Yule Brook Catchment Assessment

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1. Introduction

1.1. Background

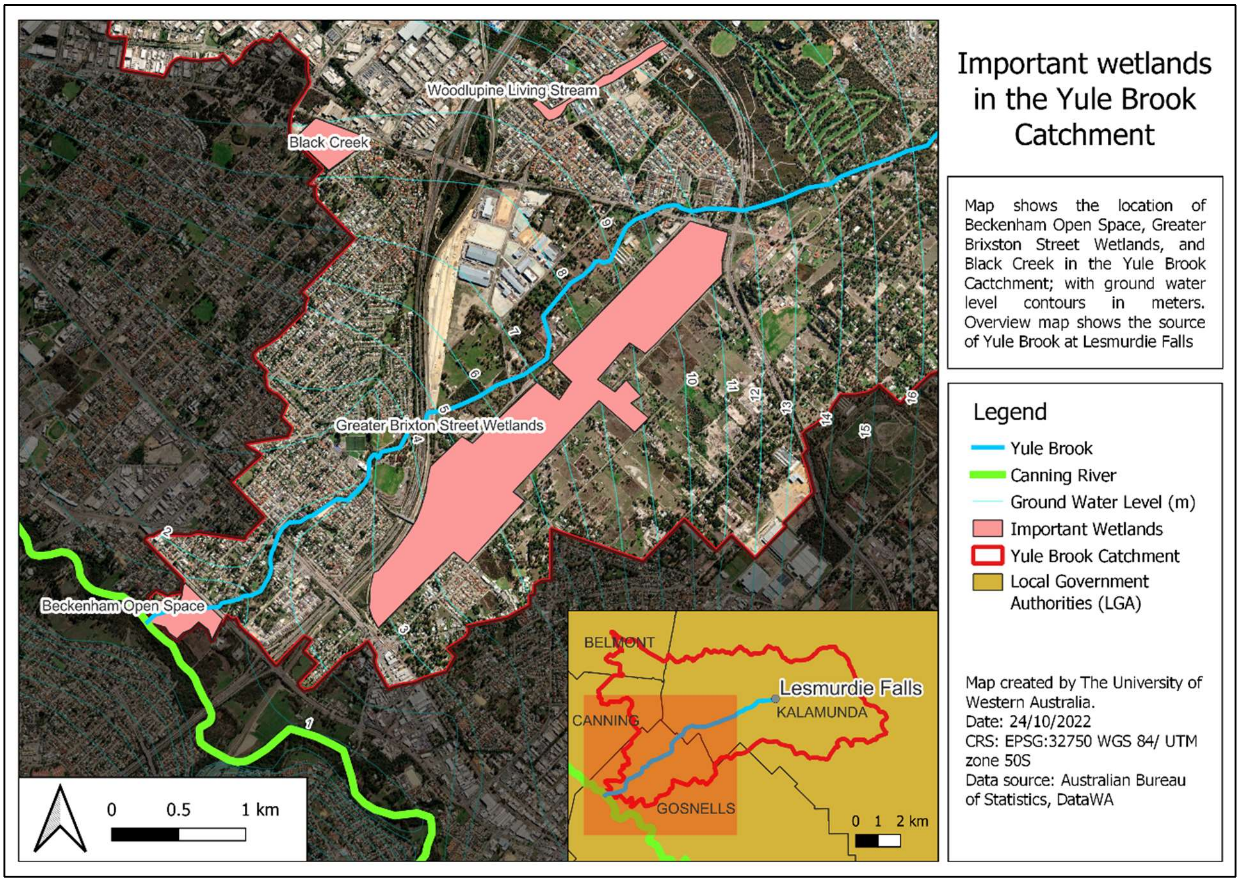
Globally, land-use change degrades water quality by adding nutrients from agricultural and industrial activities and increasing contaminated run-off through impervious surfaces (Giri & Qiu, 2016). This can lead to algal blooms, which have adverse impacts on both ecosystem and human health (Tsegaye et al., 2006; Zhang et al., 2012). Alteration of flow regimes directly affects water quality, for example, poor water quality is associated with low flows as they lead to low dissolved oxygen, temperature extremes, increased pollutants, eutrophication and salinisation (Merz, 2013). Changes in water quantity and water quality can have detrimental impacts on ecosystems, biodiversity, and breeding behaviours of species within the catchment (Department of Agriculture and Water Resources, 2013)

Yule Brook is one of the ten major sub-catchments of the Swan-Canning estuary, located in Perth, Southwest of Western Australia (Petrone et al., 2009). Due to urbanisation, the majority of the Yule Brook catchment has become industrial areas, high-density residential areas, and agricultural lands for horticulture and poultry (DWER, 2016). Monitoring of nutrients in Yule Brook from 2006 to 2017 showed that total nitrogen (TN) concentrations fluctuated throughout the monitoring period with a brief increasing trend from 2012 to 2016; whereas a small long-term increasing trend was observed for total phosphorus (TP) over the monitoring period (DWER, 2016). According to the Swan River Trust (2011), Yule Brook was the second largest contributor of TN and TP loads to the Canning River. Local nutrient reduction actions include revegetation at various areas of the catchment, restoration of Beckenham Open Space, and establishment of Woodlupine Living Stream (DWER, 2016).

Constant monitoring is crucial for management as it informs appropriate strategies to address the environmental issue. Monitoring by the Department of Water and Environmental Regulation for Yule Brook has ceased since 2017, leaving a gap of knowledge. This report aims to fill that gap by analysing the water flow spatially at different measuring stations in the catchment and temporally from past data. It will also spatially and temporally analyse the water quality in terms of nitrogen and phosphorus nutrients. Lastly, we will discuss the threats and current policies around the issue and recommend strategies for appropriate monitoring and management of water quality of the Yule Brook catchment.

