Water Quality and The Yarra's Tributaries

John Monash Water is Life

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Abstract

Water plays an essential role in Victoria's economic and social prosperity. As the population of Melbourne continues to increase towards the projected 8.5 million in 2051, the security of a steady and reliable water supply for the city is critical. Victoria's unique closed catchment system provides some of the highest quality water in the world. However, three significant challenges exist in preserving this system: rapid population growth, urban sprawl and development, and the effects of climate change and pollution. The Yarra catchment lies north and east of Melbourne, covering an area of about 4,046 square kilometres, with its upper reaches providing 70% of Melbourne's drinking water. The influence of many different land use types throughout the Yarra catchment has led to diminished water quality along the Yarra River system. As such it's middle and lower reaches are unfit for agricultural and household use. Our project monitored the water quality of two tributaries of the Yarra catchment, Scotchmans Creek and Gardiners Creek, to determine appropriate measures which could be employed to improve the water quality of the lower reaches of the Yarra catchment.

Keywords

Yarra River; water quality; wetlands; tributaries; management strategies

1. Purpose of the research

The Yarra River is synonymous with the image of Melbourne. It is one of the primary reasons that Melbourne has been named the most liveable city for the last seven years, yet it is under threat from a variety of factors including fertilisers which are used on adjacent golf courses, runoff from urban development and discharge from industrial waste. This industrial waste includes nitrogen and nitrogen compounds, sediments such as dust and soot as well as small amounts of heavy metals. These pollutants have been contaminating the Yarra River since Melbourne was settled in the 19th century. The Yarra River has degraded over time, largely due to human disturbances and a lack of understanding concerning the ramifications of their actions. In addition to these environmental issues, the sheer number of governing bodies involved in overseeing the Yarra makes it incredibly difficult to improve the river's health. Some of the governing bodies include 11 local council areas through which the Yarra River flows, Melbourne Water, Parks Victoria, Department of Infrastructure, Department of Environment, Land, Water, and Planning, and the Environment Protection Authority. As a result, protecting the Yarra River has proven to be a difficult, contentious and complex issue.

Two tributaries of the Yarra River located in the southeast of Melbourne are Gardiners Creek and Scotchmans Creek. Gardiners Creek originates in Blackburn where it then flows southwest through Box Hill South, Burwood and Ashwood. At its confluence with Scotchmans Creek in Malvern East, it turns northwest, then continues through Ashburton, Glen Iris, Malvern and Kooyong, before flowing into the Yarra River in Hawthorn. By analysing the water quality of these two tributaries, we can monitor and assess the water quality of the Yarra River in order to make appropriate recommendations for its rehabilitation to ensure clean water in the future.

It is critical for Melbourne's water supply that the water from the Yarra River is of a quality which is acceptable for multipurpose use. Due to the effects of climate change and population growth, Melbourne's already scarce water resources may be unable to sustain its burgeoning population, it is therefore imperative that all water resources available in Melbourne's catchment areas be used sustainably and appropriately. Due to the Yarra River's current degraded state, it is essential that its health be improved so it can be employed for use across a range of services, both human and natural. Ideally, water from the Yarra River could be used in areas such as industry, to reduce the reliance on water from protected catchments, thereby increasing the availability of potable water for residential use.

Currently, there is limited choice as to how the Yarra River can be used as the water quality can pose risks to health. Swimming in the CBD is currently illegal due to the high rate of bacterial infections. Pollutants including wood, large metallic objects (bikes, car parts, metal sheets) as well as higher than recommended levels of E. coli - being 88 organisms per 100mL. In order to develop potential management strategies to improve the water quality of the Yarra River, an array of data must be considered to make informed decisions as to how to improve the Yarra River's health. To build a clear picture of the health of the two tributaries it was important to consider all available data. The current and historical data for both tributaries were used to determine their conditions over time and suggest the contribution each system makes to the health of the Yarra River catchment as a whole. A selection of successful management strategies for restoring water quality in other regions of Victoria and Australia were also evaluated to guide the development of strategies that could be used in Melbourne's local context.

2. Methodology

The research was conducted in multiple stages:

1. Collection of primary data of water quality from the tributaries
2. Obtaining and analysing secondary data of water quality of the tributaries
3. Evaluation of four case studies involving water quality management.

From this research, the causes of poor water quality in the tributaries were determined. This was then used to justify which strategies outlined in the case studies would be most effective in the context of the Yarra River system.

2.1 Collection of Primary Data

Sampling

- 6 x small sampling containers
- 6 x 1.25L plastic bottle

Map Showing Location of Water Sample Sites

Figure 1: Location of Water Sample Sites

Testing/Data collection

1. 6 x plastic pipette
2. Beakers
3. PASCO SPARKView meter with water quality sensor and probes

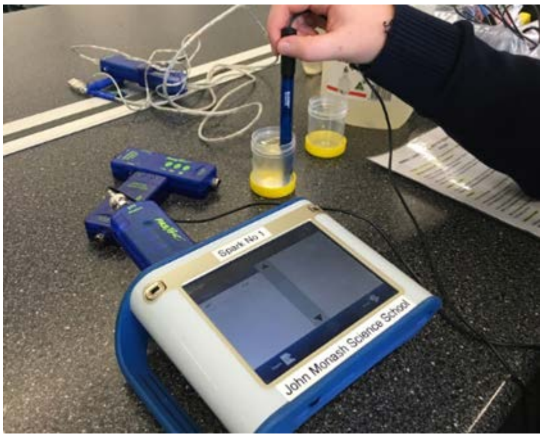

Figure 2: Analysing water samples using PASCO SPARKView
Source: Musgrave 2018

The collection of primary data involved taking six samples of water, three from Gardiners Creek and three from Scotchmans Creek. Although the primary data collected was minimal, we were able to gain an indication of the current water quality in both of the tributaries. To ensure that an acceptable range of data was collected, samples were taken at fair distances from one another (between 300m and 2.5km). Samples were also taken before and after the confluence of both tributaries.

These samples were then tested in terms of their quality. This included the pH, conductivity and dissolved oxygen content. The pH levels of a water sample can provide an indication of the health of the ecosystem from which it was taken. The types of chemicals and compounds that can be found in the water can be determined and in turn, can help scientists ascertain what organisms may live in the sample area. In most cases, the ideal pH for aquatic animals is between 6.5 and 9, and for plants, it is ideal between 6.5 and 12. A typical freshwater system has a pH between 6.5 and 8.5. Acidic water is corrosive and can lead to an increase in the rate at which heavy metals dissolve in the water. Heavy metals, once ingested or absorbed, can cause cell death and genetic damage in organisms, interfere with natural chemical processes and have significant negative impacts on both water quality and the health of river ecosystems overall. When pH does not meet these standards, water quality is considered to be low, and organisms are subjected to physiological stress. This stress on different species can lead to other species outcompeting them and taking advantage of resources within the ecosystem. Furthermore it can lead to drastic changes in the composition and biodiversity of an ecosystem, sometimes having irreversible consequences. This may lead to a loss of ecosystem services such as water filtration, soil formation and climate regulation.

