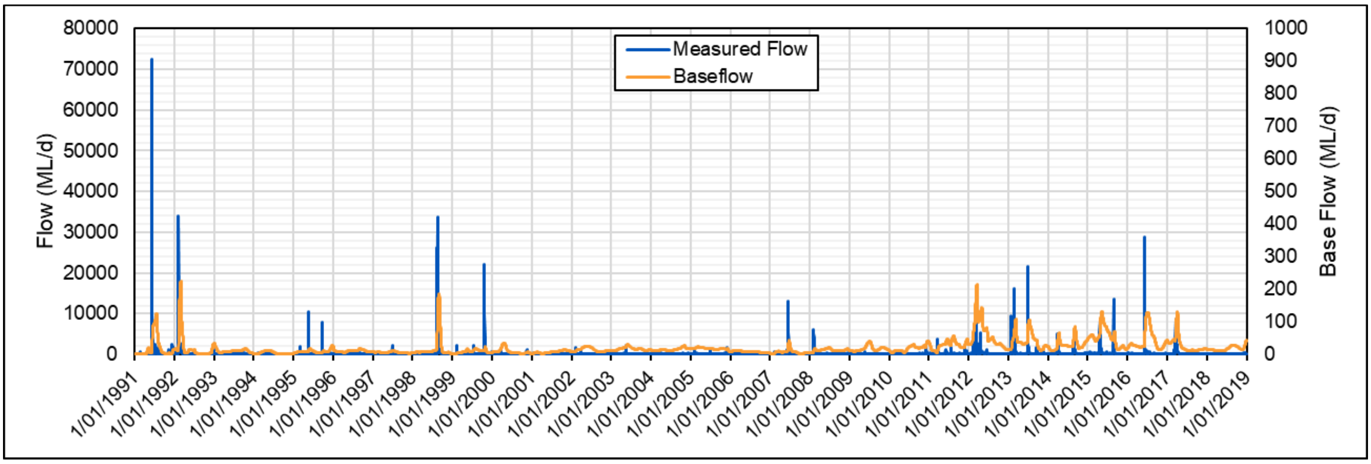


Figure 5-2 Baseflow filter results - Nepean River (N91)

The predicted risk levels related to potential creek devaluing due to the proposed discharges associated with Scenario 3 and 4 are indicated in **Table 5-3**. The proportional change from no discharge to Scenario 3 is assessed and indicated via the cell colouring, the same was done comparing no discharge to Scenario 4.

The change in zero flow frequency and duration (USIA 2 & 3) are the only metrics indicating a high risk for potentially degrading or losing creek value when comparing the upstream conditions to both Scenarios. Seven zero flow periods were simulated at Maldon weir over the assessed period with an average duration of 4 days over these events. The percentage duration of zero flow periods decreases from 0.25% to 0.11% to 0% when moving from no discharge to Scenario 3 and Scenario 4 respectively. Scenario 3 shows an increased average duration of 6 days for zero flow periods, this is due to the predicted loss of the shorter low flow periods. Adjustment of the dam operating rules could be made to ensure discharges do not occur during zero flow periods and to mitigate adverse impacts associated with the loss of these key natural conditions by maintaining dam levels at a slightly lower level.

The simulated zero flows match the recorded flows, these conditions were observed in 1991 and 1994. Subsequent to this the environmental flows have been introduced and zero flows have not been recorded since. Based on this, as well as the potential minor inaccuracies for modelling such conditions, this risk has been downgraded to a low rating, as it is not expected to cause any significant resultant impacts on creek value.

Relative changes of between 1 and 9% were associated with the other metrics indicating a low risk for potentially degrading or losing creek value. This suggests there is a low risk of increased channel forming flows altering the geomorphology and habitat conditions in Stonequarry Creek as a result of the simulated changes in discharge.

Table 5-3 USIA Metrics Comparison – Nepean River assessment (Nepean Discharges)

		Units	Maldon weir (u/s of proposed discharge)	Nepean d/s of discharge and u/s of confluence with SQ	
				Scenario 3	Scenario 4
USIA1	Mean Annual Flow Volume	ML/yr ML/d	59,026 162	59,664 163	59,886 164
USIA2	Mean duration of zero flow periods	days	4	6	none
USIA3	Percent duration of zero flow periods	%	0.25	0.11	0.00
Baseflow*	Baseflow index (ratio of baseflow to total flow)	%	10.6	10.6	11.0
	3 x median flow (freshes threshold)	*ML/d*	*61.8*		
USIA5	Frequency of freshes (flows > 3 times median)	events/yr	7.8	7.6	7.6
USIA6	Total duration of freshes (Percentage of time > 3 x median)	%	23.9	24.3	24.4

Low risk of degrading or losing creek value
Moderate risk of degrading or losing creek value
High risk of degrading or losing creek value

*The USIA4 metric, which considers baseflow frequency based on a static threshold value, was replaced with a more comprehensive analysis as described in **Section 5.1.1**

5.2 Flow duration curves

The flow duration curves representing the flow regimes as simulated for the upstream and downstream conditions for Scenario 1 and 2 are indicated in **Figure 5-3**. The graph shows minimal divergence between the upstream and Scenario 1 (baseline) flow regime. A more apparent divergence is observable when comparing the Scenario 1 and 2 results, specifically for flows less than 2 ML/d.