1.2. Catchment setting

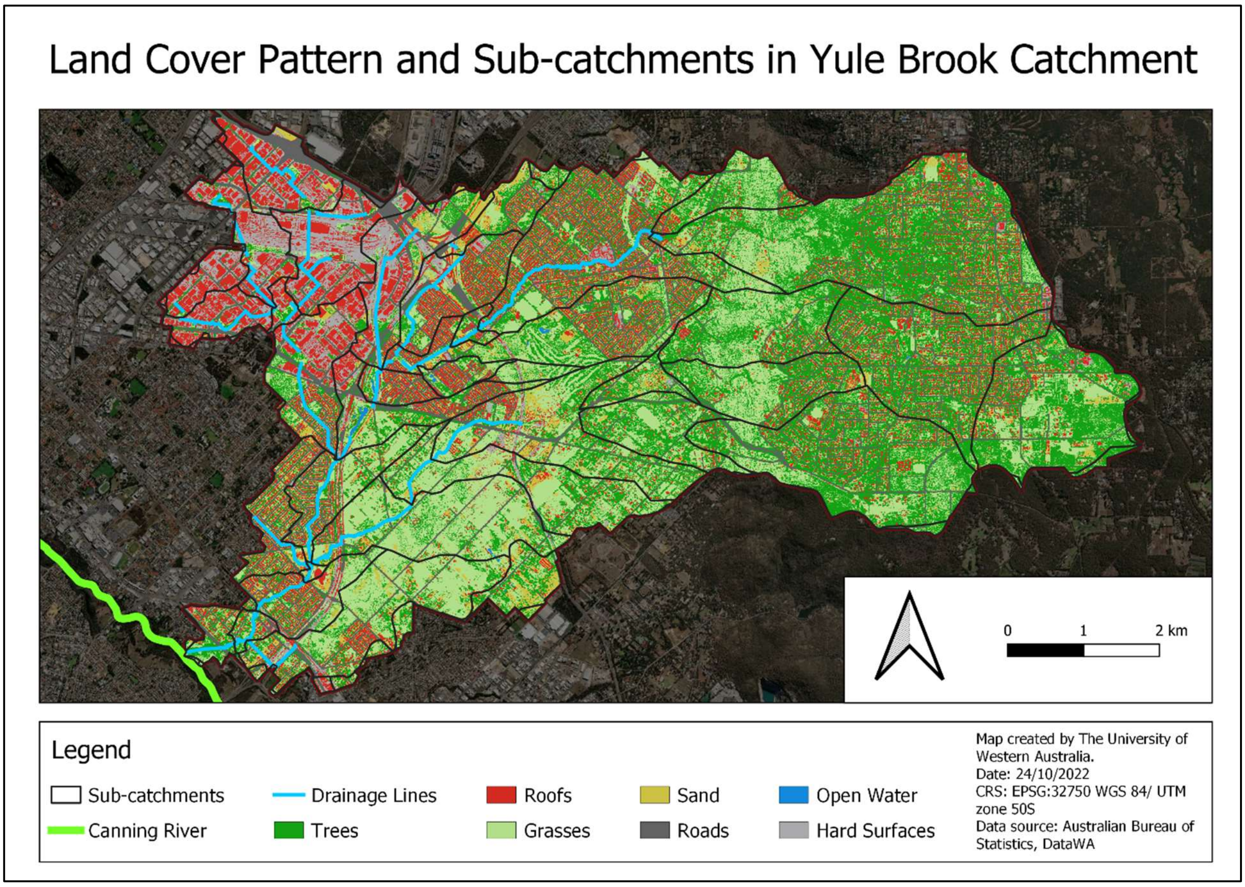
Yule Brook catchment starts as a natural watercourse in Lesmurdie, then feeds into the Canning River through a complex network of drains, covering a total area of 55 km^2 (DWER, 2016). The catchment supports more than 850 taxa of vascular plants on only 500 hectares of diverse habitats (Monks, 2019). Beckenham Open Space, a flood plain adjacent to the Canning River, has high biodiversity significance as it provides habitats to numerous waterbirds and native animals, such as ibis, spoonbills, and the long-necked turtle (SERCUL., n.d.). The Greater Brixton Street Wetlands (GBSW), one of the most floristically species-rich areas in Perth Metropolitan Region (Tauss et al., 2019), is home to 11 threatened species and 4 threatened ecological communities listed under the Environment Protection and Biodiversity Conservation Act 1999 (Evans, 2018). These wetlands also provide ecosystem services, such as dissipation of stream energy for flood control, sequestration of contaminants and nutrients, and provision of aesthetic services and recreational opportunities (Shock, 2016). Black Creek constructed wetland that highlights the various ecosystem services as it increases sedimentation of pollutants and provides habitat and food sources for several waterbirds (DWER, 2022). *Map 1* shows wetlands of high biodiversity and ecosystem services in the Yule Brook catchment.



Map 1 - Important wetlands of the Yule Brook Catchment, Yule Brook, and Canning River.

The study area has a warm Mediterranean climate with dry, hot summers and cool, wet winters (Gentilli, 1972). Southwest Western Australia has a wet period of higher intensity and longer duration than other regions of similar latitudes due to the Leeuwin Current and the orographic uplift by the Darling Scarp (Gentilli, 1972). However, rainfall in this region has significantly declined since the 1970s due to climate change and land clearing (Ali et al., 2012; Andrich & Imberger, 2013). The Yule Brook catchment has a complex geology of multi-layered aquifers that serves as the lifeblood of several wetlands (Richards, 2019). Decline in rainfall and changing land-use patterns can lead to alterations in groundwater recharge, which could severely impact the wetlands. Surface water and groundwater flow northeast to southwest, from the Darling Scarp to the Canning River (Bourke, 2017). Contours on *Map 1* show that groundwater flows from high to low elevation, making the Canning River a gaining stream. *Map 2* shows sub-catchments of Yule Brook, which are defined by elevation or drainage lines.

The lower Yule Brook catchment consists of permeable sands and duplex soils, whereas the upper catchment is characterized by sandy gravels and rocky outcrops (DWER, 2016). The soil condition of this region is severely nutrient-impoverished, which caused the richness of plants to be very high as it allowed different plant traits to evolve (Evans, 2018). This means that as phosphorus concentration in the soil decreases, biodiversity of plants increases (Evans, 2018).

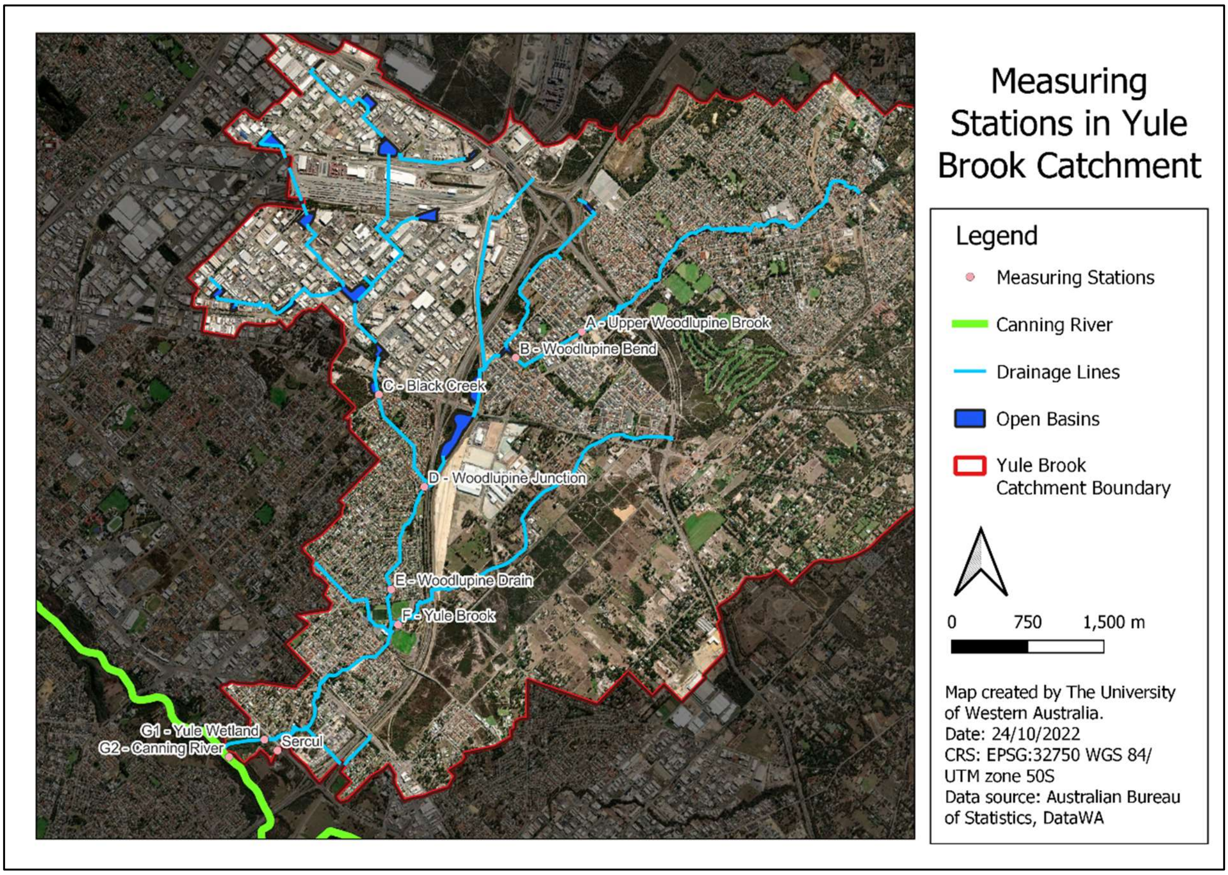


Map 2 - Yule Brook land cover pattern and sub-catchments.

