Pollution in Melbourne's western streams; current condition, future threats and opportunities

Short Report to the Waters of the West Ministerial Advisory Committee

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1 Introduction

This brief report (5 days allocation) provides an overview of the pollution issues in rivers, wetlands and estuaries of western Melbourne for the Waters of the West Ministerial Advisory Committee. These waterways are quite distinct from other parts of Melbourne and they also support distinct aquatic ecosystems. Some western streams, like Stony and Moonee Ponds Creeks, are highly urbanised and also are vulnerable to pollution from industries in the catchment. Other western streams (Jacksons, Skeleton and Kororoit Creeks and the lower Werribee River) are under great stress from urbanisation and market gardening, which is changing their natural stream flows and exposing them to a new array of pollutants. Yet other western streams like Deep Creek, the Lerderderg and upper Werribee Rivers are in rural and forested areas and support some high value aquatic habitat.

Estuaries are important habitats for the breeding of fish and support a diverse range of birds that feed on the invertebrates, fish and plants present. They are particularly vulnerable to pollutants that are relatively insoluble in water, like heavy metals, petroleum hydrocarbons and pesticides such as synthetic pyrethroids. These contaminants accumulate in the sediments where they can become toxic to aquatic life. Furthermore, some estuaries are prone to algal blooms, including the Werribee River. Some estuaries in inner Melbourne (Maribyrnong River, Kororoit and Stony Creek) are also polluted by legacy issues associated with the past development of Melbourne.

There are some natural wetlands in the western areas of Melbourne, but the majority have been constructed in urban areas for amenity values and to treat stormwater. They also provide valuable habitat for birds and other animals.

The ecological health of the western streams of Melbourne are under great threat from urbanisation and climate change, which will further reduce rainfall in an already arid region. If nothing is done, these waterways will deteriorate to a point where they will all be in a very poor condition like Stony Creek. What can be done to help keep these waterways in best possible condition? Can waterways in currently poor condition be improved?

This report consists of four sections. These are:

1. A comparison of western streams to eastern streams of Melbourne. This helps contrast the uniqueness of western streams and the different pollution issues that exist in western streams.
2. Identification of the major threats (climate change and land use) to the health of western waterways.
3. Assessment of pollution issues and discussion of opportunities to maintain or improve ecological condition in each of the major western waterways catchments.
4. Summary suggestions for protecting the health of waters of the west.

2 Western streams are very different to the eastern streams of Melbourne

The streams across Melbourne vary considerably due to changes in terrain, rainfall and geology. There is a vast range in rainfall, for example, Gembrook in the Dandenong Ranges has an annual average 1,250 mm of rain compared to Little River which only has 425 mm (Bureau of Meteorology). The streams of western Melbourne are quite distinct from those in the east. The western streams are usually ephemeral due to the low rainfall and are often saline during periods of low flows. The riparian vegetation is also very different from the forests omnipresent in eastern Melbourne. In contrast, western streams are dominated by a more open woodland dominated by river red gums. Another stark difference is that most western streams are in basaltic plains, whereas the eastern streams flow through Silurian sands (yellow clays). Melbourne's streams are

more prone to surges of water during storms as the catchments have become more impervious allowing rapid runoff of waters to local streams. In the clayey soils of eastern Melbourne, there is excessive erosion of stream bed and banks leading to degraded habitats for aquatic life. In contrast, the enamoured basalts in the western streams are much more resilient to these fluctuations in flows and there is much less erosion. Therefore, the physical condition of these streams is better than those in the east.

This erosion in eastern regions of Melbourne leads to the streams looking muddy (turbid) whereas the western streams are clearer. As a result, there are stark differences in the type and amount of aquatic vegetation present in these streams. As light can penetrate further through the clearer waters of western streams, there is often a lot of submerged and emergent plants (macrophytes) present.

The western waterways are less resilient to many pollutants than the eastern waterways of Melbourne. Western waterways are more prone to algal blooms. Nutrients from agriculture, urban areas and point source discharges, combined with a lack of flows during dry periods provides ideal conditions for algal growth including occasional blooms of toxic blue-green algae (cyanobacteria). In severe droughts, such as the recent Millennium Drought of the 2000's, the western streams of Melbourne were under extreme stress, with many streams completely drying out.