Dissolved oxygen was measured as it is essential to all water systems. Almost all aquatic life requires it for respiration; even microbes need it for decomposition. However, abnormally increased levels can result in the death of aquatic creatures, as can decreased levels. In addition to this, fluctuating temperatures caused by climate change, global warming and the El Niño Southern Oscillation (ENSO) lead to dissolved oxygen changing according to the temperature of the water and air. When water is cooler, more oxygen can dissolve as the particles are more closely packed together in the air and water, meaning there is more oxygen to be dissolved in the water.

Conductivity was also investigated as it is directly related to the number of ions dissolved in the water. A measure of conductivity can give an indication of the salinity of the water, the number of polar compounds as well as other ions - magnesium ions and potassium ions for example. As a result, conductivity is an indicator of the overall health of a system. Higher electrical conductivity is indicative of larger amounts of these substances. When water is particularly saline, it can cause water to flow from the plant roots back into the soil and water sources, leading to the death of the plants.

2.2 Collection of Secondary Data

Secondary data was obtained as it provides information on the water quality over a longer time frame than could be collected as primary data. This gives a clearer image of the typical water quality of the two tributaries and allows for appropriate management strategies to be considered. In addition, by examining the data that was collected over time and comparing it with the primary data, trends were able to be observed, and the impact of severe weather events in certain years became evident.

The secondary data - in the form of water quality readings - was obtained from the Melbourne Water website. The data available on Scotchmans and Gardiners Creeks was analysed and organised in order to see change over time. This includes data from three different sites, two from Gardiners Creek and one from Scotchmans Creek. The data collection started at various times between 2000 and 2008. The most recent data available is from 2015. By collating data on the water quality, we were able to make informed evaluations of current management strategies.

3. Results

Table 1 Data Collected from Sample Sites

	Scotchmans Creek - site 1	**Scotchmans Creek - site 2**	**Scotchmans Creek - site 3**	**Gardiners Creek - site 1**	**Gardiners Creek - site 2**	**Gardiners Creek - site 3**
Conductivity (µs/cm)	58	78	61	94	83	81
Optical dissolved oxygen (mg/L)	340.00	293.95	200.27	88.27	90.43	106.39
pH	7.7	7.6	7.3	9	10.3	10.4

3.1 Analysis of Primary Data

The data shows that the samples collected at Gardiners Creek are alkaline; with higher alkalinity recorded from upstream samples. Site 2 of Gardiners Creek had a foul smell. A number of factors could have caused the smell; the alkalinity of the water may have led to the odour, or certain pollutants like phosphates and nitrates could also have contributed to the smell. Alternatively, certain fats present in the creek could have encouraged green or blue algae to grow and subsequently decompose, removing oxygen from the waterway and causing the smell. The pH of Scotchmans Creek, when the sample was collected on the 06.02.2018 showed a pH closer to neutral, and well within State Environment Protection Policy standards. Upstream the pH became increasingly closer to neutral. While optical dissolved oxygen increases upstream in Gardiners Creek, it decreases for Scotchmans Creek. The optical dissolved oxygen in Gardiners Creek is much lower than that of Scotchmans Creek, which suggests that the temperature could be warmer in Gardiners Creek, accounting for the lack of oxygen. Conductivity increases downstream for Gardiners Creek, which suggests salinity also increases downstream. These increasing trends are most likely due to the streams passing through urban areas, picking up more debris and runoff as they flow towards their confluence with the Yarra River.

3.2 Analysis of Secondary Data

The secondary data collected has been analysed both in terms of the trends displayed over time, as well as in terms of the actual quality of the water, and whether or not levels were safe for a variety of uses.

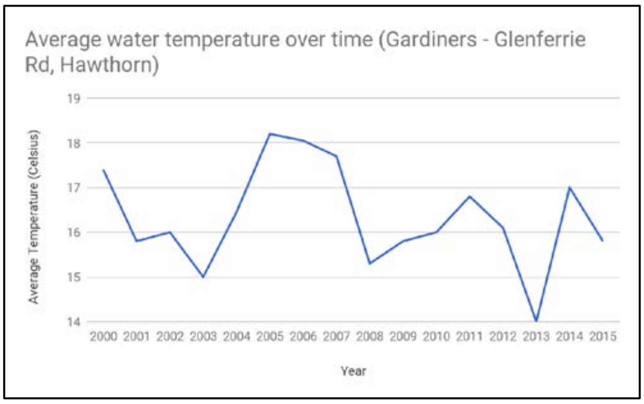

Figure 3a: Average water temperature over time (Gardiners - Glenferrie Rd, Hawthorn)

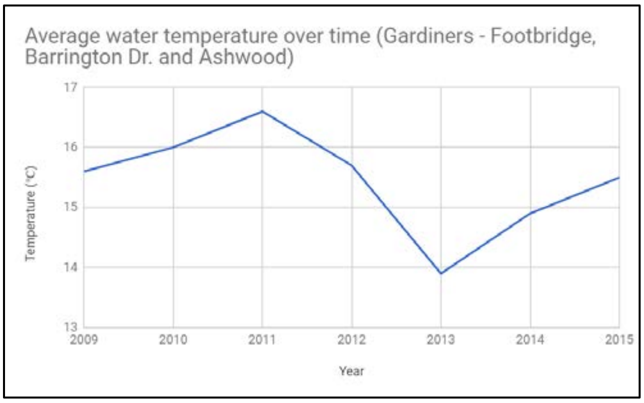

Figure 3b: Average water temperature over time (Gardiners - Footbridge, Barrington Dr. Ashwood)

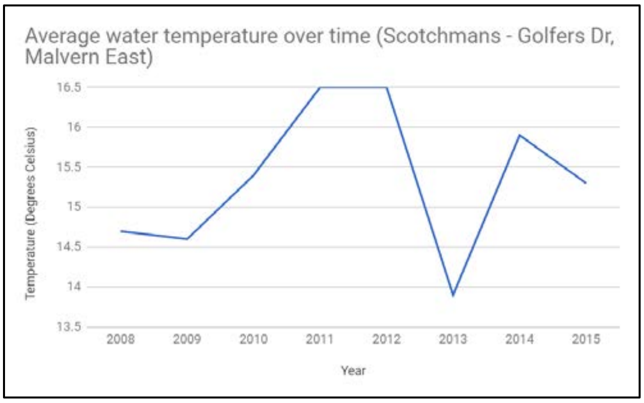

Figure 3c: Average water temperature over time (Scotchmans - Golfers Dr, Malvern East)

Water temperature over time in tributaries from the graphs of Gardiners and Scotchmans Creeks show oscillations in temperature likely due to the ENSO cycle and possibly climate change. The temperature changes could be also linked to construction work or removal of vegetation near the creeks. Temperatures ranged from 14 degrees to 18 degrees Celsius on average at Gardiners Creek. Scotchmans Creek averaged from 14 degrees to 16.5 degrees Celsius on average - slightly lower than Gardiners temperatures, as suggested by the primary data. These readings are within an acceptable range for a healthy creek system.