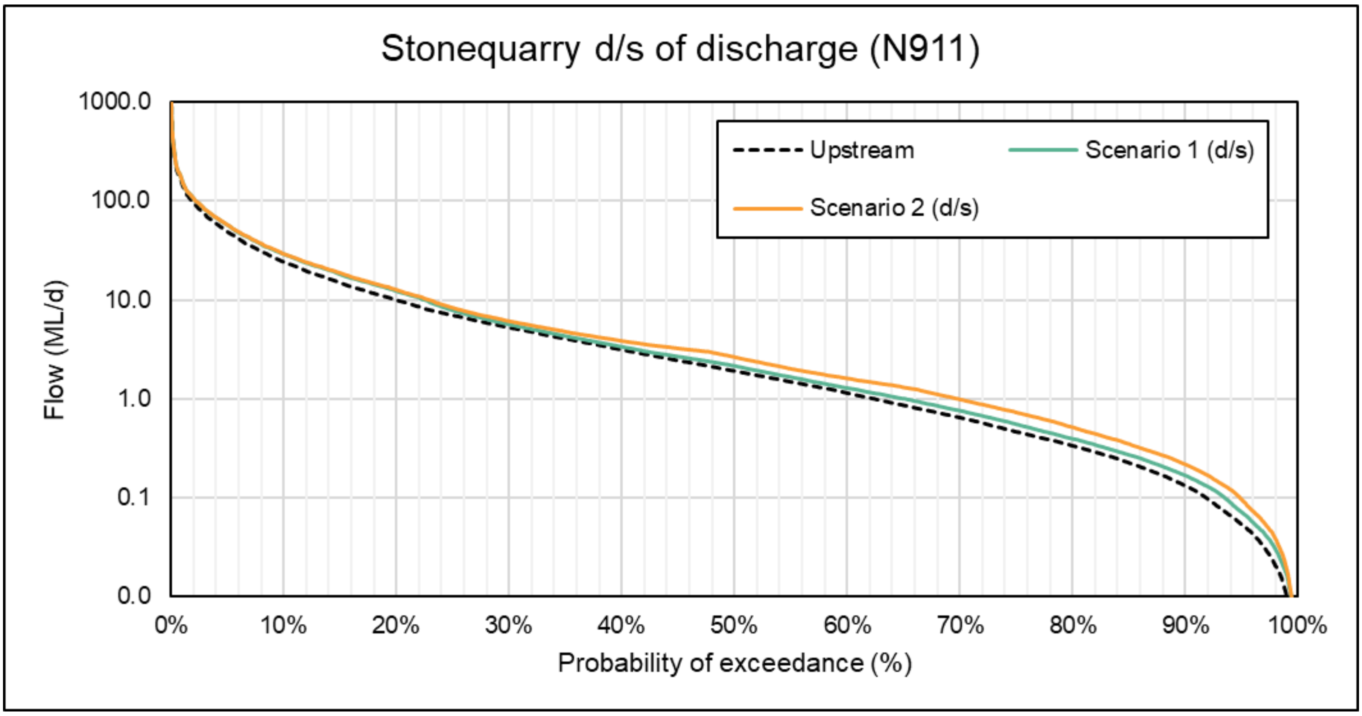


Figure 5-3 Flow duration curves for assessed scenarios (SQ discharge)

Four discrete percentile values were selected to compare the curve data numerically: 25th, 50th, 75th and 90th probabilities of exceeding, with 25th related to high flows and 75th and 90th representing low flows. The flowrates linked to these probabilities for each of the datasets are shown in **Table 5-4**. Colouring criteria have been kept consistent with that used in the USIA assessment. The results indicate minimal risk when considering high flow changes, however the increases in median and lower flows indicate a moderate risk of losing creek value.

Table 5-4 Key percentile values (SQ discharge)

Probability of exceeding	Upstream / No discharge	Scenario 1	Scenario 2	
	Flowrate ML/d	Flowrate ML/d	Flowrate ML/d	Percentage change from Scenario 1
25th	7.0	7.9	8.4	6%
50th	1.9	2.2	2.7	23%
75th	0.47	0.56	0.73	30%
90th	0.13	0.17	0.22	29%

The flow duration curves representing the flow regimes as simulated for the upstream ("no discharge") and downstream conditions for Scenario 3 and 4 are indicated in **Figure 5-4**. The graph shows minimal divergence between the "no discharge" and both Scenario 3 and 4 flow regimes for flows above 10 ML/d. A small divergence between the Scenario 3 and 4 results is also apparent for flowrates below 8 ML/d.