2. Catchment Hydrology

2.1. Data and methods

The hydrology of Yule Brook catchment was investigated using historical and short-term data. Streamflow at Brixton St provided by WIR and rainfall at Gosnell city extracted from Bureau of Meteorology were used to examine the long-term streamflow trend, relationship between rainfall and discharge, and the ARI 1:20 flood frequency of the catchment. Streamflow data collected on 22 September 2022 was analysed to compare the short-term hydrology and the difference between the four approaches used to collect data, including Ball Velocity, Weir, Swoffer and Manning equation. The location of the study sites and drainage lines of the catchment are shown by *Map 3*.



Map 3 – Locations of sites and drainage lines in the Yule Brook catchment.

2.2. Historical hydrology

2.2.1. Temporal trends in streamflow

The streamflow in the Brixton St station (station number: 616042) fluctuated throughout the years with an average of 8,338,104 m^3/year. From *Figure 1*, we observed a significant drop in the overall flow rate since 1997. The data from 2007 to 2011 were cross-checked with the Yule Brook fact sheet published by DWER, which were both approximately 7,948,500 m^3/year (Department of Water, 2011). Moreover, we have no recorded data for year 2013, 2016 and 2017. Also, the streamflow for 2020 only had data from January to July of the year. Furthermore, we found that the likelihood of low streamflow is greater than the likelihood of high streamflow, with a streamflow of 0 to 1 m^3/day having a probability of greater than 75% of occurring.

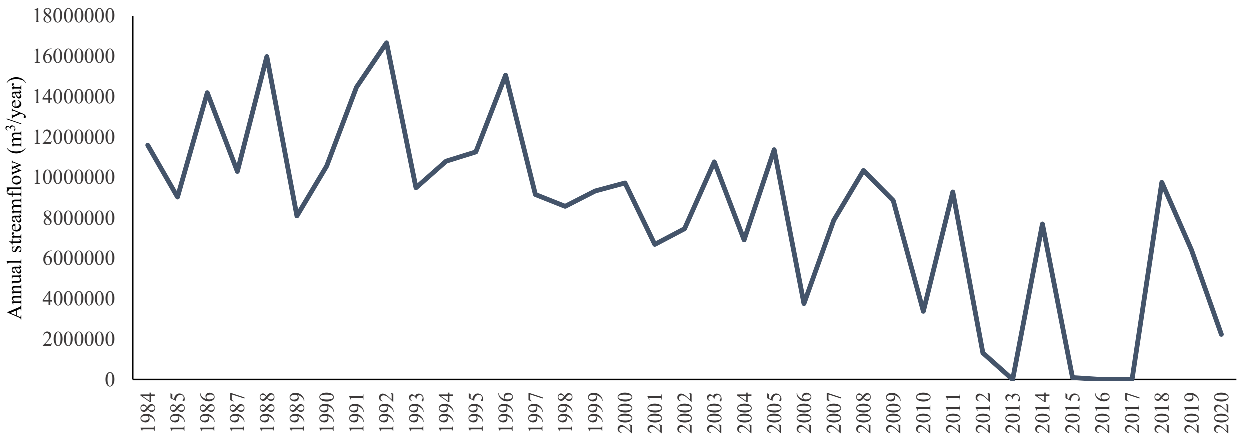


Figure 1 – Trend of all-year streamflow (1984 – 2020) in Yule Brook catchment.

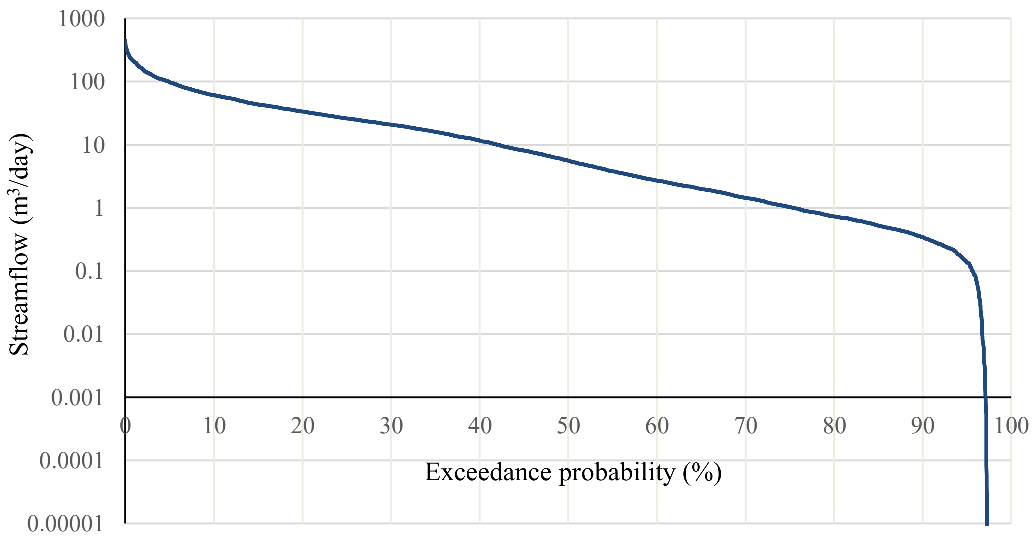


Figure 2 – Flow Duration Curve of Yule Brook catchment (in logarithmic scale).

2.2.2. Relationships between rainfall and runoff

The streamflow in the Brixton St is linearly and positively correlated with the nearby rainfall in the City of Gosnells, with a r^2 value of 0.4075. This indicates that only 41% of the variation is explained by the trendline, which could be due to some outliers, as shown in *Figure 3*. According to the trendline, we found that for every additional 1mm/year of rainfall, the annual streamflow increased by 0.3577 m^3/year.

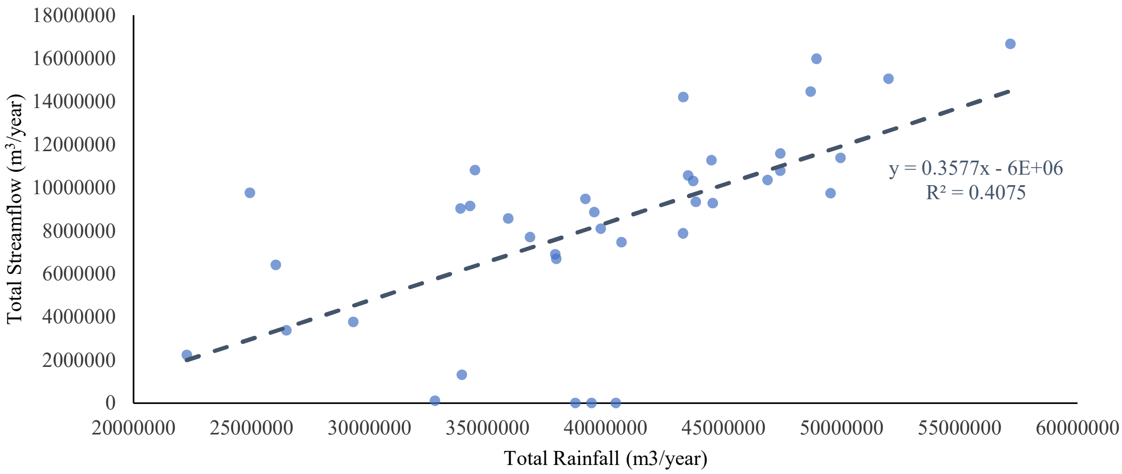


Figure 3 – Relationship between City of Gosnells rainfall and Brixton St flow.