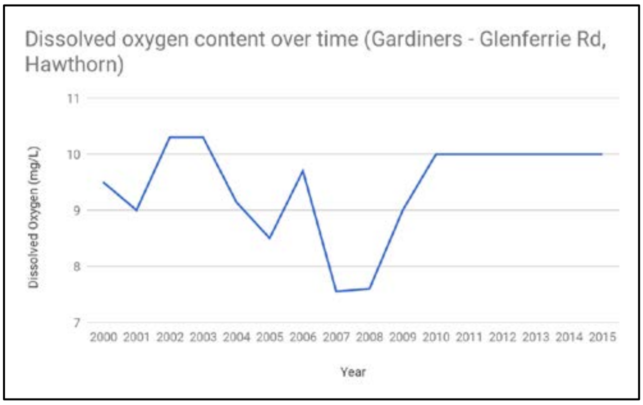

Figure 4a: Dissolved oxygen
(Gardiners Creek - Glenferrie Rd, Hawthorn)

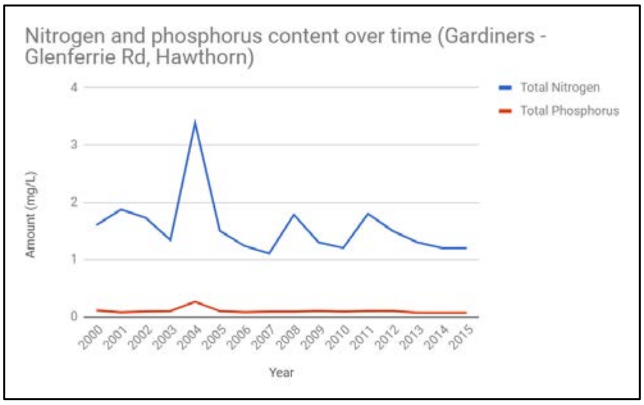

Figure 4b: Nitrogen and phosphorus content over time (Gardiners Creek - Glenferrie Rd, Hawthorn)

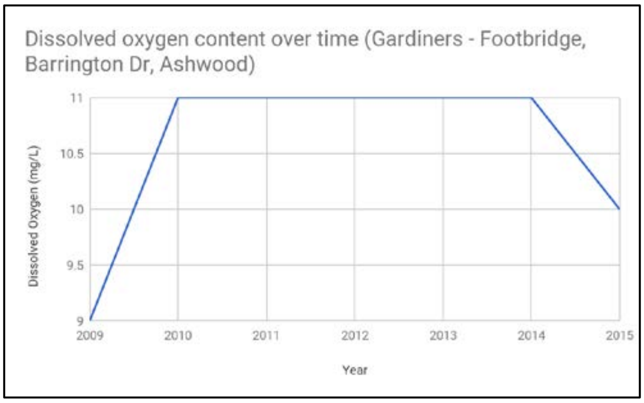

Figure 4c: Dissolved oxygen content over time
(Gardiners Creek - Barrington Dr, Ashwood)

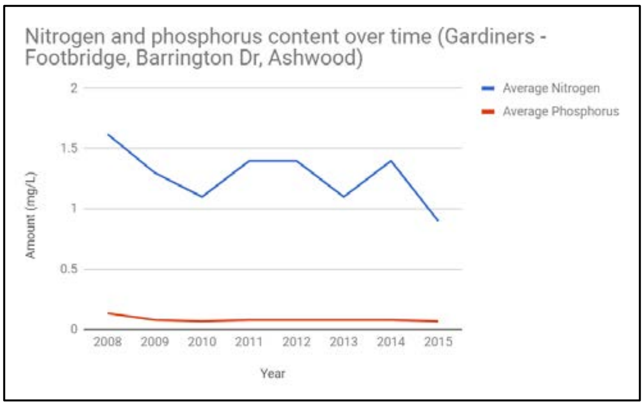

Figure 5a: Nitrogen and phosphorus content over time (Gardiners Creek - Footbridge, Barrington Dr, Ashwood)

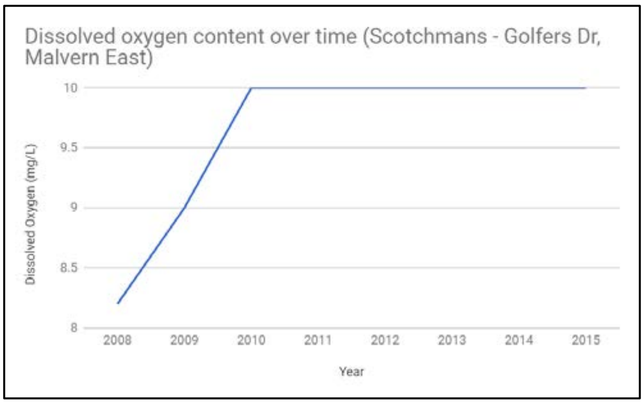

Figure 5b: Dissolved oxygen content over time (Scotchmans Creek - Golfers Dr, Malvern East)

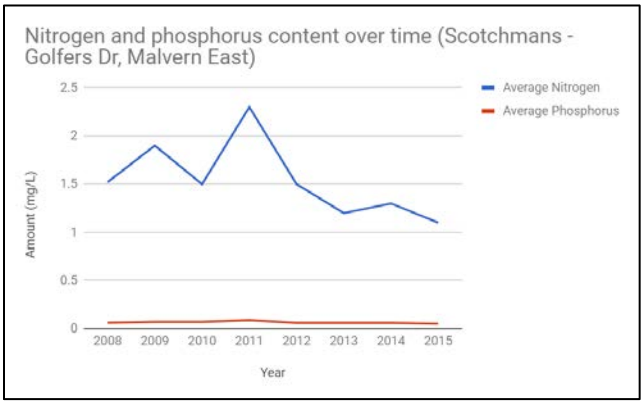

Figure 5c: Nitrogen and phosphorus content over time (Scotchmans Creek - Golfers Dr, Malvern East)

Dissolved oxygen levels, shown in the graphs display an increase over time to particularly high levels. When oxygen and nitrogen levels in the water are too great for the fish to handle it can lead to death, which is known as ‘gas bubble disease’. From the graphs, it can also be seen that, on average, nitrogen levels are far greater than The State Environment Protection Policy (SEPP) recommended levels - being 0.6mg/L. High levels of nitrogen can lead to algae blooms in water and eutrophication.