Heavy metals, such as zinc and copper, are common pollutants in urban areas. They are not very soluble and accumulate in the stream sediments. As the catchment of a stream becomes more urbanised, these heavy metals reach concentrations where they become toxic to aquatic macroinvertebrates and other organisms (Pettigrove & Hoffmann, 2005).

Pettigrove & Hoffmann (2003) compared how the concentrations of heavy metals in sediments of Melbourne streams change with increasing urbanisation. They found that western streams with basaltic derived sediments had toxic sediments at lower levels of catchment urbanisation than the eastern streams. For example, zinc reached the ANZECC/ARMCANZ (2000) national sediment quality guideline (indicating a high risk of toxicity) at 11.4% catchment urbanisation, whereas eastern streams only tended to reach this value at 46.9% catchment urbanisation. The reason for this difference is that the suspended clay particles in the waters of the eastern streams are ionically charged and capture and detoxify the metal particles whereas the western streams have fewer suspended particles and they are less ionically charged thus leaving metals in their toxic ionically charged form.

Melbourne's streams can be polluted by organic pollutants ranging from petroleum hydrocarbons, pesticides and industrial chemicals. The toxicity of organic substances is affected by the amount of carbon present in the surface waters and sediments. The ANZECC/ARMCANZ (2000) national guidelines normalise the concentrations of organic substances to 1% organic carbon. The amount of organic carbon in a stream is largely influenced by the riparian and catchment vegetation. Streams in forests receive a large input of carbon from leaves, bark and branches from the surrounding vegetation. The contribution of carbon from the grassland and woodland catchments of western streams would be comparatively a lot less. Therefore, it is possible that the western waterways may be more susceptible to organic pollution than eastern streams. Nutrient enrichment of these waterways can lead to more plant growth (macrophytes, filamentous algae and phytoplankton), that can lead to oxygen depletion. Subsequently this can lead to loss of aquatic animals.

Figure 1: A typical urban tributary from eastern Melbourne (1a) and from western Melbourne (1b). Note differences in the vegetation, bank erosion and colour of the waters.

3 Major Threats: Effects of climate change and land use on pollution impacts of western waterways

3.1 Climate Change

Since 1950, the average temperatures in the western region of Melbourne have increased by 1.2 to 1.4ºC and the average annual rainfall has decreased in some areas by up to 200 mm. Future effects of climate change are predicted to create even drier and warmer conditions, with less rainfall occurring in winter and spring and increased sea levels (https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0018/60750/Statewide-Victoria.pdf). Assuming that the amount of pollution from runoff in these catchments remains similar to current conditions, these changes to climate will increase the concentration of pollutants in western waterways. Dust is also an important transport mechanism for many pollutants such as pesticides (e.g. Pettigrove & MacMahon, 2019). Having longer periods of dry conditions will increase pollution of waterways via dust.

This means, that without any intervention western streams are going to become more ephemeral. Melbourne Water's Healthy Waterways Strategy 2018 (HWS), in accordance with Victoria's Climate Change Adaptation Plan 2017-2020, identifies three key ways to prepare for protection of waterways from future climate change. These are:

1. Environmental Flows. The HWS targets an increase of the environmental water reserve by 23 gigalitres (GL) per year by 2028. This includes target increases of 7 and 5 GL p.a. of additional water for the Werribee and Maribyrnong Rivers respectively by 2027 (HSW, p. 67). This will partially address the 10 -20 GL long term shortfall for environmental flows in both rivers.
2. Groundwater dependent ecosystems. The HWS identities the need to ensure adequate infiltration of waters in these regions to ensure that these ecosystems are protected. The

HWS recommends that assessments of the impacts of climate change on recharge rates of groundwater and interaction of surface water are needed to improve the understanding of the resilience of groundwater dependent ecosystems and their water sources. The upper reaches of Deep Creek have groundwater dependent wetlands that provide habitat for the Yarra Pygmy Perch.

3. Alternative Water Sources. Adequately treated stormwater and recycled water are identified in the HWS as being alternative sources of water for the environment.

3.2 Land Use: Urbanisation

Over the past decade, Melbourne's population has increase at 96,456 people p.a. The current population of 4.8 million is predicted to increase to 8.5 million by 2050. Much of the urban expansion of Melbourne will occur in the northern and western regions. Substantial urbanisation will occur in the lower Werribee River catchment including around Toolern and throughout the Jacksons Creek catchment. In contrast, little urbanisation is predicted to occur in the Deep Creek catchment. See:
https://s3.ap-southeast-2.amazonaws.com/hdp.au.prod.app.vic-engage.files/7215/0424/1669/142._Folder_of_material_accompanying_Ashe_Morgan_Submissions_Part_3.pdf.