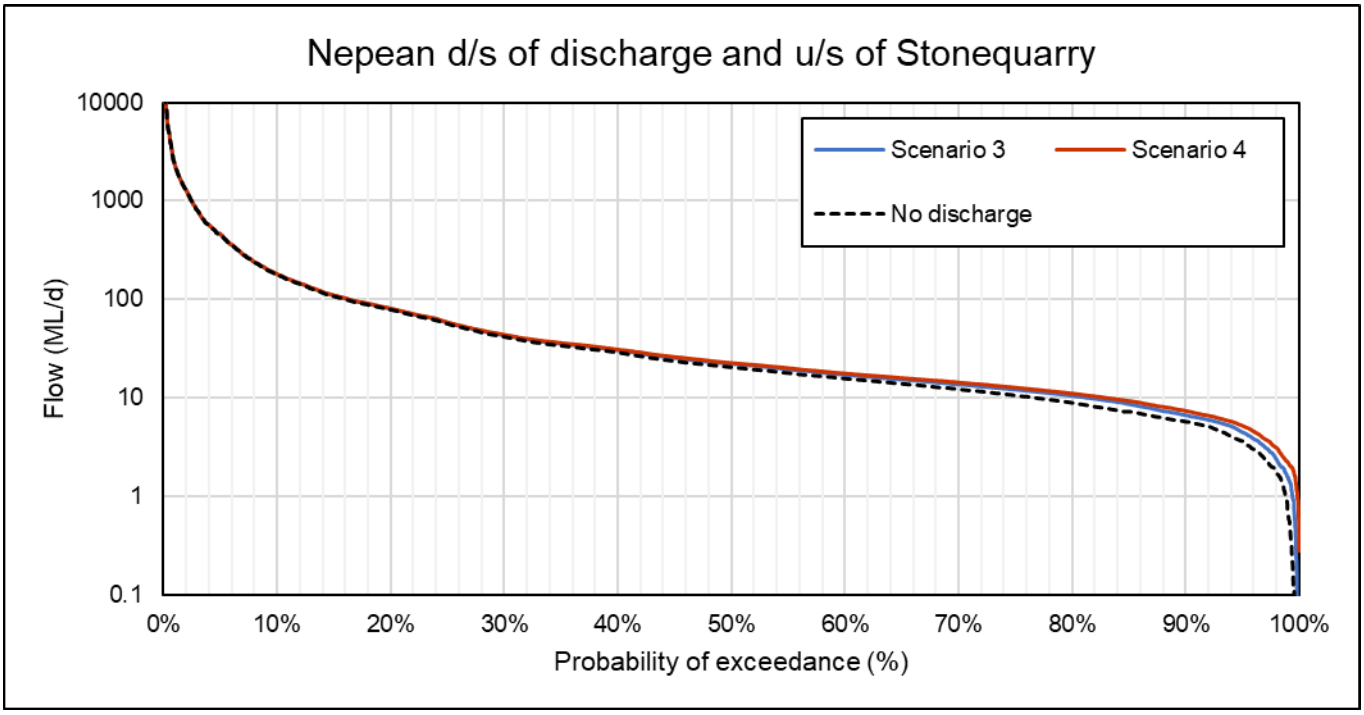


Figure 5-4 Flow duration curves for assessed scenarios (Nepean discharge)

Four discrete percentile values were selected to compare the curve data numerically: 25th, 50th, 75th and 90th probabilities of exceeding, with 25th related to high flows and 75th and 90th representing low flows. The flowrates linked to these probabilities for each of the datasets are shown in **Table 5-5.** Colouring criteria have been kept consistent with that used in the USIA assessment. The results indicate minimal risk associated with changes brought about in Scenario 3 throughout the flow range. Scenario 4 shows minimal risk when considering high flow changes, however the increases in lower flows indicate a moderate risk of losing creek value.

Table 5-5 Key percentile values (Nepean discharge)

Probability of exceeding	No discharge	Scenario 3		Scenario 4	
	Flowrate ML/d	Flowrate ML/d	Percentage change from no discharge	Flowrate ML/d	Percentage change from no discharge
25th	56.8	58.3	3%	59.0	4%
50th	20.6	22.3	8%	22.7	10%
75th	10.6	12.2	15%	12.8	21%
90th	5.8	6.7	16%	7.4	28%

A summary of the flow duration curve impact assessment is provided in **Table 5-6**.

Table 5-6 Description of flow duration curve for assessed scenarios

Scenario ID	Scenario Description	Flow duration curve impacts
2	Discharge to SQ with 60ha additional irrigation re-use	Minimal risk associated with high flow changes, however the increases in median and lower flows indicate a moderate risk of losing creek value
3	Discharge to Nepean with 60ha additional re-use	Minimal risk associated with changes brought about in Scenario 3 throughout the flow range
4	Discharge to Nepean with current re-use	Minimal risk when considering high flow changes, however the increases in lower flows indicate a moderate risk of losing creek value

5.3 Geomorphology assessment

The local soil landscape units generally have high soil erosion risks (AAJV, 2015). The steep topography combined with shallow soils poses an erosion risk and resultant sedimentation of local creeks, especially when there is an associated loss of vegetation cover (e.g. bushfire or land clearance). This is, however at higher altitudes than the confined gully channels of the Stonequarry Creek and Nepean River which flow through more resistant sandstone bedrock.

Receiving waterbody sensitivity and recovery potential for the receiving waterbodies in this Proposal are listed in **Table 5-7**.

Table 5-7 Recovery and fragility of watercourses potentially affected (after Brierley and Fryirs 2005)

Watercourse	Recovery potential	Fragility
Nepean River u/s of discharge point	None	Low
Nepean River d/s of discharge point	Conservation	Low
Stonequarry Creek	Conservation	Low
Teatree Gully Upstream	Low	High
Teatree Gully Downstream	Conservation	Low

The majority of channels considered have low sensitivity to change (based on 'fragility') demonstrating that they have low propensity to change shape, location, or condition when disturbed. This is typical for gorge systems with bedrock channel constraint. The likelihood that these same reaches will improve its geomorphic condition over management timeframes is listed as 'Conservation' suggesting that these systems are in natural condition despite anthrophonic influences. The exception to this is Teatree Gully upstream with high sensitivity to change, due to fine grained substrate being transported in higher flow conditions, and ‘Low’ recovery potential because the channel lies on ‘improved’ farm land with removal of the natural channel structure and the surrounding natural vegetation cover.