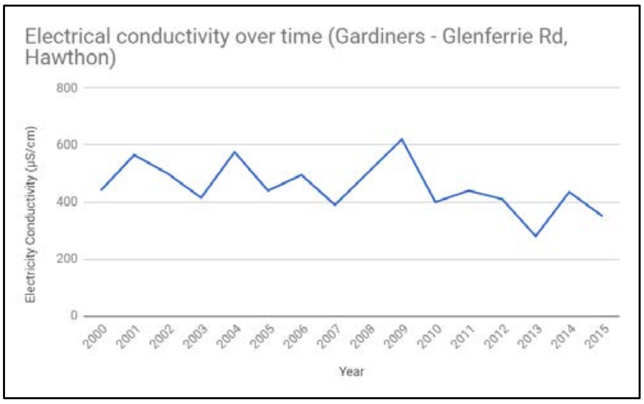

Figure 6a: Electrical conductivity over time (Gardiners - Glenferrie Rd, Hawthorn)

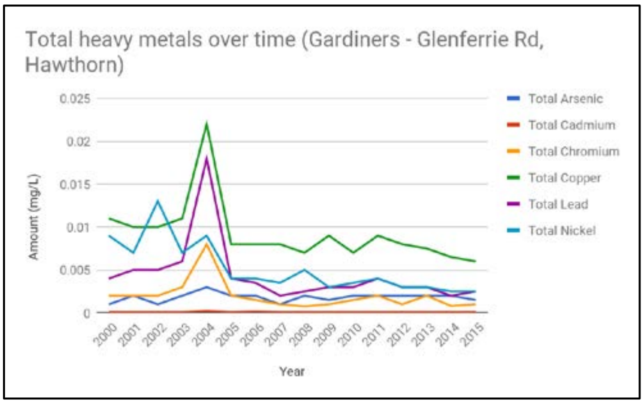

Figure 6b: Total heavy metals over time (Gardiners - Glenferrie Rd, Hawthorn).

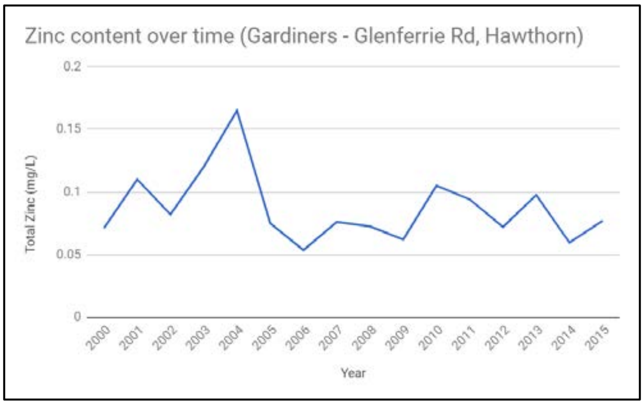

Figure 6c: Total zinc content over time (Gardiners - Glenferrie Rd, Hawthorn)

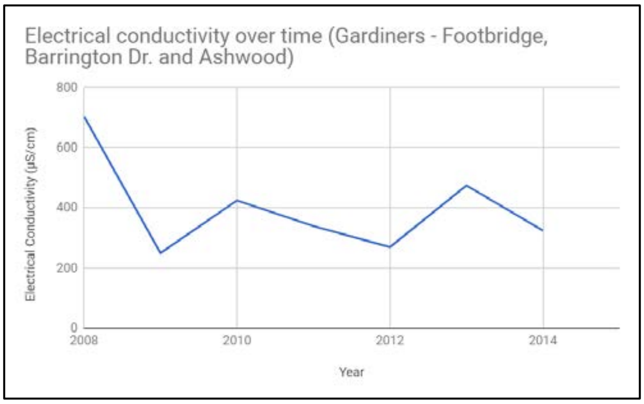

Figure 6e: Electrical conductivity over time (Gardiners - Footbridge, Barrington Dr. Ashwood).

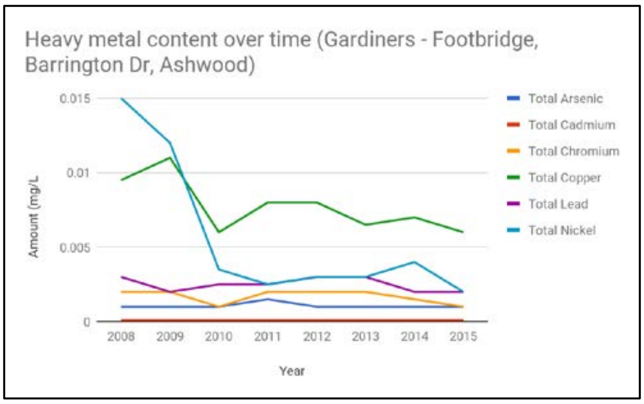

Figure 6f: Heavy metal content over time (Gardiners - Footbridge, Barrington Dr. Ashwood).

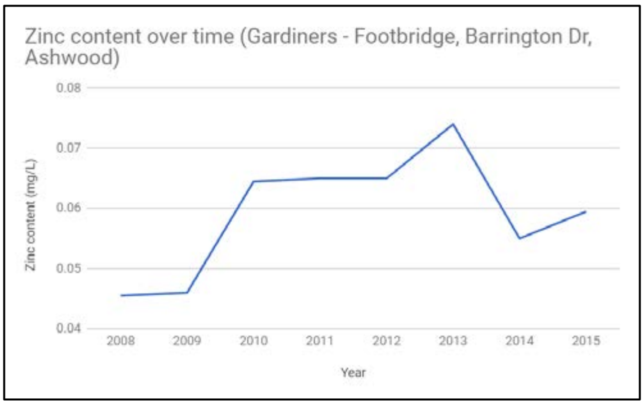

Figure 6g: Zinc content over time (Gardiners - Footbridge, Barrington Dr. Ashwood).

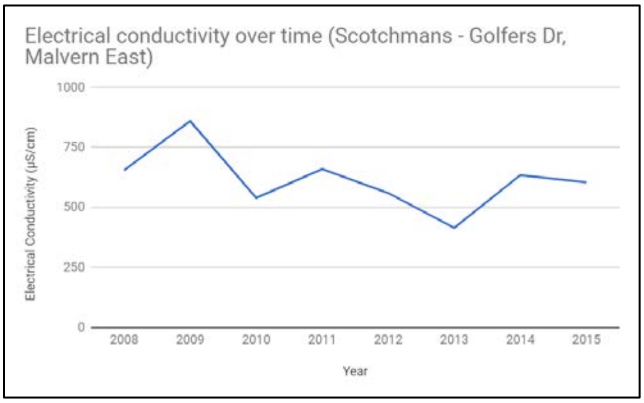

Figure 6h: Electrical conductivity over time
(Scotchmans - Golfers Dr, Malvern East).

