




International River Health

Yarra Riverkeeper Association
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MONASH University

YARRA RIVERKEEPER

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Acknowledgment of Country

The Yarra Riverkeeper Association acknowledges that the lands and waterways of the Yarra Catchment and beyond, are the unceded territories of the Wurundjeri Woi-Wurrung people. We pay our respect to their ancestors, who cared for Country since time began, and to all the Wurundjeri Woi Wurrung community, to all the Kulin Nation, to all Traditional Owners, who continue to speak and care for their Country. We acknowledge that the river now called Yarra has always been known as the Birrarung by its custodians.

Prior to the invasion and subsequent colonisation of Naarm (Melbourne), the area around Birrarung (Yarra River) was and remains culturally significant to the Wurundjeri people. The connection to places along the Birrarung extends back to the Dreamtime.

To learn more about the country of the Birrarung, contact the Wurundjeri Woi Wurrung Cultural Heritage Aboriginal Corporation through their website: https://www.wurundjeri.com.au/

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Source: Engineers for Australia

The Yarra Riverkeeper Association

Source: Yarra Riverkeeper Association

The YRKA was founded in 2004 by a group of passionate community members who wished to see river protection measures in place. Since then, the organisation has grown to be a widely respected environmental body and is now one of the premier members of the Global Waterkeeper Alliance. The YRKA has expanded to focus on five key operations: Advocacy, Citizen Science, Education & Research, Ecological Restoration and Litter.

The Yarra Riverkeeper framework is built upon our motto: “Our Yarra, healthy, protected and loved.’ Our aims are to protect the Yarra from mouth to source, revitalise the river, foster a love for the Yarra for current and future generations and contribute to both local and international advocacy for greater environmental action and protection.

The Waterkeeper Alliance, of which the Yarra Riverkeeper is a member, has a particular model for environmental advocacy. The Alliance is water focussed. Each organisation within the Alliance speaks for the environmental health of its waterway through an employed waterkeeper and regularly patrols the waterway. Waterkeepers are place-based advocates.

As a leading Waterkeeper member, the YRKA advocates for the protection of the Yarra River that provides essential drinking and irrigation water to the booming city of Melbourne. It is host to the world-famous Moomba Water festival, provides a meeting place for multicultural events such as Diwali and Lunar New Year and is the natural backdrop of one of the nation’s most economically productive suburbs, Southbank. Just the same, the Yarra River catchment provides habitat for iconic Australian species such as Kangaroos, Echidnas, Wombats and most notably, the Platypus. In addition, it is the home for the critically endangered Helmeted Honey-Eater and the Leadbeater’s Possum. This dual purpose of serving as an economic fuel source but also an ecological lifeline for so many important species is a crucial balancing act that the YRKA is perpetually working towards achieving.

Authors

Neha Shetty

Having grown up in one of the world's most water stressed countries, Saudi Arabia, Neha has developed a strong passion for environmental protection and sustainability. She holds a Bachelor's in Biotechnology Engineering with a specialisation in Environmental Biotechnology from Manipal University, and is currently completing her Masters in Environment and Sustainability at Monash University. Multilingual with fluency in Hindi, Tulu, Kannada and English, Neha has greatly enhanced the YRKA's international reach and network with other international waterkeeper organisations.

Akshayaa Pasupathi

Akshayaa is a civil engineer with a key interest for sustainable development and environmental protection and is currently pursuing her Masters in Environment and Sustainability Engineering at Monash University. She has previously conducted a detailed stakeholder analysis for the Yarra River and has volunteered and worked for a variety of conservation and environmental not for profits. Originally from Chennai, India, Akshayaa has fostered new connections, building on past networks to grow the YRKA's relationship with several Indian waterkeeper bodies.

Jonathan Law

Jonathan is the YRKA's Partnerships Manager and Knowledge Officer. He has a strong passion and interest for a variety of environmental disciplines reflected through his research and volunteering works in ecology, urban planning and public health. Having explored both mega-cities and green jungles, he is passionate about how rivers bring both people and nature together and believes blue and green urban-space are the key to ensuring mental and physical wellbeing.