Urbanisation causes massive changes to the landscape and increases pollution to local waterways. Water sensitive urban design is used in new residential developments to help attenuate stormflows and treat pollutants. Wetlands are a common feature of these developments as they not only treat stormwater but can also have high amenity value. The HWS (2018) recognises the threat posed by urbanisation to waterways and that some ecological values can be protected and/or rehabilitated if stormwater is appropriately managed. This strategy focuses on managing water quantity not water quality.

The types and amount of pollution generated from the urban landscape varies due to land uses, point source pollution and even the stage of development of the urban area.
Roads and associated traffic are a major source of heavy metals and petroleum hydrocarbon pollution from road infrastructure, the wearing of tyres and vehicles and exhaust emissions. Industrial areas are also a much greater source of pollution than residential areas. For example, the sediments of constructed urban wetlands in Melbourne had 14 times more zinc pollution if there were industrial estates within their catchment than if there were none (Sharley et al, 2017). Recent industrial fires in West Footscray and Somerton illustrate the high risked posed by the storage and use of industrial chemicals and how polluted smoke from these fires can be dispersed large distances across Melbourne.

Our research group (formerly CAPIM and now AQUEST at RMIT) found that point source pollution is still a major contributor (possibly 50%) to aquatic pollution in urban Melbourne.
The management of pollution from industries is complex. Businesses may require a trade permit from the retail water company to discharge waste to sewer. They may be regulated by the EPA, but councils also have a role in inspecting premises and a few leading councils also conduct monitoring of runoff from industrial estates.

The cause of point source pollution does not normally appear to be caused by malicious acts but due to poor practises or poor and/or old infrastructure for handling industrial chemicals. Old industrial estates may also be polluted from past activities and also have a deteriorated sewage system that may leak pollutants to waterways. The control of point source pollution requires considerable resources and needs to include regulation, education and on-stream treatment. Industrial estates are high pollution risk areas and there should be precautions taken to prevent pollution events being discharged to local waterways. AQUEST is currently working with Melbourne Water to determine better strategies to manage runoff from industrial areas.

With the development of new housing estates, there is massive soil disturbance that can lead to sediment pollution of local waterways. The use of pesticides for termite control can be transported via dust and surface runoff to local and even regional waterways (Pettigrove & MacMahon, 2018) and reach concentrations in sediments that are toxic to aquatic life (Jeppe et al, 2017). The management of soils around the perimeter of new buildings is key to reducing this pollution.

4 Major streams of the west: pollution challenges and opportunities

4.1 Moonee Ponds Creek

Moonee Ponds Creek has long had poor water quality (Ho & Pettigrove, 1994), although there has been a reduction in uncontrolled sewer spills in the lower catchment due to the construction of the north-west trunk sewer. Melbourne Airport is a major source of heavy metal and nutrient pollution (Shinwari, 2002). The effects of the airport extend all the way to Flemington Rd where in addition to elevated heavy metals, the organochlorine pesticide dieldrin was present. The dieldrin is a breakdown product of aldrin which was recently used on Melbourne Airport land.

4.2 Jacksons Creek

Jacksons Creek commences in the headwaters of Rosslynne Reservoir and flows through the urban areas of Gisborne and Sunbury and forms the Maribyrnong River when it meets Deep Creek at Sydenham. Western Water operates wastewater treatment plants at Gisborne, Riddells Creek and Sunbury and the Gisborne and Sunbury plants regularly discharge into Jacksons Creek. Water harvested at Rosslynne Reservoir are used for agriculture, for potable supplies for Gisborne, and to provide environmental flows for Jacksons Creek. After the Millennium Drought, Gisborne was connected to Melbourne's Water supply system.

The headwater streams feeding into Rosslynne Reservoir are usually dry in summer, illustrating that without this reservoir, Jacksons Creek downstream of the reservoir would naturally be ephemeral. It returned to its ephemeral state down to the Sunbury Recycled Water Plant (RWP) during the Millennium Drought when no environmental flows were remaining in Rosslynne Reservoir and all recycled water was allocated to agriculture.