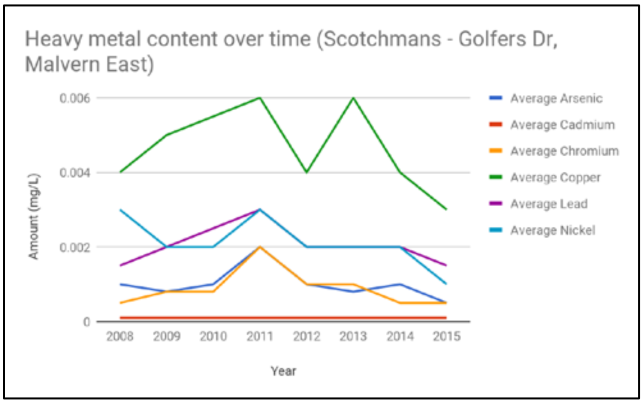

Figure 6i: Heavy metal content over time
(Scotchmans - Golfers Dr, Malvern East).

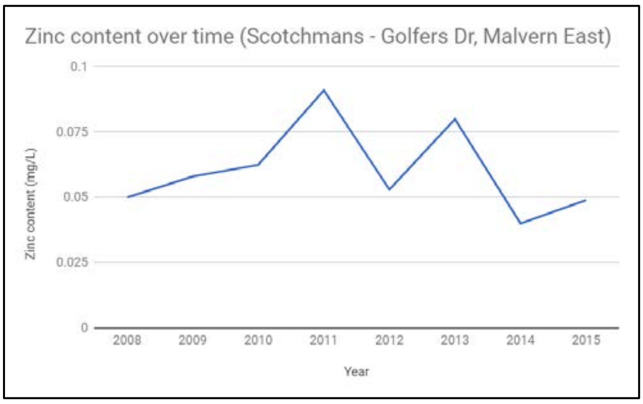

Figure 6j: Zinc content over time
(Scotchmans - Golfers Dr, Malvern East).

Electrical conductivity is a great measure of water quality as it indicates a multitude of different compounds that can be in the water. The salinity, amount of polar molecules, other ions and heavy metal content are all able to be determined from this one measurement. Readings from the data averages show fairly high conductivity consistently in both creeks. Gardiners Creek readings showed 420 μS/cm whilst Scotchmans Creek showed higher readings of about 600 μS/cm on average. This indicates that there is a large number of ions dissociated in the water, as well as higher than recommended levels of heavy metals (fig. 13, fig. 16 and fig. 19). From the data collected, it can be seen that almost all heavy metals, with the exceptions of arsenic and cadmium, all are over the recommended levels set by the EPA. Since the metals are above recommended levels, it is highly likely that the presence of them is causing stress to the aquatic organisms in the creeks. Heavy metal content is generally higher in Gardiners than Scotchmans Creek

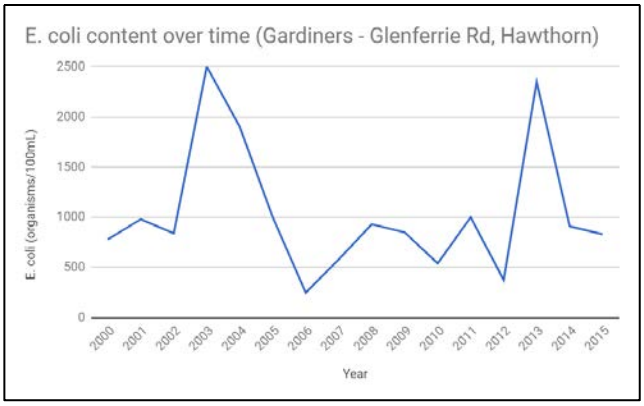

Figure 7a: E. coli content over time
(Gardiners Creek - Glenferrie Rd, Hawthorn)

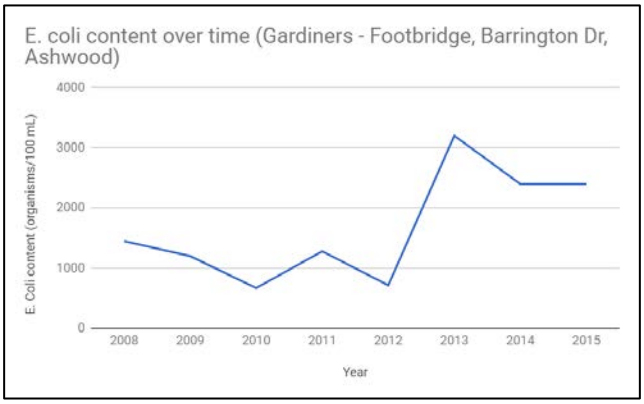

Figure 7b: E. coli content over time
(Gardiners - Footbridge, Barrington Dr, Ashwood)

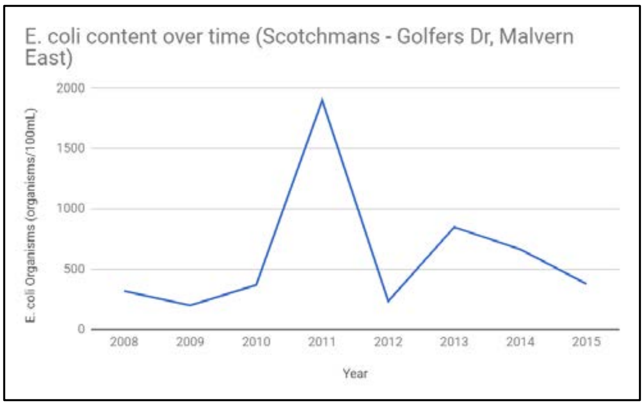

Figure 7c: E. coli content over time
(Scotchmans Creek - Golfers Dr, Malvern East)

E.coli readings on both Gardiners and Scotchmans Creek show higher than recommended levels of the bacteria. Safe swimming levels have been recommended by the EPA at 88 organisms per 100 mL of water. The data shows averages of about 900 organisms per 100 mL of water, well above the recommended safe levels for swimming. However the data trend is showing a decrease over time in the amount of E.coli present, indicating some improvement in the water quality of the creeks. This improvement could have occurred due to management strategies such as: new wetlands being constructed, education of the general public or different fertilizers being used on vegetation.

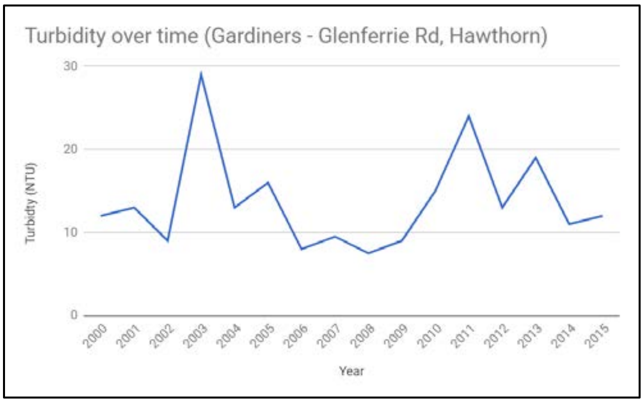

Figure 8a: Turbidity over time
(Gardiners - Glenferrie Rd, Hawthorn)