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Source: Pat Whelen/Unsplash

Executive Summary

Rivers have played a vital role in serving both man and nature across the earth since the dawn of time, carrying water and nutrients, serving as drainage channels for the water cycle and providing excellent habitat and food for countless organisms. To better understand river health and how it has changed over the past decades due to growing anthropogenic activities, we have considered six global rivers that provide significant utilities to their respective regions: Yamuna in northern India, the Periyar in southern India, the Yangtze in eastern China, the Hudson in north-eastern USA, the Hawkesbury- Nepean in New South Wales, Australia and finally, our beloved Yarra in Victoria, Australia. A range of information was collected for each river by collating data from scientific journals, government reports, empirical data and stakeholder consultations to draw on their geographical and cultural backgrounds, uses, their charismatic biological diversity, major threats faced, their impacts on their water quality and actions undertaken by the managements associated with the respective rivers.

Source: India 2018

The Yamuna river is one of India's most prominent and holiest rivers which holds a significant role in the country's cultural and religious heritage. Through consultation with Minakshi Arora, the Yamuna Riverkeeper, a clear overview of the river's background was established, as well as ongoing threats and actions taken by the government to restore the quality of the river's health. The river basin is the home to several unique flora and fauna species and the basin is well-known for its charismatic species such as the Golden Mahseer, Ganges River Dolphin, Indian Soft-shell turtle and Gharial. The catchment supports the livelihood of the communities living along the river, as well as supplying water for agriculture and industrial purposes. Drawing from the government reports and other relevant scientific articles, the major identified threats faced by the river are industrialisation, growing population, and inadequate infrastructure planning which has led to an alarming rate of water quality deterioration over the past years. In particular, contaminants such as heavy metals, pesticides such as benzene hexachloride (BHC), E-coli and dissolved oxygen are present in higher concentrations. Over the years, Minakshi Arora has conducted a number of educational campaigns to create awareness among the people on the declining water quality. In addition, the Government of India has initiated an action plan for Yamuna which will address the importance of transition from economic development to environmental protection and carry out a transparent river management approach.

The Periyar river is the largest river in the southern Indian state of Kerala and plays a significant role in the economy of the state. A small part of the river flows within the Tamil Nadu state and provides potable water supply to the major cities such as Kochi, Aluva, Neriamangalam, Kalady, and Malayattoor. Through the stakeholder consultation with Dr.Venkatesh Dutta and Dr. Sunny George, information was gathered on the river management initiatives and the ongoing threats to the river basin. The Periyar River basin hosts the famous Bengal Tiger, Asian Elephant, Nilgiri Tahr, Mugger Crocodile, Great Oriental Hornbill, and Indian King Cobra. The river provides significant ecological utilities such as domestic supply, agriculture, industries, fishing, and inland transportation. Through analysis of various scientific literature and government reports, it was found that a high volume of toxic effluents such as DDT, Lead, E-coli, and cyanide are being dumped into the river by nearly 250 industries located along the industrial belt of Periyar. The continued efforts of the environmental organizations and activists has created a huge awareness among the government who then initiated a FACT junction to display the water and air quality parameters in the area. This action has helped to create awareness among the public to watch for themselves the parameters of air and water quality in the area which will lead to a greater community engagement.

The Yangtze River is the longest river in Asia and holds a significant value both in China's economy, culture and unique biota. The river flows through major cities such as Chongqing, Nanjing and Shanghai before concluding into the East China Sea. With the insights gathered from senior water resources specialist Au Shion Yee, we were able to draw an overview on the background, ecological utilities and management initiatives of the river. Yangtze features many endemic Chinese keystone and charismatic species such as the Giant Panda, Chinese Sturgeon, Baiji Dolphin, Finless Porpoise and Chinese Paddlefish. Due to the growing population and industrialization, the health of the river has been gradually decreasing and the construction of Three Gorges Dam has led to serious river channelisation. Additionally, unsustainable harvesting has also had a huge impact on the health of the river both in terms of biota and water quality. The Yangtze Riverkeepers along with the Chinese Government have been consistently working to restore the ecology of the river through various biodiversity conservation policy and monitoring initiatives.