2.2.3. Estimation of an ARI 1:20 flood frequency

Based on the Intensity-Frequency-Duration (IFD) lookup table for Perth (Bureau of Meteorology, 2016), released by the Bureau of Meteorology, the frequency for an ARI 1:20 flood is 34 mm/h. Also, we found our catchment area has 5,300 hectares as reported in the Yule Brook fact sheet (Department of Water, 2011). The runoff coefficient was obtained from the slope of the trend line shown in *Figure 3*. All these factors were substituted in the formula for flow magnitude (*Equation 1*). As a result, we found that the flow magnitude for a 1 in 20 years ARI rainfall event is 179.05 m^3/s.

Equation 1:

Formula for flow magnitude: $Q_p = cIA/360$

c: rainfall coefficient
I: Average Recurrence Interval (ARI) in mm/h
A: Catchment area in hectare

2.3. Sub-catchment hydrology

On 22 September 2022, the streamflow of different sub-catchments at our study sites were collected using four different approaches (Table 1). According to *Figure 4*, the average streamflow from sub-catchment A to F is around 1 m^3/s, whereas sub-catchment G possesses relatively high streamflow at 6 m^3/s. However, we observed that the standard errors of Manning calculations are much higher than the other methods, which indicates that using Manning Equation as a method to calculate streamflow is not as accurate.

Table 1 Approaches used to estimate streamflow.

Method	Accuracy	Description
Ball Velocity	Coarse	Time taken for a ball to flow from starting point to ending point with a known distance was measured to derive the flow velocity.
Weir		River water level was measured and referred to the Weir rate curve.
Swoffer	Accurate	Experimental instrument was used, and data were recorded.
Manning Equation	Theoretical	$Q[m^3s^{-1}] = \frac{1}{n}AR^{\frac{2}{3}}S^{\frac{1}{2}}$ n: Manning's roughness A: cross-sectional area of flow R: hydraulic radius S: slope

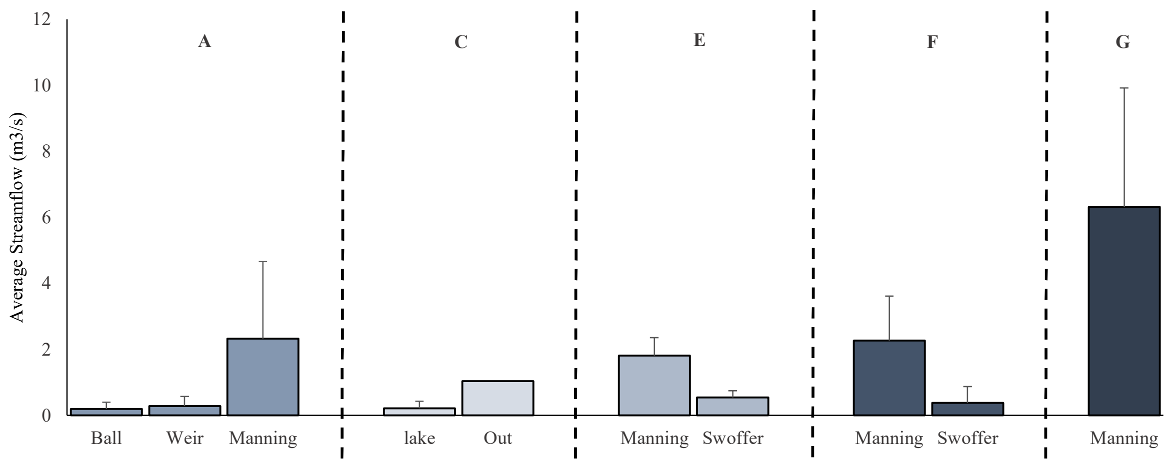


Figure 4 – Average streamflow in (A) Upper Woodlupine Brook; (C) Woodlupine Wetland Outlet; (E) Lower Woodlupine Drain; (F) Yule Brook and (G) Yule Confluence subcatchments.(Note: C-lake = C + C-in)

3. Catchment Hydrology

3.1. Data and methods

The investigation of the water quality at the Yule Brook catchment was conducted using historical data and short-term data, and land use in the catchment. Water quality was measured with TP and TN. *Equation 2* shows the components of each nutrient, where the data for those molecules were collected and compiled from the Department of Water and Environmental Regulation. The data from 1987 to 2022 was analysed for long-term changes in water quality. Moreover, the inter-site comparison of the nutrient concentrations from 2016 to 2022 were analysed to see the short-term changes in the sub-catchments. The nutrient concentrations of sub-catchments in 2022 were compared to further discuss about the current nutrient concentrations in each sub-catchment. Furthermore, the land use in the catchment was compared with the nutrient concentrations for the differences in nutrient concentrations by the sub-catchments.

Equation 2:

$$TP = PO_4 + OP$$
$$TN = NO_x + NH_4 + ON$$

The state government set a target value of phosphorus and nitrogen in the catchment to improve the water quality. In this investigation, the target values published by Australian and New Zealand Environment Conservation Council (ANZECC) and the Healthy River Action Plan (HRAP) were used. ANZECC was established to improve the water quality in Australia as a part of Australia's National Water Quality Management Strategy (NWQMS), whereas HRAP was established by the state government to improve the Water Quality in the Swan Canning River system in 2006. The target value set by ANZECC for the TP and TN was 65 µg/L and 1200 µg/L, respectively (*ANZECC & ARMCANZ (2000) Guidelines*, 2019). HRAP sets the long-term and short-term target values of TP and TN (Swan River Trust, n.d.). The short-term TP and TN were 200 µg/L and 2000 µg/L, respectively. Whereas the long-term TP and TN were 100 µg/L and 1000 µg/L, respectively. The short-term guidelines were defined to be in between 1 to 5 years and long-term guidelines were defined to be more than 10 years. Hence, the long-term guidelines were used for the historical and short-term trends, and short-term guidelines were used for the comparison of the sites.

3.2. Historical water quality

3.2.1. Historical nutrient

The historical nutrient concentration was observed by time series and seasonal changes. Stacked area graph shown in *Figure 5* represents the nutrient concentration where summation of the nutrients represents the concentration of TP and TN. The concentration of TN was mostly over the guideline by ANZECC and HRAP, but the concentration of TP was mostly below the ANZECC targeted value. There was no significant change in the concentration of TN, except for the sudden increase of Ammonium in 2017. On the other hand, the concentration of TN increases over time which exceeds the guidelines by ANZECC and HRAP. After HRAP was introduced, TP concentration increased (*Figure 5B*), however, there were no significant changes in the TN concentration (*Figure 5A*). In terms of the nutrient concentration of nitrogen, recent years recorded lower than the long-term HRAP targeted value, indicating the water quality is maintained. Seasonal changes in the nutrient concentration were represented in *Figure 6*. On average, TN was higher in winter than in summer, and TP was higher from the end of summer to autumn compared with winter to spring. Moreover, the concentration of both nutrients was higher than the HRAP guideline most times.