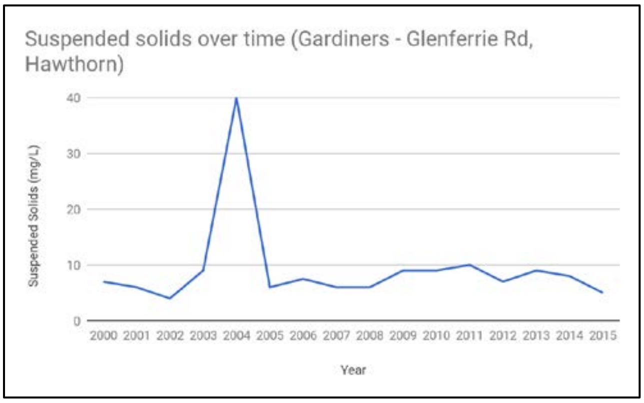

Figure 8b: Suspended solids over time
(Gardiners Creek - Glenferrie Rd, Hawthorn)

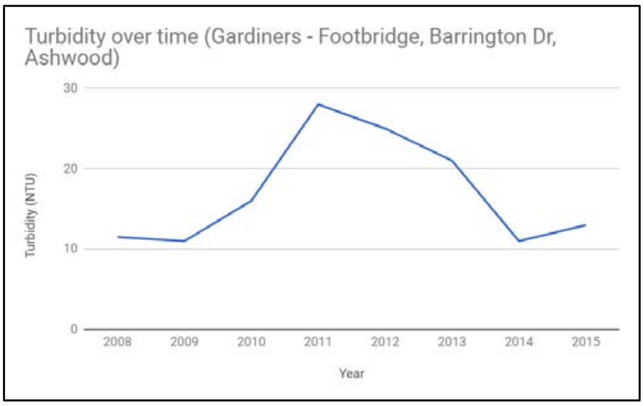

Figure 8c: Turbidity over time
(Gardiners Creek - Footbridge, Barrington Dr, Ashwood)

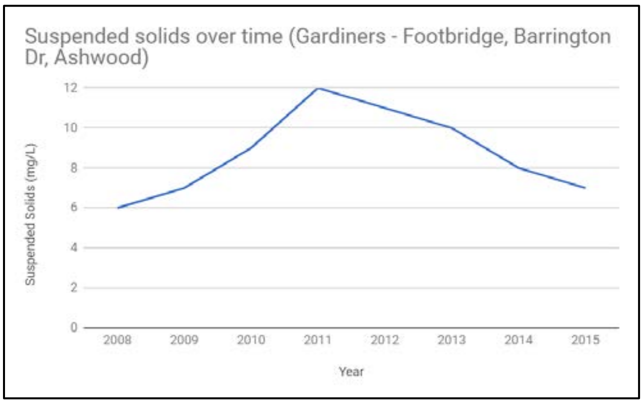

Figure 9a: Suspended solids over time
(Gardiners Creek - Footbridge, Barrington Dr, Ashwood)

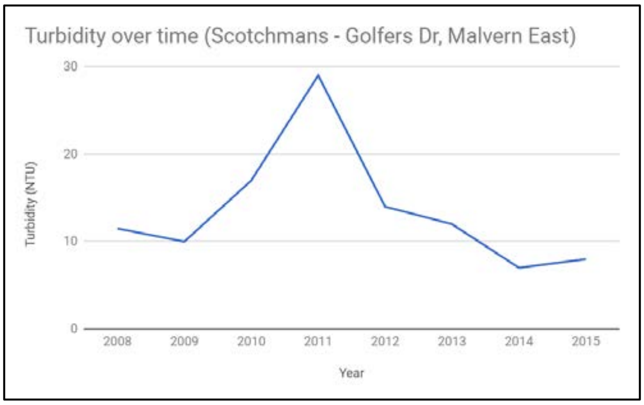

Figure 9b: Turbidity over time
(Scotchmans Creek - Golfers Dr, Malvern East)

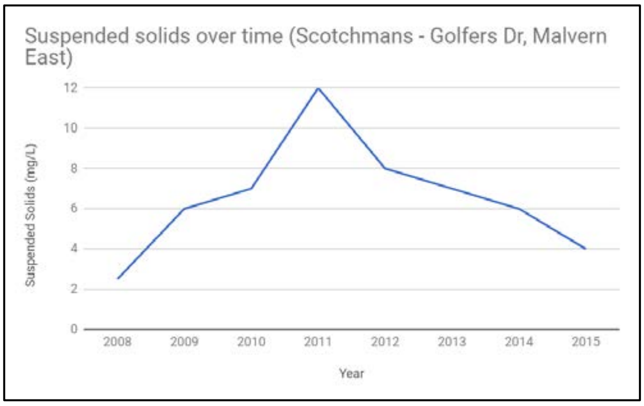

Figure 9c: Suspended solids over time
(Scotchmans Creek - Golfers Dr, Malvern East)

Turbidity is almost always above the recommended level in both creeks; that level being 10. Turbidity is the measure of the percentage of light that shines through a given water sample, and therefore correlates directly to the amount of suspended solids. The levels of suspended solids fluctuate possibly due to changes in weather patterns which can be attributed to ENSO and local climate change. When the amount of suspended solids and the turbidity is high, aquatic plants can experience difficulties when photosynthesising, sometimes dying when the water clarity is too low for an extended period of time. In addition high suspended solid levels can lead to temperature increases in water.

Overall, almost all data indicates that the water quality of both Gardiners Creek and Scotchmans Creek are poor.

4. Case Studies

4.1 Malvern to Murrumbeena Flood Mitigation Project

Near the suburb of Malvern is a section of Gardiners Creek that is prone to flooding during extreme weather events. Due to the creek’s proximity to housing, flooding has caused damage to residential properties. In response to one such flood in 2011, the City of Stonnington developed the Malvern to Murrumbeena Flood Mitigation Project. The two year project aimed to drain nearby streets rapidly to reduce the risk of flooding in these areas. Due to the effects of climate change and increased sea level rise, extreme weather events will increase in frequency and the creek is expected to flood more often. Thus, similar mitigation strategies will become more relevant to other flood prone areas of Melbourne and hence the need for a flood mitigation plan.

Figure 10: Photo showing flooding in 2011 in Murrumbeena. Source: Melbourne Water 2011

Flooding has the potential to impact the water quality of rivers and creeks, carrying debris and contaminants into the river system. As a result, the water quality is impacted in the short-term but can cause long lasting damage as well. In the aforementioned 2011 flood, a large amount of water drained into Gardiners Creek, transporting a significant quantity of pollutants into the stream. In the data obtained from Melbourne Water; higher than average levels of turbidity were recorded in 2011; the highest of all the years in the data. In 2004, there was also a major flooding event in the region.

Figure 11: Photo showing construction in Malvern East. Source: Olivia Musgrave 2018

It can be seen from the secondary data that there are significant increases in recorded amounts of heavy metals, nitrogen, phosphorus, E. coli and suspended solids. The Malvern to Murrumbeena Flood Mitigation Project involves the installation of a new 1.8 metre stormwater drain between Gardiners Creek and Murrumbeena Railway station that aims to reduce the risk of flooding in vulnerable areas by draining streets more quickly. Reducing the risk of flooding has financial and social benefits. It also lowers the overall amount of pollutants entering the waterway, and is therefore an effective preventative measure to help secure the water quality of the region.