Source: Anthony Despotellis

The Hudson river defines one of the world's most famous cities, New York City, and plays a key role in supplying drinking water and recreational purposes. Most of the water supplied by the basin is mainly utilised for commercial and industrial uses, adding especially a significant economic value to the country's tourism industry. The basin supports a rich biodiversity with keystone species such as Atlantic Sturgeon and Striped Bass as well as the USA national animal the Bald Eagle. Insights drawn from expert stakeholders Paul Gallay, Marc Yaggi and Mary-Beth Postman, were used to evaluate the major threats impacting the quality of the river and management initiatives. Given the huge population density, the major pressures on the health of the river are industrialization and rise in sea-level that has occurred over the past years. In order to protect the river, the Department of Conservation of New York State has established an Estuary Action Agenda (2015-2020) which aims to promote clean water and build resilient communities. Further, the Riverkeeper Organization along with the Waterkeeper Alliance are consistently working together to advocate and develop new strategies to protect the Hudson river.

Source: Natalee Desotell, n.d.

The Hawkesbury-Nepean river is one of the largest coastal basins in New South Wales, Australia, supporting drinking water supply, irrigation and agriculture to the metropolitan area of Greater Sydney. The basin supports some of the most distinct Australian species of flora and fauna such as the Koala, Platypus and Australian Bass. From the information gathered from Hawkesbury-Nepean riverkeeping advocate Sue Martin, it is seen that the major threats faced by the catchment are land clearance, industrial runoff, and damming. It poses a significant impact on land fragmentation and restriction in the water flow leading to a gradual decline in the water quality of the river through elevated levels of salinity, low pH and elevated metals load. The Government established the Hawkesbury-Nepean Catchment Management Authority (HNCMA) to promote stakeholder collaboration with multiple community groups to improve river health until 2018. Sue Martin is working passionately to establish a new Hawkesbury River Waterkeeper Alliance which will open gates for stakeholder collaboration on a multi-level scale to improve the catchment's health.

The Yarra River located in the south-eastern Australian state of Victoria plays a vital role in providing potable water supply to the city of Melbourne and is considered to be the most valuable natural asset. The Yarra Riverkeeper, Andrew Kelly and Dr. Teresa Mackintosh from Melbourne Water provided valuable insights on the river's background, major threats impacting the quality of the river and also the river management initiatives taken to protect the iconic Yarra. The Yarra is home to many iconic Australian species such as the Platypus, Australian Grayling, River Blackfish, Eastern Grey Kangaroo and Sugar Glider. Similar to other rivers, the increasing population and infrastructure development along the lower stream has created a huge pressure on the health of the river. The other significant threats faced by the Yarra are litter, invasive species and forest fires which comprise the catchment's water quality. In order to protect and restore the health of the river, the Yarra Riverkeeper Association alongside other community environmental groups have been working consistently to address the needs of the river by giving a voice to the river as a single living entity, as it cannot speak for itself.

Although geographically distinct, all the above rivers are facing the same major threats through the years of their existence such as population density, industrialization, damming, agriculture and improper land-use planning. To fight against these threats, the stakeholders and waterkeepers have proposed a number of initiatives that can help restore and protect the respective rivers. Greater sustainable planning, development regulations and protective legislation is needed on a collaborative, global scale. In particular, the construction of dams poses a serious threat as they restrict the environmental flow of the rivers leading to the destruction of the river habitats that are seen across the world. Stakeholder collaboration and place-based initiatives by the Riverkeepers and Waterkeeper Alliance is a way forward to protecting our beloved river ecosystems across the world. Furthermore, regular monitoring and evaluation of the water quality and making such data accessible to the public will play a crucial role in creating awareness among the community, driving collective support and citizen stewardship and care.