A study was conducted by Hassell et al (2016) used a weight of evidence approach to determine the major factors influencing the health of Jacksons Creek upstream of Sunbury. The major factors affecting the biota were heavy metals, petroleum hydrocarbons and pesticides entering the creek from Gisborne. Discharges from the Gisborne RWP may also contribute estrogenic compounds to the creek and may impact the health of fish. There are two clear messages from this catchment: treat the urban runoff coming from Gisborne and ensure that there is always water in the creek to support fish and platypus.

4.3 Deep Creek

Deep Creek flows from the foothills of the eastern slopes of the Macedon Ranges through Lancefield, Romsey, Bulla and meets Jacksons Creek to form the Maribyrnong River at Sydenham. The undulating catchment is largely rural with some stock. Although Deep Creek is ephemeral, the reach near Lancefield have numerous permanent groundwater dependent pools that persist in Deep Creek and provide vital habitat for the Yarra Pygmy Perch. The creek flows through deep gorges and has limited public access. Pollution does not seem to be a major issue in this creek, and it is under little threat from future urban development. The major issue in Deep Creek is the abundance of exotic willows present.

Figure 2: Willow infestation in Deep Creek. In autumn, all the leaves from the willows fall and can lead to oxygen depletion in these groundwater dependent pools.

4.4 Maribyrnong River

The freshwater section of the Maribyrnong River flows from Sydenham through Keilor to Avondale Heights. There is quite a long estuary that flows through Maribrynong and meet the Yarra River at Yarraville.

The freshwater section of this river was described by Gippell & Walsh (2000) as being a valuable scientific resource being one of the few large basaltic streams in Victoria. They found that the geomorphology of the Maribyrnong is stable being controlled by a series of artificial weirs, rock grade structures and natural rock bars. Removal of native vegetation cover was reported to be the biggest disruption to stream geomorphology, but it was more intact in 2000 than in 1931. They reported that "the lowland Maribyrnong River is in relatively good condition for an urban river, certainly relative to the Yarra River".

A comprehensive study of the Maribyrnong was conducted by Melbourne Water, City West Water, the former AQUEST group and Hydronumerics to identify the priority pollution issues present (Kellar et al, 2014). Water quality tends to improve from Jacksons Creek at Sunbury to the confluence of Jacksons Creek and Deep Creek at Sydenham. The sediments in the freshwater section of the Maribyrnong are healthy, having low levels of contamination. The health of the Maribyrnong is immediately impacted by severe pollution coming from Arundel Creek and the highly urbanised Taylors Creek. Arundel Creek drains a large proportion of the runways at Melbourne Airport and is a major source of toxic pollutants such as zinc (presumably originated from the tyres of landing aircraft and their recent use of the banned organochlorine aldrin. The use of PFAS in fire retardants on airport land has led to contamination of the Maribyrnong and the EPA has released an advisory on the consumption of fish caught from the freshwater section

https://www.epa.vic.gov.au/our-work/current-issues/land/pfas-in-maribyrnong-river-catchment. A similar advisory has existed for the past 20 years on the consumption of these fish due to polybrominated biphenyls (PCBS).

Sediments of the Maribyrnong Estuary is polluted from past industrial activities and possibly sewerage discharged into this river during the 20th century. However, the water quality is now more affected by urban runoff. Swimming still occurs in the upper reaches of the estuary, but this should be discouraged as the catchment becomes more urbanised and the risk of exposure to water borne pathogens from untreated sewage becomes a greater risk.

4.5 Stony Creek

Stony Creek is one of the most industrialised catchments in Melbourne and arguably the most polluted stream in Melbourne. The recent West Footscray fire caused additional massive insult to this creek. The broad range of contaminants present in the sediments are not typically of what is present in normal urban runoff. Therefore, the major source of pollution is point-sources. The first steps to rehabilitate this creek is to address point source pollution from industrial runoff and to have plans in place to prevent any major pollution events being discharged into the creek. The Aquatic Pollution Prevention Partnership, a partnership between Melbourne Water and AQUEST are currently reviewing world best practice in treating runoff from industrial sites.

4.6 Kororoit Creek

High mercury concentrations present in the lower reaches of Kororoit Creek is a legacy issue from methyl mercury being discharged into the creek up to the 1980s (Christoff, 1988). As the offending industries were connected to the sewerage system, the concentrations of many of these contaminants have declined over past decades. Emerging contaminants in the creek are now zinc and synthetic pyrethroids which come from urban runoff.

