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The Impact of Urbanisation on New Zealand Freshwater Quality

Abstract

Urban waterways represent less than 1% of the total river length in New Zealand. However, they are the most visible of all rivers, as 86% of New Zealanders live in urban areas. Urban waterways are impaired due to elevated levels of pathogens, turbidity, nutrients and heavy metals originating from anthropogenic activities. In addition to being conduits of storm water run-off from urban areas, some urban waterways also receive discharges from wastewater treatment plants and combined sewage overflows, thus greatly reducing their capacity to provide ecosystem services such as recreation, tourism, biodiversity and mahinga kai. This article summarises the state of New Zealand's urban freshwater quality, the major drivers of pollution, and mitigation measures needed to restore urban waterways.

Keywords storm water, impervious coverage, overflows, water sensitive urban design, source control

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Eighty-six percent of New Zealanders live in the 0.85% of the country classified as urban (Statistics New Zealand, 2018). Around 3,344 kilometres of waterways flow through urban areas, and this represents 0.86% of the total river length in New Zealand, but studies show that over 80% of this river length exceeds the relevant default guideline values for most of the measured water quality variables (Whitehead, 2018). For example, urban rivers have 30 times higher E. coli, 3.3 times higher turbidity, 19.5 times higher nitrate-nitrogen levels, and 4.7 times higher dissolved reactive phosphorous than rivers dominated by native land cover. Data collected in the past five years revealed that 94% of the total river length in the urban land-cover class is at high risk for swimming because the predicted average campylobacter infection risk is greater than 3%. Only 6% of river length in the urban land-cover class poses low or zero toxicity risk to aquatic biota with regard to nitrate-nitrogen and ammonia (Ministry for the Environment and Statistics New Zealand, 2019). In 12 out of 17 monitored urban sites, concentrations of dissolved copper exceeded toxicity guidelines, while 27 out of 50 monitored urban freshwater sites exceeded dissolved zinc guideline levels (Gadd, 2016).

This grim picture of the New Zealand urban freshwater environment is partially due to historical neglect and current lack of environmental stewardship. Urban freshwater bodies (be they streams, rivers or lakes) are often used as sinks for untreated urban run-off from a wide range of land uses, with the predominant urban pollutants being heavy metals (zinc and copper), nutrients (nitrogen and phosphorus), total suspended solids, polyaromatic hydrocarbons, and pathogens (e.g. *E. coli*). In addition to storm water run-off, a few urban waterways in Auckland also receive combined sewage overflows (CSOs), in catchments where storm water and sewage are not separated. CSOs

- diffuse source: this type of pollution is either a composite of different point sources or originates over large areas. Rainfall run-off from different land use types is considered diffuse source pollution as it collects litter, sediments, oil, grease, bacteria, fertilisers (excess nutrients), heavy metals and other toxic substances as it travels across different surfaces. Because of this diffuse nature, it is more difficult to control than point source pollution.

In urban areas, point source pollution is regulated by resource consents; in contrast, diffuse source pollution occurs mostly during storm events and its impacts depend on land use patterns and run-off controls. Diffuse pollution is characterised

of 35–50% can result in three times the run-off volume (Paul and Meyer, 2001). Without proper storm water control measures, this run-off carries numerous pollutants from the catchments in its path to the receiving waters. Even 10% impervious cover in the catchment can result in reduced water quality (Brabec, Schulte and Richards, 2002). Both urban population growth and urban sprawl are responsible for the conversion of native land cover into residential and commercial properties, roads, carparks and other impervious surfaces. During heavy storm events, the amount of water draining from the average roof can exceed the amount of wastewater flows from more than 40 households (Watercare, 2019). The number of storm water discharge outlets in major cities of New Zealand is variable, with Auckland having by far the most at nearly 20,000 (Water New Zealand, 2018).

The most visible degradation in receiving waters is caused by gross pollutants (litter, debris and sediment greater than 5mm in size). Studies have shown that nominal annual gross pollutant loads can be estimated to be 90kg/ha/yr of wet weight, with an expected volume of 400L/ha/yr (Fitzgerald and Bird, 2010). Although gross pollutant traps can be used to remove the larger size pollutants before the storm water enters the receiving waters, they are ineffective at removing chemicals, sediments, bacteria and heavy metals, which all contribute to urban waterway degradation.

Suspended sediment is contributed by storm water run-off via build-up and wash-off from impervious surfaces; sources include breakdown and degradation of materials, soil erosion and vehicular sources (Zanders, 2005). Suspended sediment can smother biota, causing respiratory damage and reduced light penetration, decreasing food supply for benthic organisms. It may also settle once in the waterway as deposited sediment, which causes clogging of the waterway bed and smothering of biota, and can affect water supply intakes (Clapcott et al., 2011; Ryan, 1991).