Introduction

Rivers are the arteries of the Earth, not only do they provide the essential element of freshwater, nutrients and habitat for countless species, but they also provide many ecological services to humanity, driving our recreational cultural and economic practices. Rivers are resilient and continue to evolve because of their dynamic nature, they are the highways of transportation and trade, serve as recreational hotspots for mass cultural and sporting events, irrigate farmlands, serve as drainage channels by carrying away wastes and pollutants, are the sources of our drinking water and in many cultures, are the pathways to life and death. Nearly 75% of the earth's surface is drained by the rivers and the distribution and movement of water across the landscapes influence a broad suite of ecological, geological, biological, historical and cultural factors (Sponseller, Heffernan & Fisher 2013).

Wild rivers are earth's renegades, defying gravity, dancing to their own tunes, resisting the authority of humans, always chipping away, and eventually always winning.-Richard Bangs.

The importance of rivers has been observed almost immediately from the very early beginning of human civilizations, fundamentally catalysing the birth and the development of societies. Reflective of how important rivers are, many of the world's most famous and populous cities are built around waterways, as they provide an efficient natural landscape that supports planning, horticulture, agriculture, transport and tourism. Indeed rivers are the arteries that feed two of the world's most biodiverse ecosystems, the Amazon and Nile. Whilst at the same time, the biggest civilisations such as the ancient Egyptians and Indians have settled along the biggest rivers (Nile and Ganges), a trend that has continued in the modern age across the globe where the world's most well-known cities are situated on the rivers such as London, New York, Shanghai, Kolkata, Paris etc.

However, because they provide so many ecological services, rivers are therefore subject to overuse, mismanagement and neglect, threatening the very processes and functions we rely so heavily upon. As humanity grows and continues to develop, anthropogenic activities have posed a serious threat to river ecosystems which has the potential to lead to a case of life-or-death for many species (WWF n.d). The construction of dams and reservoirs have led to fragmentation and flow regulations which have resulted in the loss of river connectivity across the world (Grill et al. 2019). No two rivers are exactly alike, yet almost all rivers share the threat of biodiversity loss, exploitation and water quality degradation.

This report was commissioned by the Yarra Riverkeeper Association to contribute to a better understanding of the impact that water quality has on the health of major rivers and their catchments across the globe. The report explores six iconic rivers: the Yamuna in northern India, the Periyar in southern India, the Yangtze in eastern China, the Hudson in north-eastern USA, the Hawkesbury-Nepean in New South Wales, Australia and the Yarra in Victoria, Australia. These six iconic rivers were considered as they are well-known for their ecological utilities provided to the respective regions. The focus of each section is on the water quality in each river, and the implications this has for the environmental health of the catchment. The rivers were selected to give a broad global representation of the implications of water quality for different rivers with different geographies and socio-economic profiles. The main purpose of the report is to understand the ecological health of each river through government reports, scientific research, literature analysis and importantly key stakeholder consultation. and how they have been impacted by anthropogenic activities over the past decades. Each section will outline each river's background, uses, richness in biodiversity, major threats faced and actions taken to improve the water quality of the rivers. Finally, there will be a comparison and contrast of the common threats that are faced by these rivers, thereby learning from each other from their respective management initiatives.

YAMUNA

EXPERT SPOTLIGHT

Minakshi Arora *Mid-Upper Yamuna Riverkeeper*

Minakshi Arora is the Yamuna Riverkeeper for the mid-upper region of Yamuna and has been a key member of the Global Waterkeeper Alliance for more than a decade. She leads and runs the conservation organisation ‘Trust for Research on Water & Environment’. Minakshi has a strong background in political science and law and has more than 12 years of experience in the social and development sector, previously working as the chairperson and consultant at Water Community Indian and Greenpeace India respectively. Minakshi has been working as a researcher at the Indian Institute of Technology, Delhi for the past seven years and has published nine journal articles in both Hindi & English. Minakshi coordinates and monitors the Indian Water Portal (www.indiawaterportal.org), an information hub with a readership of over 20 million, and is available in three languages to provide people with information about the waterways through grassroot programs in attempts to sensitise the community about the rivers and waterways. Minakshi also believes that,

“The Government provides the people with false knowledge; they give people different information than what the actual truth is”.