Figure 12: Scotchmans Creek bike path. Source: CycleLife HQ 2016

Although the project has many positives for a variety of different groups including residents and the council, there are also negative impacts on the community, the economy and the environment. The project involves loud night works and consistent work throughout the day, as well as a semi-permanent detour on the Scotchmans Creek Trail, which has a negative impact on residents, as a number of tradesmen vehicles are parked in the local streets, taking up places where locals would normally park. Their heavy machinery also causes congestion and safety hazards and destroys vegetation by crushing it. All vegetation that falls within the path of where the new drain is to be installed is also being removed. Although not disclosed to the public, the project is likely to be a costly investment. However, as the project was approved, it is clear that it was deemed to save money over time, as the potential cost of flood damages has been valued at a higher the cost of the project itself.

4.2 Murray-Darling Basin Plan

The Murray-Darling Basin is an area that covers over 1,000,000 km2 or 14 per cent of Australia, located in the southeast of Australia. To both the South and the East, it is bound by the Great Dividing Range, the central Queensland sandstone belt in the North, and the arid interior in the West. The basin is made up of a total of 23 river catchments. All of the streams, creeks and rivers of the basin flow into either the Murray or Darling rivers, and eventually into the Southern Ocean at the mouth of the Murray River. Along the rivers, much of the water is evaporated, soaked up by one of the 30,000 wetlands, or used up by towns, cities, industry and irrigation.

The Murray-Darling Basin Plan is a collaborative approach to water management between the Federal Government and State governments involved. The states are Victoria, New South Wales, South Australia and Queensland. It was developed as a required part of the Commonwealth Water Act (2007) and is an important step in the ongoing sustainable management of the water in the Murray-Darling Basin for the benefit of all users as well as the environment.

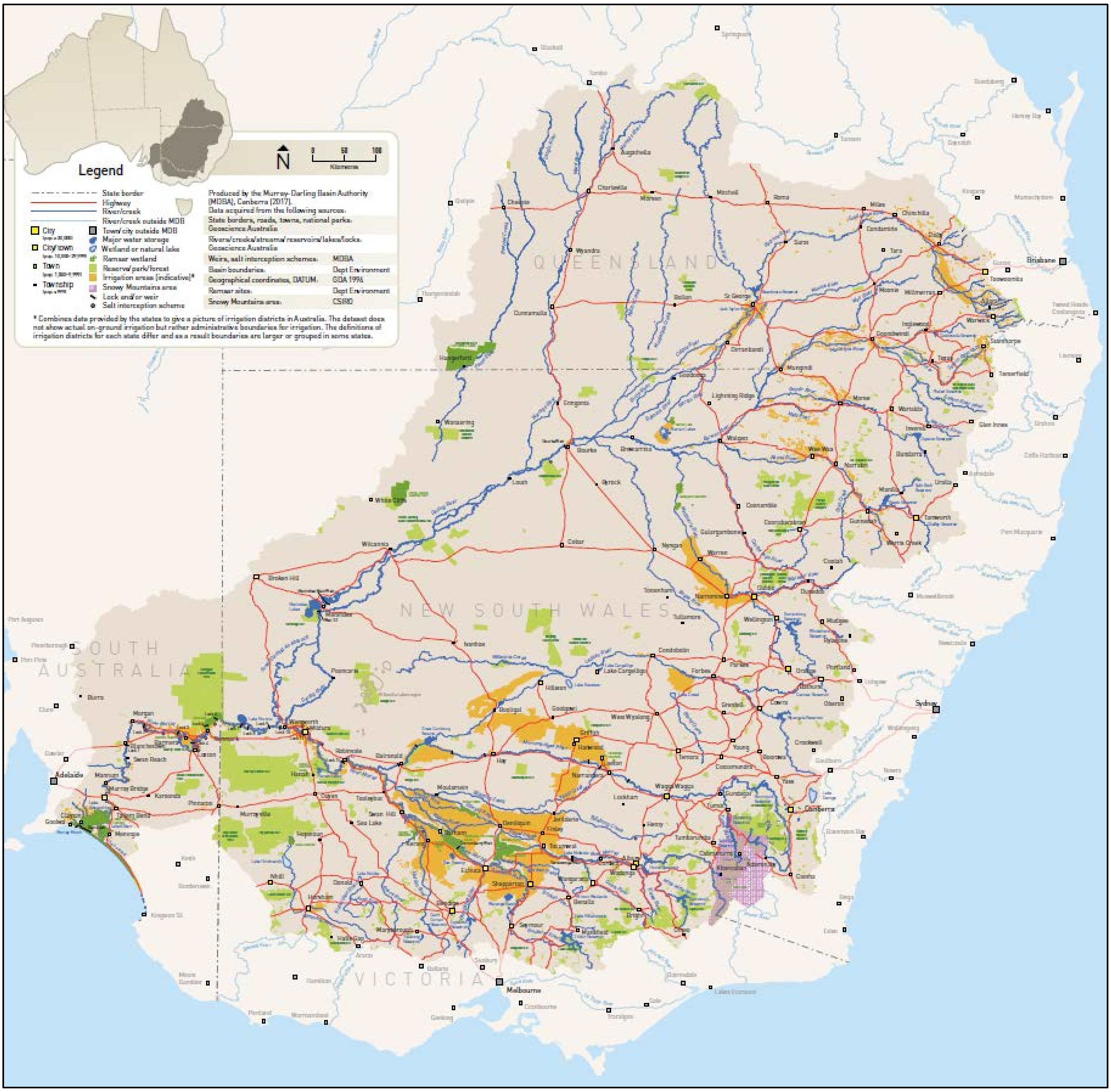

Figure 13: Map of the Murray-Darling Basin
Source: www.mdba.gov.au 2018

Its aims were to achieve a healthy, working, Murray-River system by ensuring there was water available not only for the farmers, but also for the river. However, the management is complex due the nature of state politics and the requirements of different stakeholders. Conflict amongst the states and stakeholders is common due to their different interests. This has led to degradation of environmental assets throughout the region leading to a loss of ecosystem services and costing the governments millions of dollars in productivity and remediation efforts.

The main objective of the Basin Plan was to introduce sustainable diversion limits, which mandated the maximum amount of water that could be taken annually from the Basin for urban use, use in agriculture and industry. Water must also be available for the environment, furthermore it must be used effectively. State governments remain committed to the Plan although the changing of government can pose a threat to it as the interests of groups shift. The Basin would allow communities to have sustainable access to safe drinking water and ensure that the trade of water is both fair and efficient. Additionally, the river is continuously monitored and the Plan adjusted to ensure it remains effective under the changing conditions of the Basin. The collaborative approach to the Basin Plan highlights the importance of working together to meet the current needs of the people and the environment whilst not compromising the ability of future generations to meet their needs.