The increased discharge has the potential to slightly increase bank erosion rates, primarily due to the periodic increased flowrates and associated velocities. The hydrology and geomorphology assessment undertaken previously (AAJV, 2015) demonstrated that bank erosion as a result of the proposal is likely to be insignificant compared to erosion during flood events. This erosion would primarily transport ‘reworked’ contemporary sediment in Stonequarry Creek that has been deposited on ‘terraces’ within the constrained gully. There are also isolated pockets of tertiary sediments in the banks along this watercourse that support larger bedrock boulders. Erosion of this softer material on meander bend apexes could lead to cantilever failure and subsequent rockslide of large bedrock material from the banks into the channel.

The results provided in **Table 5-4** and **Table 5-5** indicated that the flow frequencies diverge in the lower ranges with less changes in the high flow conditions - it is the larger flood events (likely to be less than once a year) that have the biggest influence on the overall geomorphology of the creek. The proposed discharges will be a relatively small proportion of these higher flow ranges.

The other potential impact on river geomorphology is at the discharge entry point to the channels. The hydraulic drop associated with the gradient change at these two points into the gully below could lead to erosion at the base of the discharge point as high exit velocity water strikes the bedrock.

5.4 Erosion risks

5.4.1 Methodology

The relationship between increasing flow speed and the erosive power of flowing water has been frequently reported (e.g. Aktar, 2013; Bartley, 2006; Dragicevic, 2017; NRW, 2006). Stream power is the rate of energy dissipation against the bed and banks of a river or stream per unit downstream length. As such, stream power is a useful surrogate for attritional scour and reflects the direct removal of material from the river channel or banks by the physical action of flowing water and the sediment that it carries. Stream power is used extensively in models of landscape evolution and river incision, river channel migration and in some cases is applied to sediment transport.

It should be made clear, however, that actual bank erosion and sediment transport in the Stonequarry Creek and Nepean River channels could be caused by a whole range of complex factors not associated with changing stream power that would not be detected by this simple treatise including:

- Complex sediment composition with a wide range of sediment sizing and associated differences in erosion resistance
- Intense rainfall events (e.g. cyclones)
- Inundation of bank soils followed by rapid drops in flow after flooding
- Mixtures of cohesive and non-cohesive sediments
- Redirection and acceleration of flow around infrastructure, obstructions, debris or vegetation within the stream channel
- Removal or disturbance of protective vegetation from stream banks as a result of trees falling from banks or through poorly managed stock grazing, clearing or bushfires
- Saturation of banks from off-stream sources of moisture
- Soil characteristics such as poor drainage or seams of readily erodible material within the bank profile
- Stream bed lowering or infill

The responses to these changes can be complex, often resulting in accelerated rates of erosion and sometimes affecting stability for decades. Mass failure or collapse / slumping of banks can be caused by a combination of these various mechanisms and the causes of these types of failures are often difficult to determine.

Despite this, we would anticipate that there is a positive, if complex, relationship between increasing effective stream power and increasing erosion / sediment transport. As such, relative changes in effective stream power are used here to assess the impact of increased flows on downstream environment bank erosion. Effective stream power data was estimated for Q10, Q50 and Q95 flow events in Stonequarry Creek and Nepean River based on the following equation:

$$\omega = \frac{\rho g Q S}{b}$$

Where ω is the unit stream power, ρ is the density of water (1000 kg/m^3), g is acceleration due to gravity (9.8 m/s), Q is discharge (m^3/s), S is the channel slope and *b* is the width of the channel.

5.4.2 Results

The effective stream power for the upstream / no discharge Scenario, Scenario 1 (base case) and Scenario 2 have been derived for Stonequarry Creek (**Table 5-8**). Similarly, the effective stream power for the upstream / no discharge Scenario, Scenario 3 and Scenario 4 have been derived for Nepean River (**Table 5-9**).

Table 5-8 Impact on effective stream power for the SQ discharge

Flow event	Probability of exceeding	Effective stream power (kilojoules / metre)			
		Upstream / No discharge	Scenario 1 (Base case)	Scenario 2	Percentage change from Scenario 1
Q10	10th	538	609	611	0%
Q50	50th	81	89	104	16%
Q95	95th	4.2	5.4	7.0	29%

Table 5-9 Impact on effective stream power (joules/m) for the Nepean discharge

Flow event	Probability of exceeding	Effective stream power (kilojoules / metre)				
		Upstream / No discharge	Scenario 3	Percentage change from no discharge	Scenario 4	Percentage change from no discharge
Q10	10th	612	623	2%	623	2%
Q50	50th	139	143	2%	144	3%
Q95	95th	58	66	15%	72	26%

This derivation shows that:

- Effective stream power increases with increasing flow for both Stonequarry Creek and the Nepean River, for the three-flow metrics considered in this analysis. This is not always the case, in the event of bank overtopping at high flows which can sometimes lead to lowering of effective stream powers.
- The Stonequarry Creek stream power is slightly lower than the Nepean River stream power
- Discharge scenarios are very similar for the Q10 flow metric in Stonequarry Creek and the Q10 and Q50 flow metrics in the Nepean River compared to the base case. This suggests that for high flows in Stonequarry Creek

and for median-high flows in the Nepean River, there is no appreciable difference in effective stream power, and thus erosion potential, between no discharge and discharge scenarios.

- Discharge scenarios are considerably higher for Q50 (16%) and Q95 (29%) flow metrics in Stonequarry Creek and for Q95 (26%) flow metric in Nepean River. This suggests that for low-median flows in Stonequarry Creek and for low flows in the Nepean River, there is an appreciable difference in effective stream power, and thus erosion potential, between no discharge and discharge scenarios.