Sources of copper include brake pads, roofs, claddings, facades and air conditioning pipes (O'Sullivan, Wicke and Cochrane, 2012). Rubber tyres and

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contribute primarily towards the faecal pollution of waterways, thus making the receiving environment (rivers or coasts) unsafe for swimming. When direct discharges of outfalls from wastewater treatment plants to the freshwater environment occur, nutrients and pathogens, in addition to micropollutants such as pharmaceuticals, result in significant impacts to waterway health (Ebele, Abdallah and Harrad, 2017). Such pollution greatly reduces the capacity of urban waterways to sustain and provide ecosystem services such as recreation, tourism, biodiversity and mahinga kai.

There are two types of pollution influencing the water quality in receiving urban water bodies:

- point source: this type of pollution is caused by localised pollutant discharges. Municipal wastewater outfalls, industrial wastewater outfalls, septic tank discharges and waste spills fall under this category of pollution. They are readily identifiable as single or multiple point locations;

by its 'first-flush' effect, where pollutant concentration is highest in the initial run-off because of flushing of accumulated pollutants from the surface. The concentration decreases as pollutants are washed away; however, it can still remain well above in-stream guideline values for the remainder of the storm event. Hence, treatment for diffuse source pollution is more about source control (to minimise generation of polluted run-off in the first place) than 'end of the pipe' solutions.

Impact of storm water

The principal difference between urban and non-urban areas in relation to freshwater and coastal impacts is the proportion of the catchment made up of impervious surfaces. These are the surfaces that do not allow infiltration into the soil, such as roofs, roads and sealed carparks. In catchments with 10–20% imperviousness this can result in increased peak storm water run-off, which is double the volume of run-off compared to areas with no impervious surfaces. Impervious cover

galvanised roofs contribute zinc to the waterways. Accumulation of lead in waterways may also have occurred due to historical usage of leaded fuels and lead in old paints (Egodawatta, Ziyath and Goonetilleke, 2013).

Heavy metals cause ecotoxicity in the aquatic environment (Harding, 2005). Metals can switch from particulate (attached to sediment) to dissolved phase depending on the chemical conditions in the receiving waters. Metals in dissolved fraction are more readily available for uptake by freshwater biota (bioavailable) and hence can bioaccumulate in the freshwater biota and be carried up the food chain. Algae, crustaceans and salmonids are particularly sensitive to elevated levels of heavy metals in water. Chronic effects of toxic levels of these metals include reduced growth, lower reproduction rates and higher mortality in aquatic biota. Human consumption of shellfish containing high levels of accumulated metals is a public health risk.

Impact of overflows

Wastewater networks in cities are designed to convey wastewater (residential, commercial and industrial sewage) to treatment plants. However, these systems can have both controlled and uncontrolled overflows that can affect urban waterway health. Within the wastewater pipe network, uncontrolled inflow and infiltration from storm water run-off through gully traps, illegal connections, broken pipes or unsealed manholes can cause total inflows to the wastewater network to exceed its storage and pumping capacity.

In cities such as Auckland with combined sewer systems, CSOs are used to divert excess flows received during storm events into nearby receiving waters. This is done to reduce pressure in the system and prevent possible flooding due to system failure. However, these CSOs contain untreated wastewater discharging into receiving waters and pose a public health risk. Targeted monitoring during wet weather events showed that CSOs in Auckland carried more than 2 million *E. coli* bacteria per 100mL in the first flush (Coup, Clarke and Sharman, 2012). In addition, CSOs carry increased levels of organic matter from untreated wastewater.

Decay of such organic matter by bacteria, respiration, flux of benthic oxygen into the sediment and ammonia oxidation contributes to oxygen depletion. Such low or zero oxygen conditions can be fatal to aquatic organisms, particularly those that cannot relocate to a more oxygenated area.

The sewage discharges also carry pharmaceuticals, and other drugs such as aspirin and caffeine (Stewart et al., 2014). These chemicals bioaccumulate through the food chain from shellfish and consequently affect human health upon consumption.

Even during dry weather, overflows can occur due to blockages or mechanical faults (such as pump failures or power outages). Blockages can happen due to

to the level of treatment. Plants treat sewage at three different levels: primary, secondary and tertiary. Contaminant removal efficiency at each stage is 10%, 50% and more than 90% respectively (Strokal et al., 2019).

The potential ecosystem effects of primary or secondary treated effluents include increased nutrient loading and eutrophication (Gücker, Brauns and Pusch, 2006). The effluents also reduce natural biological and chemical variability, and increase biotic homogenisation in the river ecosystems (Drury, Rosi-Marshall and Kelly, 2013).

Out of the 152 wastewater treatment plants that discharge to fresh water in New Zealand, only 42 discharge effluent treated

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‘fatbergs’ (congealed lumps of cooking fat and other material). In 2018 there were approximately 1,642 dry weather wastewater overflows reported due to blockages (Water New Zealand, 2019).