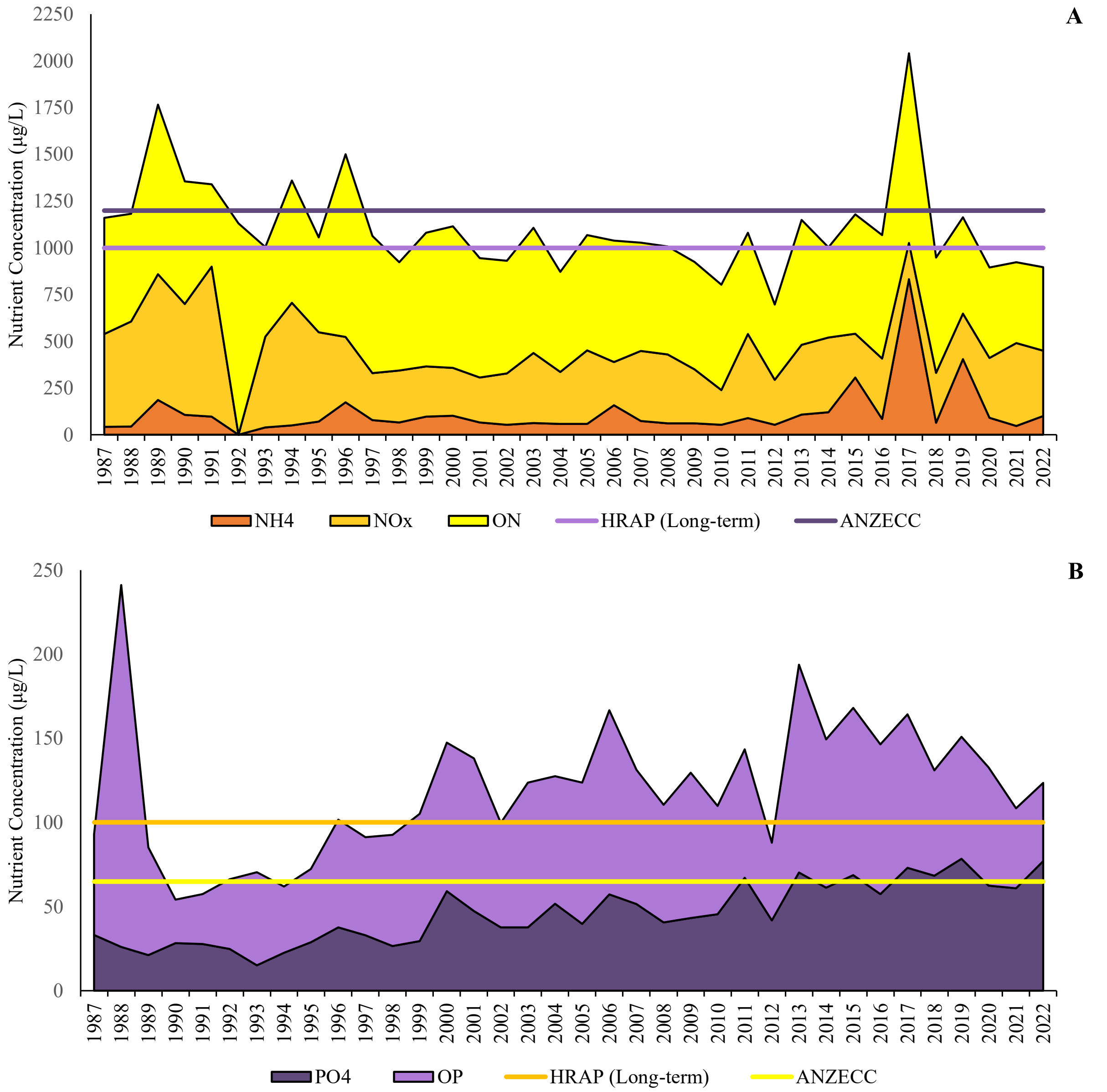


Figure 5 – Concentration of all-year (Panel A) nitrogen and (Panel B) phosphorus (1984 – 2020) in Yule Brook catchment.

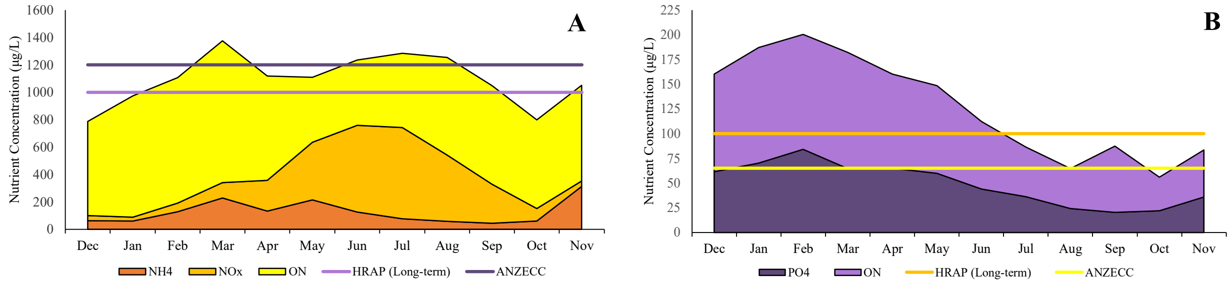


Figure 6 – Concentration of all-year (Panel A) nitrogen and (Panel B) phosphorus (1984 – 2020) during different seasons in Yule Brook catchment.

3.2.2. Inter-site comparison

The concentration of nitrogen and phosphorus are compared with different sites in the catchment, shown in *Figure 7*. Station C-in indicates the nutrient level of the Black Creek and C-out indicates the nutrient level of the river after passing through the Black Creek. Since station G – bridge was not recorded before, the changes of TN in station G-bridge cannot be analysed. The HRAP short-term targeted value for the TN and TP were 2000 µg/L and 200 µg/L, respectively. The most sub-catchments recorded less nutrients concentrations than the HRAP short-term targeted value. As shown in *Figure 8*, TN decreased in most stations within the recent 7 years, where they become lower than HRAP long-term guidelines. In terms of the concentration of TP, most stations recorded a decrease in concentration (*Figure 9*), however, their concentration was more than the HRAP long-term targeted value except for stations A, F, and G-bridge. Moreover, the TP concentrations recorded the lowest within the recent 7 years in most stations (*Figure 9*). Due to the decrease in TP and TN concentration in recent years and the lower concentrations than most of the targeted values, the water quality is getting better in the catchment.

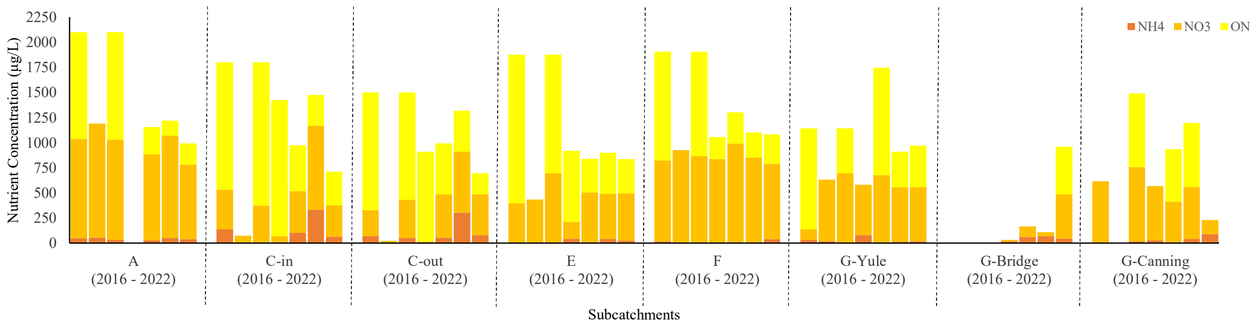


Figure 7 – Concentration of nitrogen in different sub-catchments.