The effective stream power for Stonequarry Creek, however, in low flows is two orders of magnitude lower than for high flow events and in median flows is one order of magnitude lower than for high flow events. The range of effective stream powers (4.2 – 7.0 and 81 – 104 kilojoules / metre, respectively in low and median flows) are within the range of inherent errors introduced through the calculation approach. Furthermore, for low flows in the Nepean River, stream power is one order of magnitude lower than for high flow events and the range of effective stream powers (58 – 72 kilojoules / metre) are also within the range of inherent errors introduced through the calculation approach.

This suggests that for low and median flows in Stonequarry Creek and low flows in the Nepean River, effective stream power is not significantly different between the no discharge and discharge scenario. It is during these lower flow periods that water will generally run through the sandstone baserock constrained channels in both Stonequarry Creek and the Nepean River (rather than activating side-channel or bank deposits which may be less resistant to erosion). This further supports the theory that the differences seen in estimated effective stream power for no discharge and discharge scenarios will not have a large impact on geomorphology in the two channels.

5.5 Flood impacts

Stonequarry Creek

The maximum discharge rate to Stonequarry Creek will be 15 ML/d or 0.17 m^3/s. Estimated flowrates within Stonequarry Creek during flood conditions were sourced from the Wollondilly Shire Council's 2019 Flood Study as indicated in **Table 5-10.** These results indicate that the WRP discharge will proportionally add less than 1% of the flow during a 50% AEP event (or 1- in 2-year event). This ratio decreases even further when looking at larger, less frequent flood events. The resultant impact on flood levels would thus be negligible.

Table 5-10 Flood Frequency Analysis (FFA) Results – Stonequarry Creek at Picton Gauge (WMAwater, 2019)

AEP	Peak Flow (m^3/s)		
	FFA	2017 Flood Study	1989 Flood Study
50%	23.4	Not documented	Not documented
20%	68	Not documented	Not documented
10%	121	Not documented	Not documented
5%	193	431	345
2%	331	509	424
1%	474	578	494

Nepean River:

For both Scenarios 3 and 4 the maximum discharge rate will be 15 ML/d or 0.17 m^3/s. Historic (pre-environmental flows) flood frequency curves (Sammut & Erskine, 1995) for the Nepean River at Maldon weir were sourced and compared to this maximum discharge rate (red line on graph). The data suggest a

50% AEP flow rate of almost 100,000 ML/d. The resultant impact of ARP discharges on flood levels would thus be negligible.

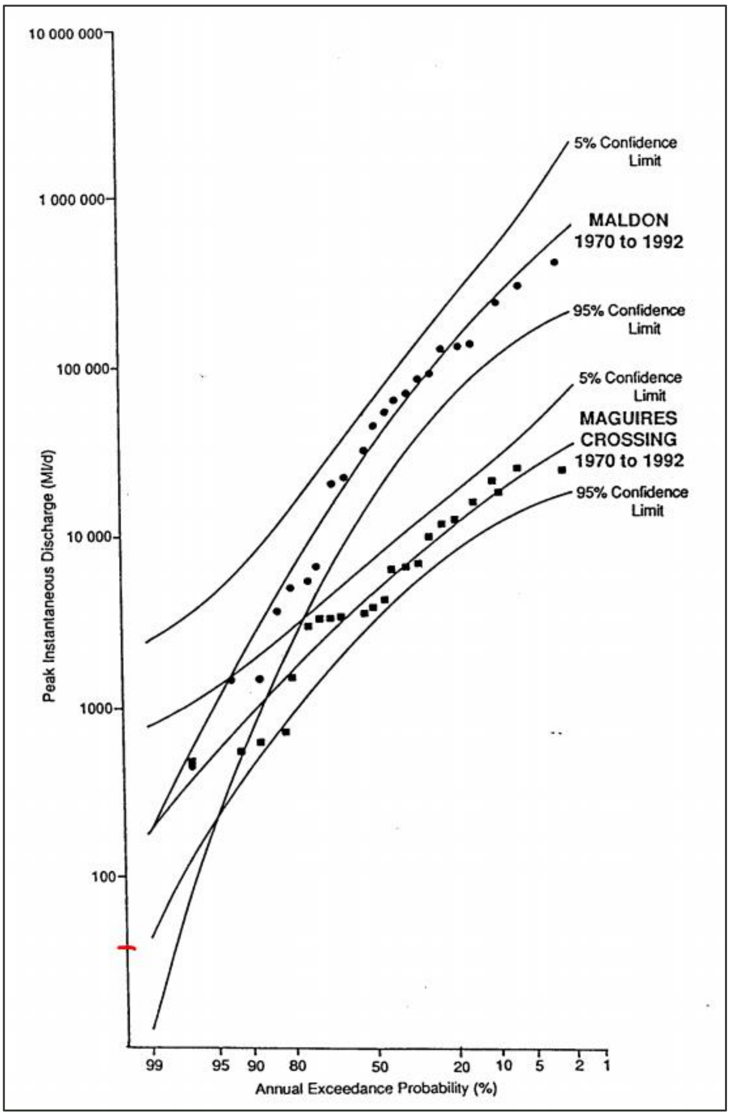


Figure 5-5 **Flood frequency curves for the Nepean River (1970-1992)**

5.6 Summary of potential impacts, proposed mitigation measures and management

The significance of any potential project impact on the local hydrology has been determined by considering the sensitivity of the environment related to the assessed criteria as well as the magnitude of the expected change. The resultant matrix of significance is shown in **Table 5-11**.