The complexity of multiple governing bodies managing the Murray-Darling Basin region is similar to that of the Yarra River and its tributaries where both are governed by multiple Local and State government bodies. Although it can be difficult to meet the needs of all stakeholders who share the resources of the Yarra River the success of the Basin Plan provides an excellent example as to how the Yarra River and its tributaries could be managed to deliver an increase in water quality, sustainable use and long term survival.

4.3 Dandenong Wetlands

The Dandenong Wetlands are located in the southeast of Victoria. They are 48 hectares in size, contained within a 14,500 hectare catchment. The wetlands are just one of the 43 wetlands created as part of the Nitrogen Reduction Program, which was implemented in 2000 in order to reduce the nitrogen runoff that was threatening the health of Port Phillip Bay. The Dandenong Wetlands contributed to removing over a quarter of the 56 tonnes of nitrogen which was removed from the river system in 2007. These wetlands have reduced the annual cost of nitrogen removal from the system by $57 million, while costing $15 million to develop.

Figure 14a: Aerial Image of Dandenong Wetlands and Surrounds
Source: Google Earth 2018

Figure 14b: Aerial Image of Dandenong Wetlands
Source: Google Earth 2018

The design of the wetlands consists of a sediment pond to slow the flow rate of Dandenong Creek and trap course sediment, heavy metals and toxins. Following the sediment pond a wetland and macrophyte zone uses a variety of aquatic plants arranged perpendicular to the direction of water flow to encourage bacteria and algae to absorb soluble pollutants and fine sediments. The plant density is higher in areas exposed to high wind to reduce rapid water movement and river bank blowouts. In the initial months of the wetland's operation insufficient aquatic plant coverage in high wind areas led to river bank blowouts and sediment discharge into the river system. At times of high water flow plant coverage is also reduced which negatively impacts the biodiversity of the wetlands, contributing to an inefficient filtering of water from Dandenong Creek. A combination of four wetland cells, parallel to each other, helps to slow the rate of water movement down throughout the wetland system.

Currently, there is little data to show how effective the wetlands have been in reducing the nitrogen content of the water. However, the data available does show that the wetlands were efficient (in 2007) at removing nitrogen, removing approximately 14 tonnes of nitrogen from the river system. In addition to benefiting the water quality, wetlands have the ability to improve a region's biodiversity and reduce the risk of flooding in some areas by reducing flow rates.

4.4 Glen Iris Wetlands

The Glen Iris Wetlands are located adjacent to Gardiners Creek on High Street, on the former site of Glen Iris and Tooronga Bowls Club. They were completed in 2009 with a total cost of $3.6 million. Compared to the Dandenong Wetlands, the Glen Iris Wetlands are of a smaller scale, draining from an urban catchment of 90 hectares. As a result they have had a smaller impact, removing 18.5 tonnes of sediment, 150 kg of nitrogen and a total of 8 tonnes of pollutants annually. The wetlands consist of three wetland cells arranged in a linear pattern, contrasting to Dandenong's design, but have still allowed biofiltration of stormwater runoff, which removes pollutants and improves water quality before the water enters the Yarra River.

Figure 15: Aerial Image of Glen Iris Wetlands and Surrounds
Source: Google Earth 2018

They also provide habitat for birds and aquatic species, and water for irrigation purposes, which is serviced by a connected underground facility capable of holding 350,000 litres of water.

Although the Glen Iris Wetlands do reduce pollutants and suspended solids, the overall water quality of Gardiners Creek has remained poor. However as the wetlands are located in an urbanised area, expansion can be difficult. In order to overcome this, another wetland could be developed downstream at the confluence of Back Creek and Gardiners Creek. Though currently water is cleaned at Glen Iris, unfiltered water enters at the confluence; a wetland in this position would allow further filtration of the water before it enters the Yarra.

This supplementary wetland is expected to reduce the amount of pollutants, toxins, heavy metals and suspended solids in Gardiners Creek and therefore the amount that enters the Yarra. This is useful especially as the data demonstrates the creek to have poor water clarity, which is improved by the removal of suspended solids, and heavy metals. Though they may take a few years to be developed, the filtration of water through the wetlands will have long term positive impacts on the Yarra River. Apart from lowering pollution levels, this can reduce algal blooms, improve water clarity, and enhance the overall water quality of the river. This not only increases liveability for aquatic species, but allows the usage of water for multiple purposes. Additionally, wetlands can provide a habitat for wildlife. However, the response does not address all aspects of the problem; wetlands typically do not reduce plastic pollution nor does it reduce the amount of pollution entering the creek itself.

As the scale will be similar to Glen Iris, the estimated cost is $3 to $4 million. For this response to be implemented, the local council must be encouraged to spend on the environment. Additionally, wetlands require ongoing maintenance to ensure functionality and access the effectiveness; this could further discourage the council, but could also encourage their construction due to the amount of jobs that would be created in its construction and maintenance. The awareness of the residents could be raised to pressure the local council through educational campaigns and allow the project to succeed. Overall, the development of wetlands near the confluence of Back Creek and Gardeners Creek should improve the water quality of Gardiners Creek and therefore the Yarra, with the benefits outweighing the costs.

Conclusion

Through exploration and investigation of the data and the evaluation of case studies, it became evident that wetlands are key in remediating the water quality of degraded tributaries. It is therefore, recommended not only that more wetlands be created, but that the wetlands currently located along the tributaries of Scotchmans and Gardiners Creeks be restored so that they are able to filter water before it enters into the main river system.

Wetlands have many environmental, economic and social benefits, including: increase in biodiversity and thus ecosystem services, filtering and cleaning of polluted water as well as flood and sea level rise mitigation. Additionally, they provide a wind buffer, act as a carbon sink and are a cheaper option in the long-term as they are a one-off cost and do not require much maintenance, all whilst being a natural management strategy.

Many other wetlands in the region have proven to be a cost effective, natural and successful way to reduce pollution in river systems, demonstrating that they are a sustainable and natural bioremediation process that can also be put in place in smaller creeks and tributaries.

In addition to this proposed strategy, there are already some management strategies being put in place in Gardiners Creek. One of these strategies is the previously discussed Malvern to Murrumbeena Flood Mitigation Project. The main aim of this project is to reduce the risk of flooding to the area between Malvern and Murrumbeena.

The Murray-Darling Basin Plan demonstrates that a project can be managed with many competing stakeholders; a positive example for the groups involved in managing the Yarra River. Additionally, the involvement of local communities is crucial to the improvement of the creeks' water quality. Without this, it is difficult to lessen the amount of pollutants entering the creeks from both industrial and household sources. Furthermore, local involvement is required to encourage the local council to improve and create wetlands.

The recognised threats to Melbourne's water quality and its supply include population growth, urban sprawl and climate change. From the research conducted and the analysis completed it is recommended that wetlands be a compulsory part of all appropriate future urban planning and catchment management.

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