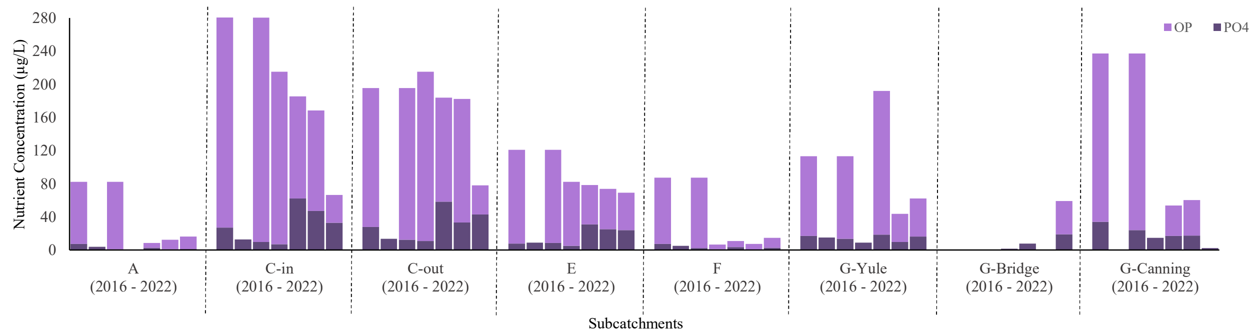


Figure 8 – Concentration phosphorus in different sub-catchments.

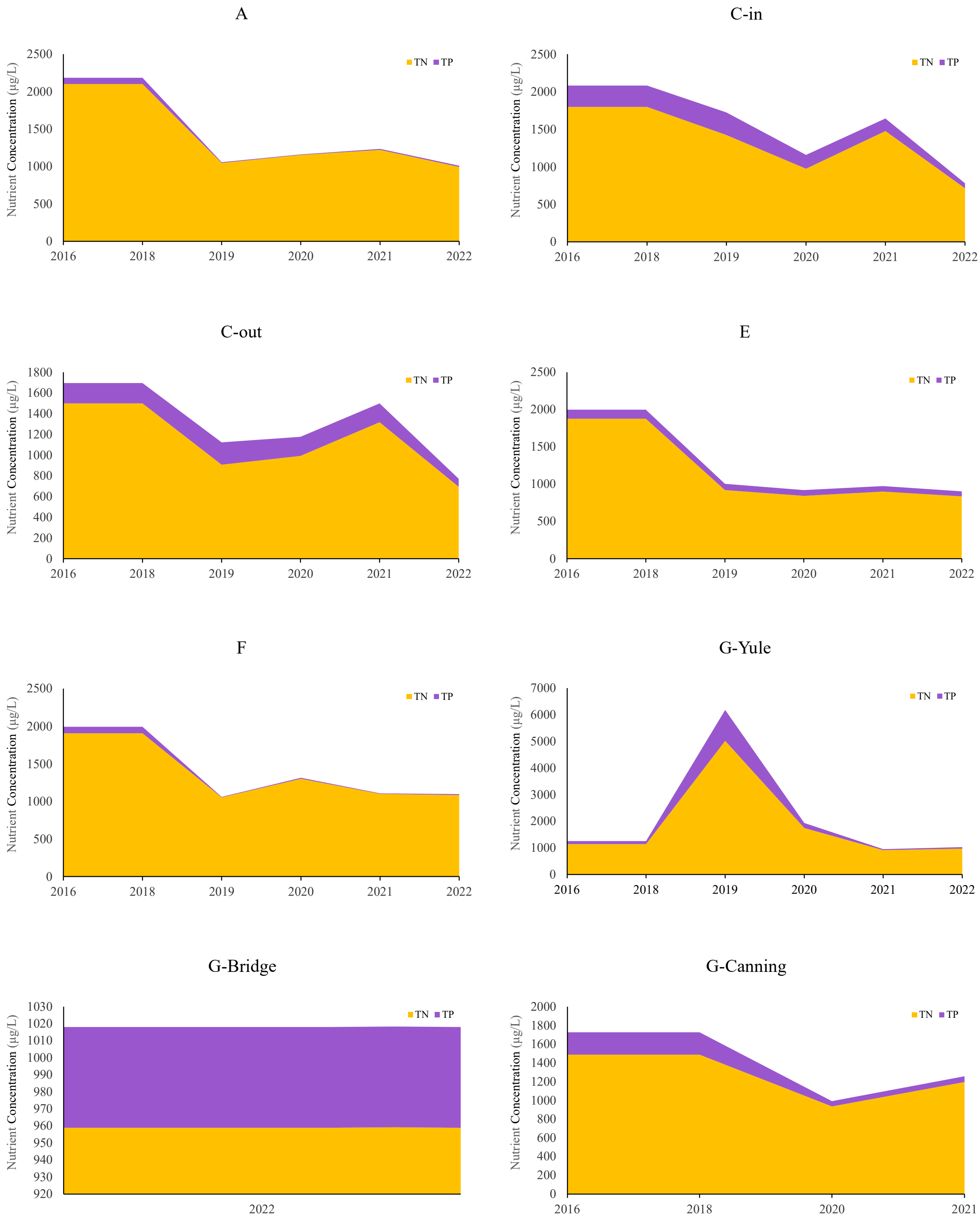


Figure 9 – Concentration of Total Nitrogen (TN) and Total Phosphorus (TP) in different sub-catchments.

3.3. Sub-catchment water quality

The changes in nutrient through the Yule Brook catchments was observed. As shown in *Figure 7*, the two drains interact at station D, which assumes of the nutrients in station A is not relative to the nutrient in station C. Hence, the nutrient after station D represents nutrient concentration after the two drains intersect. From *Figure 11*, station F had the highest TN, and C-out had the lowest TN. On the other hand, C-out had the highest TP, whereas station F had the lowest TP. Moreover, station C-out had the highest TN, whereas station F had the lowest. The concentration of TN and TP were below the ANZECC and HRAP short-term target value, indicating the water quality is good in the Yule Brook Catchment.

In terms of the TN flow, station A in the Roe Hwy drain had higher TN compared with station C in the Lower Woodlupine drain. It was predicted to be no change or a slight change in TN from the interactions of the two drains to station E, as the amount of TN in station E was between the two stations. Then, it increases through E to F and decreased when it flows through G.

In terms of the TP flow, station A had lower TP compared with station C. The amount of TP had increased in Black Creek shown as the difference between C-in and C-out, and the TP slightly decreased at station D after the two drains interacted. There was a significant decrease in station F, then increased at station G indicating the loss of nutrients between station E and F, and gained after station F.

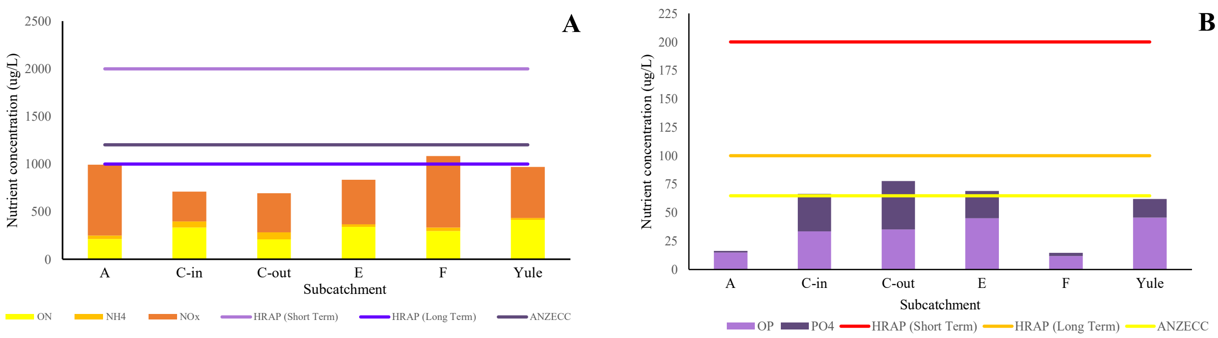


Figure 11 – Concentration of TN (A) and TP (B) in different sub-catchment in 2022.