Table 5-11 **Matrix of significance**

Magnitude of impact	Sensitivity of Environmental Values		
	High	Moderate	Low
High	Major	High	Moderate
Moderate	High	Moderate	Low
Low	Moderate	Low	Negligible

The *Sensitivity of Environmental Values* evaluation is influence by the following criteria:

- Condition of the environmental value, i.e. how far is it understood to have already been changed from its original natural form or state?
- How unique or rare is the condition or value or it's dependant ecological receptors?
- How sensitive are the dependant receptors to changes?

Due to significant land use changes within both the Stonequarry Creek and Nepean River catchments, the flow profiles are assumed to have already been impacted to a moderate extent at both assessed locations. These impacts would lead to higher peak flowrates, and steeper recession responses following a storm event, resulting in lower baseflow volumes. High flow values at these locations are also relatively common and are likely to have changed significantly from natural conditions due to areas of urbanization and resultant quick stormflow response from these areas.

Using the above assessment technique, the significance of the potential impacts for all three future scenarios for pre and post-mitigation measures were determined and are shown in **Table 5-12**.

Table 5-12 Summary of potential impacts, proposed mitigation measures and management

Metric/ Value	Sensitivity to Environmental Values	Pre-mitigation			Proposed Mitigation/management measure	Post-mitigation		
		Scenario 2	Scenario 3	Scenario 4		Scenario 2	Scenario 3	Scenario 4
USIA1 (Mean Annual Runoff Volume)	Moderate	Low	Low	Low	Not applicable (Local re-use contributes to reduced changes associated with MARV) Stormwater runoff from the catchment results in significant changes to hydrology. Stormwater offset projects could be considered.	Low	Low	Low
USIA2 (Zero flow)	Moderate	Low	Low	Low	Adjustment of the dam operating rules to ensure discharges do not occur during zero flow periods.	Low	Negligible	Negligible
USIA3 (Zero flow)	Moderate	Low	Low	Low	Adjustment of the dam operating rules to ensure discharges do not occur during zero flow periods.	Low	Negligible	Negligible
USIA5 (Freshes)	Low	Negligible	Negligible	Negligible	Not applicable	Negligible	Negligible	Negligible
USIA6 (Freshes)	Low	Negligible	Negligible	Negligible	Not applicable	Negligible	Negligible	Negligible
Baseflow	Moderate	Low	Low	Low	Not applicable	Low	Low	Low
Erosion/sediment	Low	Low	Low	Low	**Stonequarry:** Stabilisation of Teatree Gully eastern dam overflow channel, if required. Reduce hydraulic drop of discharge pipe and stabilise exit point **Nepean:** If feasible, a submerged discharge would result in reduced probability of local scour or erosion **Both:** Adaptive management plan implemented based on monitoring bank erosion and channel sediment movement changes	Low	Negligible	Negligible
Flooding	Low	Negligible	Negligible	Negligible	Not applicable	Negligible	Negligible	Negligible

5.7 Cumulative impact assessment

Stormwater runoff

The urbanized areas associated with the towns of Picton and Thirlmere, located upstream of the Picton WRP, is currently impacting stormflow runoff patterns and subsequently the Stonequarry Creek and Nepean hydrology.

Impervious areas result in higher peak flows and steeper recession curves following storm responses, as shown in **Figure 5-6**. Increased impervious portions also lead to reduced recharge to the shallow groundwater aquifers, which could in turn reduce the baseflow to the local watercourses. Flowrates in natural watercourses tend to become more varied with a much more frequent and more pronounced oscillation between very high and very low flows.

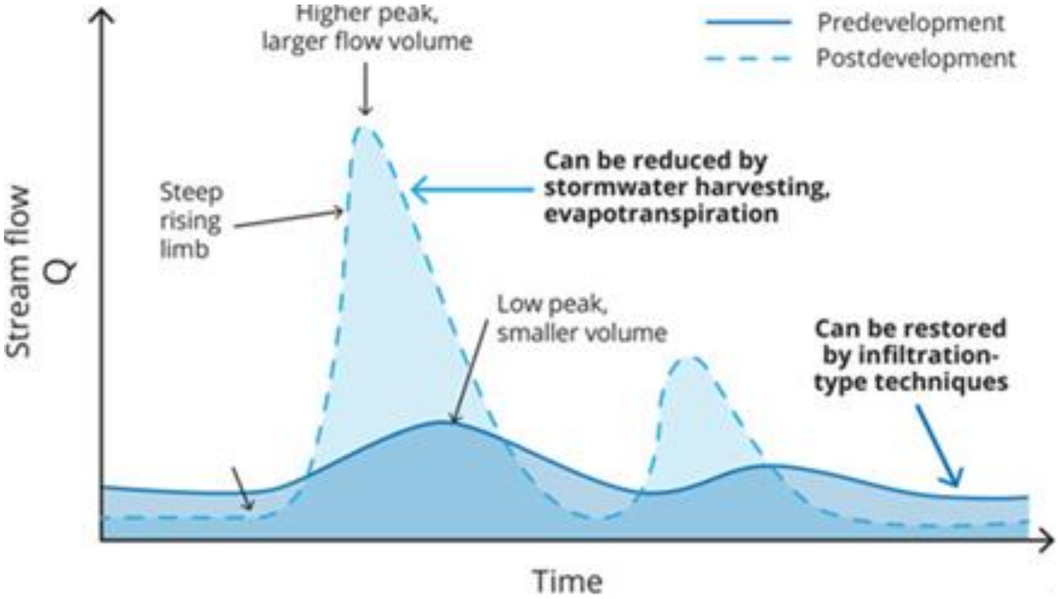


Figure 5-6 Effects of urbanization on a typical hydrograph (Horne et al, 2017)

Because there have been inadequate stormwater management controls on changes in hydrology in the upper part of the catchment the natural baseflow regime has been significantly altered already.