She aims to educate and bring the community together to raise a unified voice for the river. Minakshi has also been a pioneer in raising her voice for giving Yamuna River and Ganges River legal rights, she actively protests against builders and developers that have been a constant threat to the Yamuna River Health. Minakshi hopes the National Green Tribunal would bring a change in the environmental conservation and restoration of India’s waterways.

Background

The Yamuna River is one of India's most prominent and holiest rivers. It is the largest tributary and the sub-basin of the Ganges River with a total catchment area of 345,848 sq. km, equating to approximately 40.1% of the total Ganges River Basin (Central Pollution Control Board [CPCB] 1980-1981). Originating from the Yamunotri glacier, the river flows through the seven Indian states of Uttarakhand (formerly known as Uttaranchal), Uttar Pradesh (UP), Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh and the National Capital Territory of Delhi (NCT) (Appendix 1) (Sharma & Kansal 2011). The Yamuna River traverses a distance of 1376 km in the plain from Saharanpur district of Uttar Pradesh through to the city of Allahabad where it meets with the Ganges River (Figure 1).

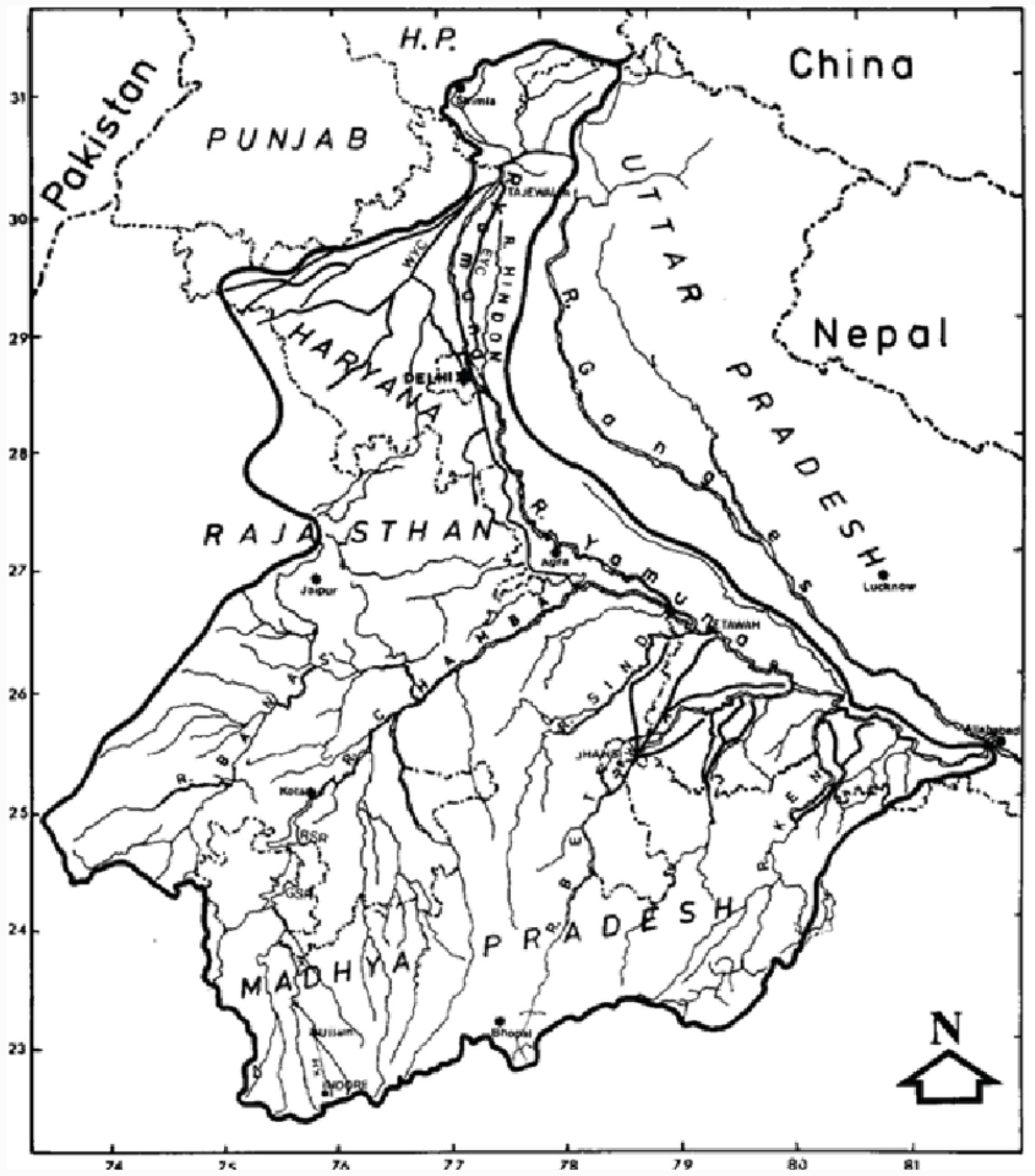


Figure 1 Yamuna River Basin (CPCB, 2006)