3.4. Sediment loads

The estimated load of water constituents passing through station E to station G was calculated. The daily load was calculated from *Equation 3*, however, in some cases, they don't calculate the concentration. Q in equations shows the discharge rate, C represents the concentration, and EC represents the electrical conductivity. The coefficients in *Equation 4* convert FTU to NTU which has the unit of g/m^3 to find the loads. The results of the daily loads were summarised in Table 2.

Equation 3:

$$\text{Load (g/day)} = Q\ (m^3/\text{day}) \times C\ (g/m^3)$$

Equation 4:

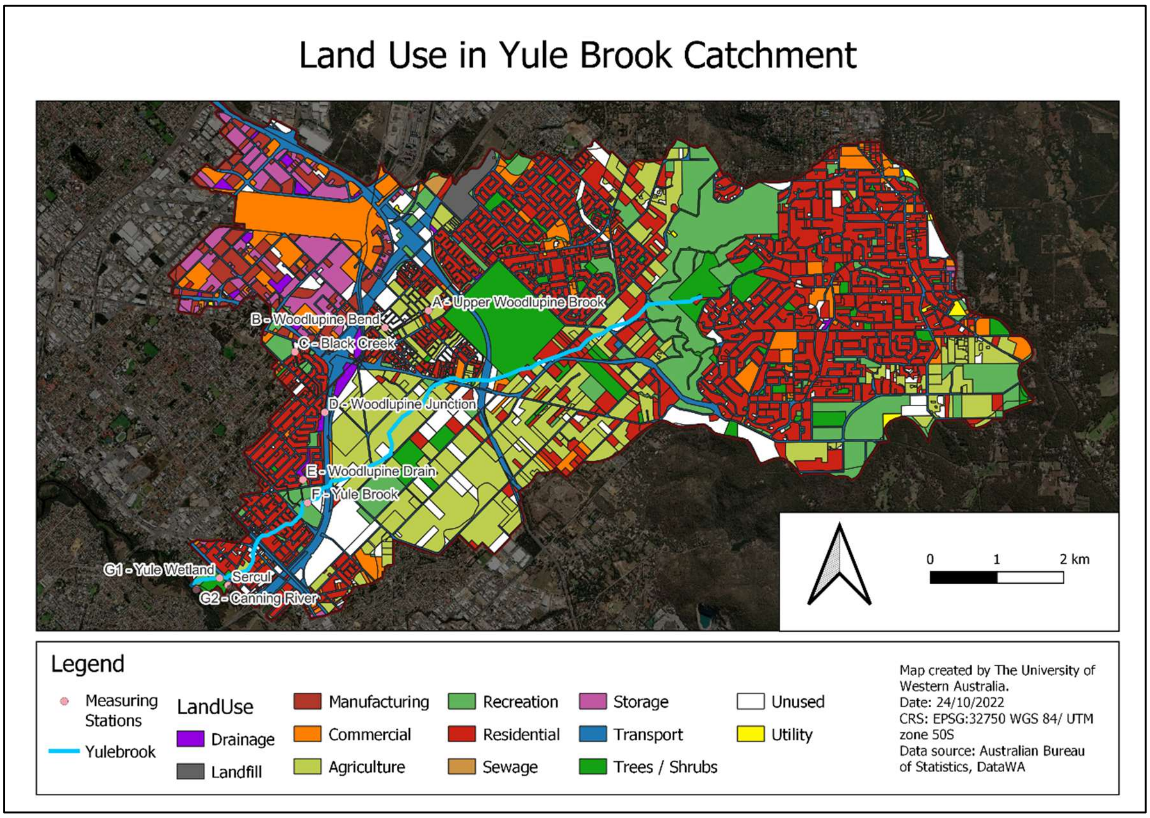
$$\text{Sediment load} = Q\ (m^3/\text{day}) \times \text{Turbidity (FTU)} \times 0.5$$

Table 2 Summary table of the daily loads in station E, F, and G

Daily loads	E: Woodlupine sub-catchment (kg/day)	F: Yule Brook sub-catchment (kg/day)	G: Entire catchment (kg/day)
Phosphorus	1856	1999	13107
Nitrogen	152	13	629
Sediment	441.35	653.19	-

3.5. Land-use

Land use plays an essential role in conserving and improving water quality. The land use map of the Yule Brook catchment is shown in *Map 4*. The land use of sub-catchments and the nutrient concentrations are represented in Table 3. Most stations are located in nature, however, they are surrounded by the manufactured area, such as land used for residential, transport, and manufacturing. Nutrient concentrations are relatively lower in areas that have trees and shrubs than in residential, manufacturing, recreational, and agricultural areas (Table 3).



Map 4 – Land-use of Yule Brook catchment in 2022.

Table 3 Nutrient concentrations and land-use

Site	TP	TN	Land-use
A	12.23	1220.80	Agriculture
C-in (Black Creek)	168.38	1474.95	Recreation
C-out	182.35	1317.36	Residential
E	73.84	899.40	Manufacture / Residential
F	7.14	1100.21	Recreation
G- Yule	43.67	909.88	Trees / Shrubs

4. Waterway management and restoration

4.1. Threats to catchment health

Due to many anthropogenic forcings such as such as land use and land cover changes, and climate change, catchment quality has decline in not only Australia, but the world. These threats can be both direct and indirect, affecting both living and non-living components of a catchment (Threats to Our Waterways, 2015). Some of these many threats can be summarised as seen below:

4.1.1. Clearing of vegetation

Vegetation provides a crucial role to the health of catchments, aiding in the oxygenation of the water, the cycling of nutrients and sediments and stabilising the flow, banks and beds of a waterway (Aquatic and Riparian Vegetation, n.d.). The expansion of urban and industrial regions has seen the removal of this vegetation, causing the degradation of catchments including erosion, increase sediment deposits, pollution of water ways, oxygen depletion and increased turbidity of the catchment (Oates, 2000).

4.1.2. Nutrient contaminants

Land use and land cover changes brought on by human development hugely effects natural landscapes. A large way in which this effect takes place is by the removal of vegetation that utilise excess nutrients in the soil. Additionally, unnecessary nutrients are further added onto landscapes via agricultural fertiliser and animal manure (Threats to Our Waterways, 2015). Phosphorous and Nitrogen are the most common nutrients found in catchments that cause damage to ecosystems (Threats to Our Waterways, 2015). Excess amounts of these nutrients in catchments have the capability to stimulate plant growth, resulting in algae blooms causing loss of biodiversity, thus harming water quality (Sources of Nutrients to the Swan and Canning Rivers, 2000).

4.1.3. Non-nutrient contaminants

Runoff around industrial and commercial land use areas often result in contaminants entering catchments. Contaminants that have the capability to harm catchment health include metals, pesticides and bacteria (Contaminants, n.d.). These contaminants are often caused by increased industry, urbanisation and agriculture and harm vegetation and other life around catchments (Contaminants, n.d.).