By discharging small volumes to the creek on a more frequent basis, the potential exists for shifting the flow regime slightly back to more natural pre-urbanization conditions.

Mining

Current subsidence caused by mining activities within the Redbank Creek catchment likely result in a reduction in runoff from this area, as surface runoff and discharge is pooled and potentially lost to subsurface systems. The potential exists for future subsidence to aggravate these conditions and lead to further reductions in runoff generated from this area. These changes are most likely to affect the low flow ranges, high flows and flood flows will proportionally be less affected.

Given that the affected catchment makes up less than 10% of the entire contributing catchment to Stonequarry Creek, and that these changes have already partially occurred, any future changes are expected to have minimal impact on the current assessment results.

5.8 Summary sheets

Summary sheets of the Hydrology review of environmental factors' results are provided below.

Discharge to Stonequarry Creek: Scenarios 1 & 2

Scenario ID	Discharge location	Avg inflow *(ML/d)	Additional irrigated area* (ha)	Estimated avg future discharge (ML/d)
1	Stonequarry Creek	2.7	0	1.35
2	Stonequarry Creek	4	60	1.66

Results interpretation

Initial application of the USIA flow metrics indicated that the change in zero flow frequency and duration (USIA 2 & 3) are the only metrics indicating a high risk for potentially degrading or losing creek value when comparing the upstream conditions to the baseline (Scenario 1). This is due to a single simulated zero flow event lasting 8 days, during which time an EOP discharge took place. Given the rarity of such an event within the simulated upstream conditions, as well as the potential minor inaccuracies for modelling such conditions, this risk has been downgraded to a low rating, as it is not expected to cause any significant resultant impacts on creek value. Relative changes of between 3 and 12 % were associated with the other metrics indicating a low risk for potentially degrading or losing creek value.

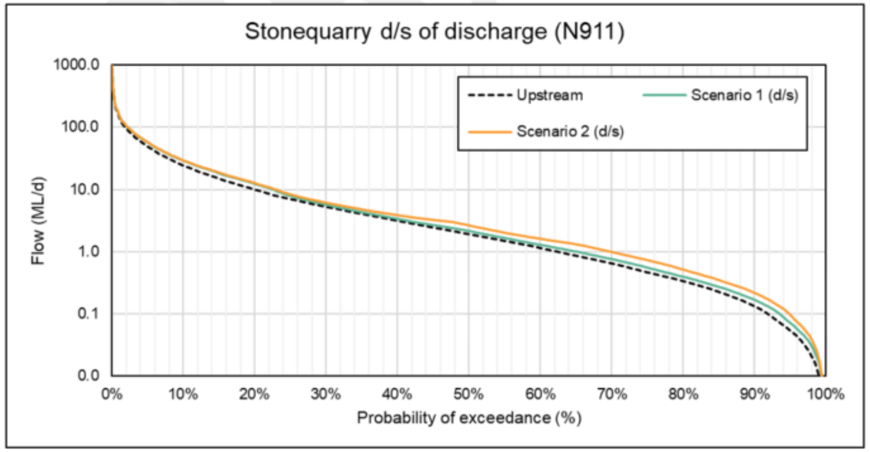
The flow duration curve comparison indicates minimal risk when considering high flow changes, however the increases in median and lower flows indicate a moderate risk of losing creek value.

USIA metrics comparison

Metric		Units	SQ upstream	SQ downstream	
				Scenario 1	Scenario 2
USIA1	Mean Annual Flow Volume	ML/yr ML/d	4,086 11.19	4,578 12.53	4,691 12.84
USIA2	Mean duration of zero flow periods (<0.001 ML/d)	days	8 (1 event in 28 yrs)	none	none
USIA3	Percent duration of zero flow periods	%	0.08	none	none
Baseflow*	Baseflow index (ratio of baseflow to total flow)	%	7.9%	7.4%	8.0%
	3 x median flow (freshes threshold)	*ML/d*		*5.8*	
USIA5	Frequency of freshes (flows > 3 times median)	events/yr	18.8	19.4	19.8
USIA6	Total duration of freshes (Percentage of time > 3 x median)	%	28.4%	29.8%	31.2%

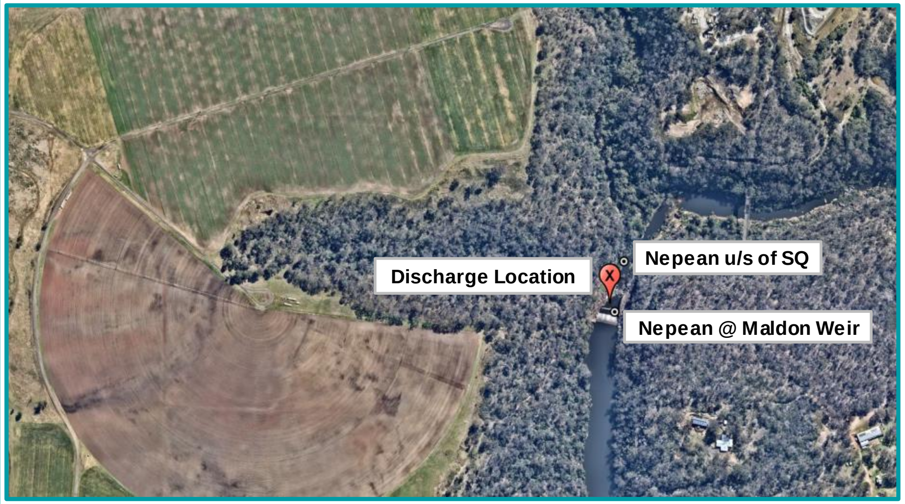
Low risk of degrading or losing creek value
Moderate risk of degrading or losing creek value
High risk of degrading or losing creek value