4.7 Laverton Creek

Little is known about the current pollution levels in Laverton Creek and the associated Truganina Swamp. The last data available was collected in the nineties when there was strong evidence of industrial pollution with the carcinogenic organochlorine hexachlorobenzene. Since then, the catchment has become highly urbanised and pollutants ubiquitously present in urban runoff (heavy metals, petroleum hydrocarbons and synthetic pyrethroids and likely to be the major pollutants. Truganina Swamp is of high value and efforts should be made to ensure that its sediments do not become toxic to the estuarine invertebrates that it supports.

4.8 Skeleton Creek

There is extensive urban development in this catchment. There is no increase in heavy metal pollution in these sediments and this may be due to land disturbance from new housing development diluting concentrations of other urban pollutants.

4.9 Werribee River

The upper catchment contains areas of relatively intact streamside vegetation and is an important habitat for native fish, platypus and macroinvertebrates. The middle reaches provide good habitat for fish and a significant platypus population. The plains between Bacchus Marsh and Werribee are covered with several basalt layers but the top layer has weathered into clay and the groundwater is

saline (Southern Rural Water, 2014) The lower estuarine reach is home for migratory wading birds, fish including black bream and highly values river red gums.

A report prepared by the City of Wyndham (2015) concluded that the lower Werribee River is in poor condition due to the low flow rates downstream of the Werribee Diversion Weir (where 90% of water is diverted for irrigators at Werribee South) and the large amounts of litter coming from stormwater drains between Shaws Rd and the Maltby Bypass.

The aquatic fern (*Azolla pinnata*) can cover large sections of western waterways including the Maribyrnong River during stagnant/ low flow and warm conditions. For example, *Azolla* covered 6 km of the Werribee River downstream of the Werribee Diversion Weir. This can lead to reduced oxygen concentrations and can lead to the death of submerged plants that are blanketed by the *Azolla* (Morris et al, 2003).

The Werribee estuary is also subject to blue-green algal blooms. Groundwater inputs from the Western Treatment Plant and the Werribee Irrigation District add nutrients to this estuary.

4.10 Little River

There is little data from this arid and rural catchment. The data available suggests that the sediments are low in contaminants. Large amounts of filamentous algae have grown in warm stagnant conditions. After decent rain I have seen large (up to 1 m) balls of this algae deposited at the weir near the head of the Little River estuary, although in recent years the road weir inside WTP has been rebuilt to allow fish passage, so this may no longer be a pinch point. This does however illustrate that even when the water quality is good, plant productivity will still occur.

5 Suggestions for protecting the health of waters of the west

Like all waterways, the health of waterways of the west depends on pollution, stream hydrology and instream and riparian habitat. Rarely do these factors work in isolation. In some cases, like upper Deep Creek the presence of exotic willows and maintenance of groundwater for wetlands are the primary issues. In contrast, the biggest threat to aquatic health in the freshwater section of the Maribyrnong is clearly pollution, especially from urban developments in Jacksons Creek and the urbanised Taylors Creek and the polluted Arundel Creek.

Climate change and urbanisation will have massive impacts on Waterways of the West. Predicted less rainfall maybe offset to some extent by potable waters being transferred to the west from Melbourne's water supply system. This may allow for more water in to be allocated to environmental flows.

- Transfer potable water to the west, potentially freeing up water for environmental allocations from Rosslynne and Melton Reservoirs
- Subsidise supply of water to South Werribee irrigation district with large quantities of recycled water from the Western Treatment Plant rather than from Melton Reservoir
- Where appropriate look to subsidise environmental flows with treated discharges. DELWP, Southern Rural Water and Melbourne Water would have critical roles in determining the allocation of environmental flows. Treated discharges from wastewater treatments plants (Sunbury, Gisborne, Melton) can provide environmental benefits in certain circumstances (see Morris et al, 2017).

Urbanised areas will provide a permanent base flow to local waterways. This can help support aquatic life during the prolonged dry periods that occur in the region. Water sensitive urban design (WSUD) will help treat contaminants in the urban runoff (dry and storm event flows). Melbourne Water and councils play a lead role in WSUD.