4.1.4. Low dissolved oxygen

Low dissolved oxygen can be naturally induced, however in the case of the swan and canning river estuaries, the cause of this high oxygen demand is due to nutrient enrichment and organic loading (Low Dissolved Oxygen and Oxygenation, n.d.). Low oxygen levels in a catchment can cause algal blooms and large fill kill events which are detrimental to the health of a catchment (Water Science Notes, 2015).

4.1.5. Salinity

Although moderate amounts of salt are needed for the prosperity of aquatic vegetation, too much dissolved salt can be detrimental to a catchment and harmful to salt intolerant plants and other organisms in the area (Understanding Salinity, n.d.). In places where native vegetation has been removed due to land use and land cover changes, more water is lost through evapotranspiration and evaporation, and more salt accumulates in the given catchment (Understanding Salinity, n.d.).

4.1.6. Erosion and sedimentation

Deepening channels for flood control, agricultural grazing, the building of infrastructure and other activities that interfere with the nature of waterways cause vastly increased rates of erosion and sedimentation in catchments and waterways (Erosion and Sedimentation, 2017). Increased sediment in water can cause increased turbidity of the water and thus reduced photosynthesis, harming macroinvertebrates (Till, 2000).

4.2. Opportunities for management

The Australian government aims to manage waterways by 8 crucial steps as described below (Managing Our Waterways, n.d.):

1. Implementation of policies, legislation and guidelines
2. Water allocation planning and the licencing of water
3. Land use planning and development restrictions
4. Water quality improvement plans
5. Restoring waterways via river action plans
6. Remediation activities such as oxygenation and soil amendment
7. Managing urban waterways with water sensitive designs
8. Assessing waterway health to gage the effect of management actions

An example of these management actions is the swan canning Clean-up program:

The swan-canning estuary much like the rest of the world are experiencing low dissolved oxygen in waters due to nutrient enrichment and organic overloading (Water Science Notes, 2015). High amounts of nutrient enrichment can cause organisms like phytoplankton to thrive at the expense of other organisms, causing algae blooms which have catastrophic impacts on the health of a catchment (Oxygenating the Swan and Canning Rivers, 2000). In order to resolve this issue, the Australian government have implemented a swan canning clean-up program which aims to use oxygenation as a method of reducing nutrient availability (Water Science Notes, 2015). By artificially increasing oxygenation in the water, aerobic decomposition and recycling processes within the catchment and can function optimally, thus removing nutrients at a faster rate. The implementation of this program has successfully reduced the amount of phosphorous and nitrogen in trialled regions, with drops of 64% and 97% respectively (Greenop et al., 1999).

4.3. Policy Context

4.3.1. HRAP

The HRAP, also known as the healthy rivers action plan, is a policy aimed to help the health of the swan canning river conducted by the Swan River Trust. This plan aims to reduce nutrients and other contaminants in catchments, minimised the amount of sediment in rivers, oxygenating water in the catchment and protecting and conserving wildlife and the structure of the foreshores (Healthy Rivers Action Plan, n.d.).

This plan aimed to have a 30% reduction in the amount of nutrients in the swan canning by 2015 (Healthy Rivers Action Plan, n.d.). As can be seen in figure 5, there has been a decrease in the amount of phosphorous in the Yule brook catchment, which could be explained by the implementation of this policy.

4.3.2. Infill Sewerage program

The infill sewerage program is a treatment method conducted by water corporation which aims to take wastewater away from domestic regions for effective processing (Sewer Infrastructure - Infill Sewerage Program, 2015). The full implementation of this system will see 100,000 properties in Australia will be a part of this system which will effectively reduce leach wastewater runoff into the environment and surrounding catchments (Sewer Infrastructure - Infill Sewerage Program, 2015).

4.3.3. MKSEA

MKSEA, or the Maddington Kenwick Strategic employment area, is the development of land in the city of Gosnells. According to the city of Gosnells, the development of this area will recognise environmentally sensitive areas, reserve land for the appropriate draining of water and provide public spaces that both protect and conserve wetlands and waterways (Maddington Kenwick Strategic Employment Area Precinct 1 | City of Gosnells, n.d.).

4.4. Green Infrastructure case studies

4.4.1. Woodlupine Living Stream (Site A and B)

This project aimed to transform the Woodlupine brook into a living stream (Woodlupine Brook Living Stream Design •, n.d.). This was achieved by changing the brook from a linear steep sided drain into a meander with wetland landscaping with pathways for both human enjoyment and environmental benefit (Project Details | City of Kalamunda, n.d.). This project was completed in 2020.

As can be seen in figure 8, site A (near the location of the woodlupine living stream), has relatively low phosphorous levels compared to its catchment counterparts, although the concentrations have been increasing since 2020. This is when this green infrastructure was introduced, and thus more research must be conducted on the efficiency of this infrastructure on phosphorous levels. However, nitrogen levels have been decreasing in this catchment (figure 7) over time, and therefore this could be effective at reducing nitrogen levels

4.4.2. Black Creek (Site C)

The Black Lake green infrastructure involved the construction of wetlands that aimed to both improve nutrient cycling and reduce the amount of sediment through the natural ecosystem services of wetlands (DWER, 2022). Figure 8 shows an extreme reduction in the amount of phosphorous in station C (black creek location). Due to wetlands and vegetations ability to filter nutrients, it is safe to assume that this change in land use in this area improved the quality of the catchment.

4.4.3. Mills Park revegetation efforts (Site E and F)

The mills park revegetation effort is a part of the Mills Park wetland management plan which includes the revegetation of native species to improve catchment quality. 10,000 native riparian species were initially planted to start the project and improve catchment health (City of Gosnells, 2021). To ensure the catchment is appropriately managed, overland flow patterns are maintained, water sensible urban designs implemented along the catchment and a fertiliser plan to minimize nutrient overload.

Both sites E and F, which where closest to the Mills park revegetation effort show a reduction in both phosphorous and nitrogen past the year 2018, as can be observed in figure 7 and 8. These consistent results from both sites E and F for nitrogen and phosphorous give reason to conclude that the revegetation effort from Mills park is highly effective at improving catchment quality.

5. Recommendations

The swan canning estuary has experienced significant stress in recent years, as has majority of waterways around the globe. Reasons for this stress include land use and land cover changes as well as climate change. The alterations of catchments because of human development can have significant effects on water way health, including increased turbidity, low dissolved oxygen, increased salinity and nutrient contamination (Threats to Our Waterways, 2015).

No exception to these damages is Yule brook, which has experiences fluctuations in nutrients such as nitrogen and phosphorous that are harmful to catchment health and damage ecosystems. In order to manage catchment health in the Yule brook, appropriate measures must be undertaken including rehabilitation and conservation of the catchment. The swan canning clean-up program which increased dissolved oxygen in water, and the HRAP to improve catchment health are both effective methods in improving water quality.

However, if long term improvement is to be made, green infrastructure and water sensitive urban designs must be implemented, and any more development in the region should be planned and regulated in the same manner MKSEA was. Both Black creek and Mills Park have seen a large reduction in nutrient contaminants due to correct implementation of green infrastructure and water sensitive designs. Correct drainage of water paired with maintaining riparian vegetation zones will ensure that wastewater is minimised and treated correctly.

Although land use and land cover changes have degraded water quality and catchment health in Perth, resulting in the increase in harmful levels of nutrients and removal, restoration in the Yule brook and surrounding catchments is possible. Reduction in nutrients through planting of native riparian vegetation as well as the correct treatment of wastewater through water sensitive urban designs will ensure improved catchment health. Yule brook catchment is a place of environmental and social importance, and with catchment quality decreasing worldwide, we must do everything we can to ensure our waterways are conserved.

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