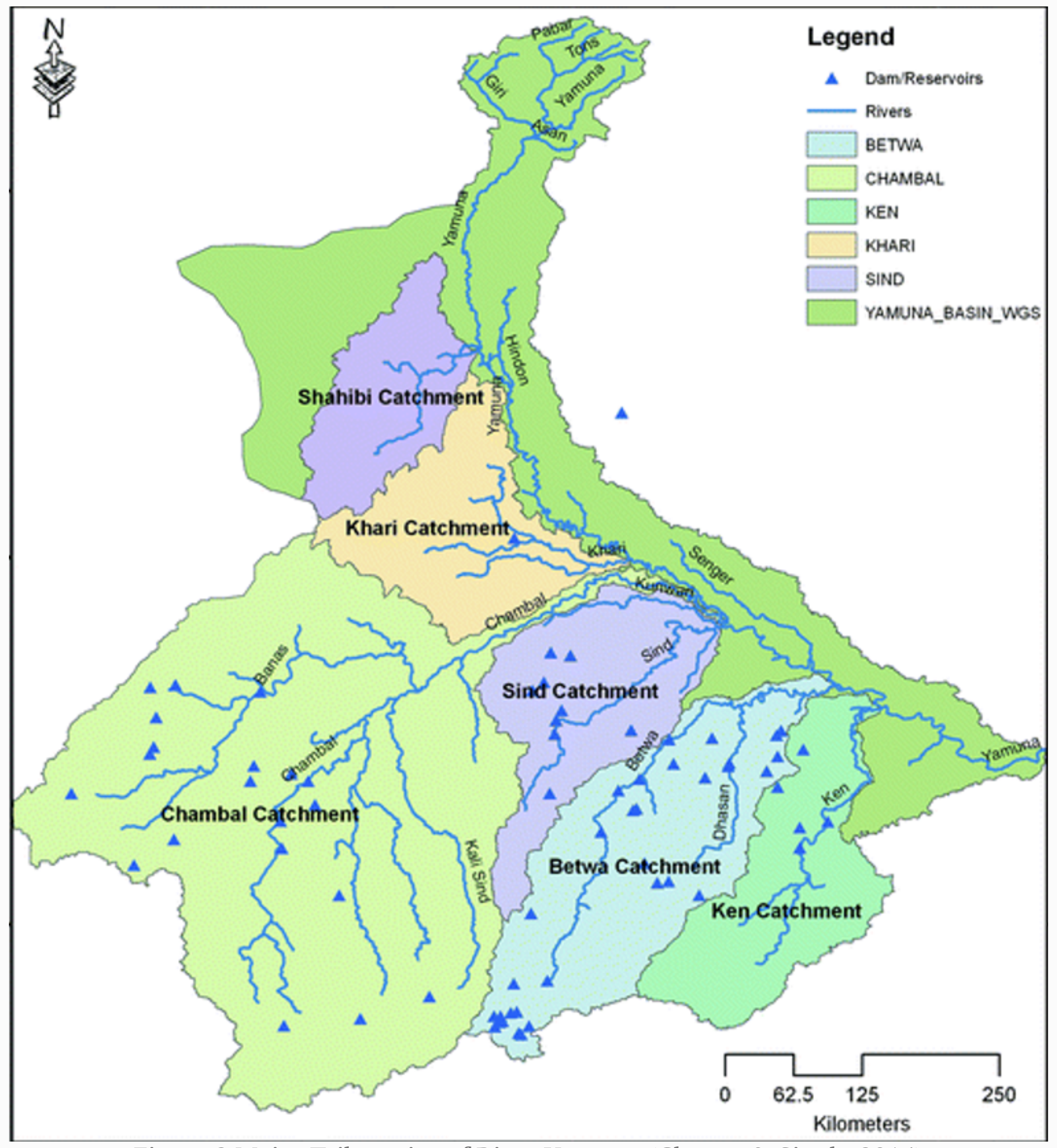


Figure 2 Major Tributaries of River Yamuna (Chopra & Singh, 2016)

The major tributaries of Yamuna are Tons, Betwa, Chambal, Ken and Sindh; contributing 70.9% of the total Yamuna catchment area and the remaining 29.1% is the direct drainage of the main and smaller tributaries (Figure 2) (Sharma & Kansal 2011).

The Yamuna is divided into Himalayan Stretch which constitutes its origin (Himachal Pradesh) to Tajewala Barrage (Haryana), Upper Stretch from Tajewala Barrage to Wazirabad (Delhi), Mid-Upper Stretch from Wazirabad to Okhla Barrage (Delhi), Mid-Lower Stretch from Okhla Barrage to confluence with Chambal River (Madhya Pradesh) and the Lower Stretch from Chambal confluence to the Ganges River confluence at Allahabad (Uttar Pradesh) (Sharma & Chaudhry 2015).

Due to high population density and disruptive anthropogenic activities, the Mid-Upper and Mid-Lower Stretch of Yamuna have been highly polluted for more than a decade (Sharma & Chaudhry 2015).

Uses of the River

The Yamuna holds a significant role in India's religious and cultural heritage, with approximately 57 million residents of India's population depending on the river for its ecological services. The river not only provides a livelihood for the communities living on the banks of the river but also offers life support to agricultural, industrial and urban sectors situated in the catchment (Sharma & Chaudhry 2015). The vast catchment of Yamuna is mainly utilised for its water abstraction by the Indian States which vary based on the Monsoon periods. During the pre-monsoon period (March-June), Haryana, as one of India's agricultural bread-baskets, extracts more than 50% of the river water whereas U.P & Uttarakhand combined extract nearly 29% and the remaining states of Rajasthan, NCT & Himachal extract just 5% each respectively. However, during the monsoon period (July-October), Haryana's water extraction reduces by 5% thereby increasing UP & Uttarakhand's water extraction share to 35% (Sharma & Kansal 2011). Haryana extracts the most for its irrigation purposes, whilst the NCT abstracts the least, more than 70% of the drinking water supply for Delhi comes from the Mid-Upper Stretch of the Yamuna (Upadhyay et al. 2011).

Irrigation still remains the main use of the Yamuna River, with its entire basin supporting nearly 12.3 million hectares of agricultural land, from which, 49% is irrigated exclusively from surface water. To support agriculture, approximately 70% of the total cattle population within the seven states are bathed and washed in the Yamuna River (Sharma & Kansal 2011). Apart from irrigation, Yamuna is utilised for its domestic water supply and industrial use.