All urban waterways of the west should be free of litter, not be contaminated by faecal pollution and not have point source pollution. Melbourne Water, EPA Victoria and councils should work together to develop strategic approaches (including prevention of illegal dumping) to intercept and prevent litter entering streams. City West Water and Western Water should ensure that their sewerage infrastructure is sound and not leaking human faecal pollution to local waterways, particularly during dry weather. Councils, Melbourne Water, EPA Victoria need to work together to locate point source pollution in all urban waterways. The use of passive samplers has been effectively used by AQUEST to locate point source pollution, even up stormwater drains (see Tillett et al, 2018).

Industrial catchments need to be given special attention because they pose a high risk to the environment and human health. There would be great benefits in developing a strategy for all Melbourne about what measures can be taken to intercept, remove, divert to sewer or treat industrial runoff, especially pollution events.

Areas of the western waterways that urgently need to be assessed are those undergoing urbanisation. However, established urban areas should not be neglected.

Many agencies need to cooperate to protect the health of western waterways. This raises the question of whether there needs to be an overarching government supported group to help this to occur.

6 Acknowledgements

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7 References

Christoff P (1988). State of the environment report. Victoria's inland waters. Office of the Commissioner for the Environment.

EPA (1989). Lower Kororoit Creek assessment study. Sinclair Knight & Partners.

Gippel CJ & Walsh C (2000). Geomorphology of the Maribyrnong River, Victoria. Report prepared by Fluvial Systems Pty. Ltd. For Melbourne Water Waterways & Drainage Group, East Richmond, VIC. https://urbanstreams.net/Isc/Docs/Gippel_Walsh_2000.pdf.

Hassell K, Kellar C, Townsend K, Arora M, Berg K, May A & Pettigrove V (2016). Assessment of impacts from a wastewater discharge in a whole-of-catchment context. *Online journal of the Australian Water Association Volume* 1 (2): ISSN 2206-1991.

Ho J and Pettigrove V (1994) The water quality of Moonee Ponds Creek. Catchment & Drainage Branch, Melbourne Water.

Jeppe KJ, Kellar C, Marshall S, Colombo V, Sinclair GM and Pettigrove V (2017). Bifenthrin causes toxicityin urban stormwater wetlands: Field and laboratory assessment using Austrochiltonia (Amphipoda). *Environmental Science & Technology* 51 (12): 7254-7262.

Kellar C, Hassell K, Jeppe K, Myers J, Long S, MacMahon D, Townsend K, Rose G, O'Neill C and Pettigrove V (2014). Identifying the primary factors influencing aquatic ecosystem health in the Maribyrnong River. CAPIM Technical Report No 68. University of Melbourne, Australia.

Melbourne Water (2018). Healthy waterways strategy 2018. State Government Victoria.

Morris K, Bailey P, Boon P, Hughes L (2003). Alternative stable states in the aquatic vegetation of shallow urban lakes. II. Catastrophic loss of aquatic plants consequent to nutrient enrichment. *Marine and Freshwater Research* 54: 2-1-215.

Morris L, Colombo V, Hassell K, Kellar C, Leahy P, Long SM, Myers JH and Pettigrove V (2017). Municipal wastewater effluent licensing: a global perspective and recommendations for best practise. *Science of the Total Environment* 580: 1327-1339.

Pettigrove V and Hoffmann A (2003) Impact of urbanisation on heavy metal contamination in urban stream sediments: influence of catchment geology. *Australasian Journal of Ecotoxicology* 9:119-128.

Pettigrove V & Hoffmann A (2005). A field-based microcosm method to assess the effects of polluted urban stream sediments on aquatic macroinvertebrates. *Environmental Toxicology & Chemistry* 24(1): 170-180.

Southern Rural Water (2014). Port Phillip & Western Port groundwater atlas. Srw.com.au.

Tillett BJ, Sharley D, Almeida MIGS, Valenzuela, Hoffmann AA and Pettigrove V (2018). A short work-flow to effectively source faecal pollution in recreational waters – A case study. *Science of the Total Environment* 644: 1503-1510.

Wyndham Council. (2015). The health of the Werribee River. https://www.wyndham.vic.gov.au/sites/default/files/2017-04/Health%20of%20the%20Werribee%20River%20-%20Report%20-%20Final%20report%20-%20Adopted%20by%20Council%20-%202015-10-26%20%28A1179350%29.pdf