Impact of wastewater treatment plants

Centralised wastewater treatment plants are found in many towns and cities of New Zealand. The majority of them were constructed in the past 60 years and they serve about 85% of the New Zealand population (Water New Zealand, 2019). More than 500 billion litres of sewage flows into these plants annually (Ministry for the Environment, 1997). Out of the 321 publicly owned wastewater treatment plants, about 152 of them discharge to fresh water (GHD-Boffa Miskel, 2018).

Although wastewater treatment plants effectively reduce contaminant load and biochemical oxygen demand, the effluent does not exactly match the receiving waters in terms of water quality. The effluent water quality varies across regions, primarily due

to the tertiary stage. More than 50% of outfall discharges contain high *E. coli* levels which do not meet the National Policy Statement for Freshwater Management attribute state C target in the receiving waters, and 95% do not meet the attribute state B target (Ministry for the Environment, 2017; GHD-Boffa Miskel, 2018).

Mitigation measures

Mitigation measures to reduce storm water and wastewater contamination of urban waterways can be classified into broad categories of targeted infrastructure and source control management. Compliance requirements imposed by national or local guidelines or legislation, in addition to local activism, often trigger local authorities to act in implementing solutions.

In New Zealand, the principal measure to mitigate the impact of storm water and wastewater on the freshwater environment has been upgrading infrastructure. For example, in Auckland the 13km-long Central Interceptor aims to reduce

overflows by 80%. With a capacity of 200,000m³, it will collect wastewater and storm water from more than 100 overflow points and transport the water to the wastewater treatment plant at Māngere, with the total cost estimated to be \$1.2 billion (Bhatia, 2019). The total cost of upgrades to wastewater treatment plants so that the outfall discharges meet the national policy statement's attribute state B is estimated to be between \$1.4 and \$2.1 billion (GHD-Boffa Miskel, 2018).

Water sensitive urban design, an approach to planning and designing urban areas, is increasingly being considered for mitigation of storm water impact on New Zealand's urban freshwater environment. The implementation of water sensitive urban design can effectively address both water quantity and water quality issues. Water sensitive urban design promotes the use of natural resources and integration of natural water systems into urban landscapes to assist in trapping of sediments and pollutants for improved water quality, increase residence time in ponds and wetlands to allow more sediments to settle, enhance infiltration (as it would occur naturally if the impermeable surfaces were not there) and increase groundwater recharge for healthier aquatic ecosystems (Moore et al., 2019).

Popular treatment systems included in water sensitive urban design in New Zealand include wetlands, vegetated swales, bioretention systems, rain gardens and pervious pavements. New systems are also being developed locally utilising recycled or waste materials for contaminant removal at source. One example is Storminator™,

which has been shown to remove more than 80% of metals directly from roofs by treating the storm water run-off as it drains through the building downpipes. It is designed to have a minimal footprint by retrofitting and sitting in line with existing downpipes (University of Canterbury, 2018).

Water sensitive urban design also allows for integration of mātauranga Māori and principles of tikanga Māori (Māori knowledge and practices) to provide a holistic approach to water protection for future generations. This integration aligns with natural hydrological water cycle processes and provides enhanced sociocultural outcomes in addition to environmental stewardship (Afoa and Brockbank, 2019). The Ministry for the Environment's ten urban water principles also reflect this position (Ministry for the Environment, 2018). The integrated holistic approach to urban water management following te ao Māori recommends maintaining sufficient water flow to support ecosystems, increasing water use efficiency, decreasing wastage of water resources, reducing or eliminating wastewater and storm water flow, and encompassing the views of tangata whenua for development.

Management-based initiatives to target reduction in source pollution are also being more frequently implemented. For example, some local councils have adopted and promoted the use of copper-free brake pads in their vehicle fleets to reduce copper contamination of urban waterways. Street sweeping to remove total suspended solids and metals before they enter the storm

water network is also a common management practice of several councils around New Zealand. Other management initiatives have focused on removing legacy contamination from heavily polluted waterways through dredging or vacuuming as a way to reduce resuspension of contaminants.

Proactive management initiatives have also been undertaken to identify hotspots of pollutant sources through modelling (Chakravarthy et al., 2019). Modelling approaches allow for more targeted infrastructure or management solutions to be implemented.

Conclusion

New Zealand's urban waterways have historically been viewed as drainage networks to quickly remove storm water and waste from urban centres. Until recently, these waterways received less attention from media, the scientific community and government than waterways in rural areas. As a result, most urban waterways currently have poor water quality, degraded habitat and impaired ecological health due to elevated levels of sediments, bacteria, nutrients, heavy metals and other pollutants originating in the urban environment. In addition to identifying the primary sources of waterway pollution in urban areas, targeted national and local policies are required to trigger appropriate remediation activities. Restoring degraded urban waterways to full health will require a combination of infrastructure upgrades and technical and policy-based advancements in storm water management.

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