Impacts on flow duration curve



Discharge to Nepean River: Scenarios 3 & 4

Scenario ID	Discharge location	Avg inflow *(ML/d)	Additional irrigated area* (ha)	Estimated avg future discharge (ML/d)
3	Nepean River	4	60	1.75
4	Nepean River	4	0	2.35

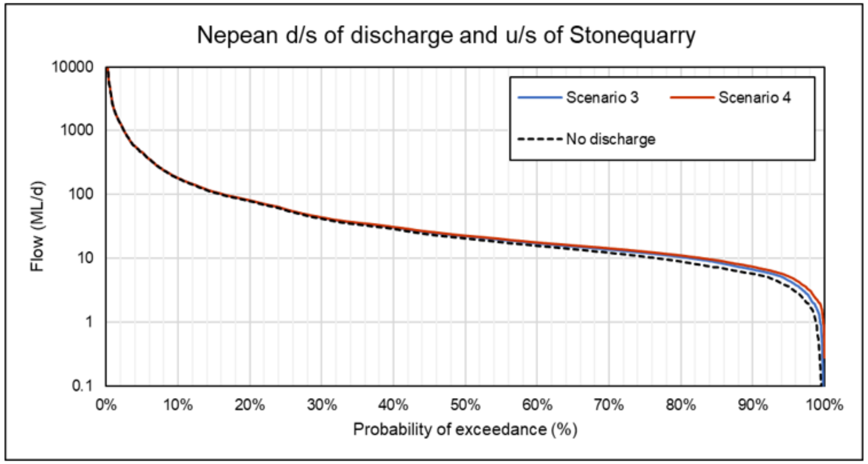


USIA metrics comparison

		Units	Maldon weir (u/s of proposed discharge)	Nepean d/s of discharge and u/s of confluence with SQ: Scenario 3	Nepean d/s of discharge and u/s of confluence with SQ: Scenario 4
USIA1	Mean Annual Flow Volume	ML/yr ML/d	59,026 162	59,664 163	59,886 164
USIA2	Mean duration of zero flow periods	days	4	6	none
USIA3	Percent duration of zero flow periods	%	0.25	0.11	0.00
Baseflow*	Baseflow index (ratio of baseflow to total flow)	%	10.6%	10.6%	11.0%
	3 x median flow (freshes threshold)	*ML/d*	*61.8*		
USIA5	Frequency of freshes (flows > 3 times median)	events/yr	7.8	7.6	7.6
USIA6	Total duration of freshes (Percentage of time > 3 x median)	%	23.9	24.3	24.4

Low risk of degrading or losing creek value
Moderate risk of degrading or losing creek value
High risk of degrading or losing creek value

Impacts on flow duration curve



Results interpretation

The change in zero flow frequency and duration (USIA 2 & 3) are the only metrics indicating a high risk for potentially degrading or losing creek value when comparing the "no discharge" conditions to both Scenarios. Seven zero flow periods were simulated at Maldon weir over the assessed period. Adjustment of the dam operating rules could easily be made to ensure discharges do not occur during zero flow periods. Relative changes of between 1 and 9% were associated with the other metrics indicating a low risk for potentially degrading or losing creek value.

The flow duration curve comparison indicates minimal risk associated with changes brought about in Scenario 3 throughout the flow range. Scenario 4 shows minimal risk when considering high flow changes, however the increases in lower flows indicate a moderate risk of losing creek value.

6 Conclusion

The findings based on the review of environmental factors works conducted to assess the potential impacts to the receiving environment, with respect to the current local hydrology is listed below:

- The risk of degrading or losing creek value due to changes in the flow regime is deemed low for most aspects, other than zero flow conditions.
- The understanding of the zero flow conditions is limited given the short record of available accurate low flow gauging's at the Stonequarry discharge location, which results in a heavy reliance on the Source modelling results. Calibration of hydrological models to accurately reflect these extremely low flow conditions is challenging. Thus, there may be minor inaccuracies when comparing actual to simulated conditions and the indicated and comparable zero flow conditions may be affected.
- As the available simulation data does provide a significant amount of insight into the comparable flow rates when considering the scenarios proposed, the results remain valid.
- Geomorphological baseline indicates that the Stonequarry Creek and Nepean River receiving channels for the proposed discharges are stable and have low potential for change.
- The potential impacts resulting in the loss of any zero flow conditions can relatively easily be mitigated by adjusting the dam operating rules and minimize the probability of any discharges taking place when there is no flow in the receiving watercourse by maintaining dam levels at a slightly lower level.
- These changes will reduce the resultant risks of degrading or losing creek value from high to low for this impact.
- Based on this, all impacts are classified as low risk post-mitigation for all scenarios assessed.
- The relative changes to the flow regime (and subsequent potential impacts) when discharging to the Nepean (1 to 9% change) is less than when discharging to Stonequarry Creek (3 to 12% change).
- Overall, there is not expected to be any significant impact to hydrological and geomorphological conditions downstream as a result of the proposal.

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Appendix A – Historical Aerial Imagery

Figure A-1 **Stonequarry Creek near discharge location - Aerial imagery (Source: Nearmap Imagery)**

Figure A-2 **Nepean River @ Maldon Weir - Aerial imagery (Source: Nearmap Imagery)**