Source: Shrey Khurana/Unsplash

According to Central Pollution Control Board (CPCB) (2000), there were more than 359 industrial units situated near the Yamuna, out of which 22 industrial units in Haryana, 42 units in Delhi and 17 units in Uttar Pradesh were found to be discharging untreated water directly into the river (Ali et al. 2001). Other uses of this river include river bathing and washing due to religious rituals, illegal fishing, tourism, hydropower and water sports such as river rafting and boating.

Biodiversity

The Yamuna basin has a unique range of native flora and fauna (Figure 3), hosting many wildlife sanctuaries and protected areas. In the upper stretch of Yamuna lies the Govind Pashu Vihar National Park and Sanctuary, home to the rare Snow Leopard (Panthera uncial) and the Bearded Vulture (Gypaetus barbatus) (Chopra & Singh 2016). The Golden Mahseer (Tor putitora), a freshwater carp with golden yellow scales, is a well-known fish species of the Yamuna and considered a prize catch by the local fishermen. The species have severely declined due to overfishing, population and habitat loss, and has been listed as endangered in the IUCN's Red List (World Wide Fund [WWF] India n.d.; Chopra & Singh 2016). As per the Yamuna Riverkeeper, Minakshi Arora, the Golden Mahseer is considered a keystone species for the upper stretch of the Yamuna River. The species play a key ecological role in consuming debris, controlling smaller species and removing carcass materials from the waterways.

The Golden Mahseer inhabits mostly in moderately cold water stretches and spawns over rocky bottoms and they can barely tolerate a modified water environment. In the Yamuna, the Golden Mahseer migrates to gently flowing pools and warmer stretches for breeding purposes. However, due to the construction of high amounts of dams and barrages, the water flow has significantly decreased causing major threats to the Golden Mahseer species through habitat-loss and migration prevention (Chopra & Singh 2016).

Figure 3 Biodiversity of the Yamuna. (Clockwise from top-right): Indian Leopard, Gharial, Golden Mahseer (bottom), Soft-shell Turtle (top), Bearded Vulture, Golden Jackal and the Ganges River Dolphin

Out of the 47 species of Mahseer in the world, India is home to nearly 15 species, and they are rapidly declining due to the ongoing deterioration of water quality. The Yamuna is also home to fish species such as Goonch (Bagarius bagarius) a giant catfish, Red-finned Mahseer (Tor tor), and the common Snow Trout (Schizothorax richardsonii) that have also been classified as vulnerable by the IUCN (WWF India n.d; Chopra & Singh 2016).

Yamuna biodiversity park is home to a strong array of wildlife including northern Indian icons such as the Golden Jackal, Indian Crested Porcupine and Indian Leopard. The park has been hailed as a strong provider of eco-tourism and is a key supplier to the urban biodiversity in the cities of Delhi and Chandigarh (Joshi & Puri 2017). Amongst the 140 species present in the Yamuna, the Gharial (Gavialis gangeticus) have been quite prominent as one of Yamuna River's charismatic species.

This crocodilian grows up to 6 meters long and plays a significant role in various religious Hindu folklores. Their population was considered to be fragmented, however, there has been an increase in Gharial sightings in 2020 as they are returning to the Yamuna for nesting (M.Arora 2020, pers. comm. 23 September). In Yamuna's tributaries, the Chambal River holds the largest population of Gharial, in comparison to the Ken River which holds the least (IIT 2012).

The Indian Tent Turtle (Kachuga tentoria) is the most common species of turtle found in the Yamuna River. In addition, there are five other species reported namely Painted Roofed Turtle (K. kuchuga), Three-striped Roofed Turtle (K. dhongoka), Indian Flap-shell Turtle (Lissemys punchata), Indian Soft-shell Turtle (Aspideretes gangeticus) and Narrow Headed Soft-shell Turtle (Chitra indica) (IIT 2012).

India's national aquatic animal, the Ganges River Dolphin (Platanista gangetica) considers the Yamuna River and Ganges River as its home, but due to anthropogenic activities there has been a severe decline in the species population and as a result it has been listed as endangered in the IUCN's Red List.

IIn the Yamuna, the River Dolphin is mainly found in the mid-lower stretch and is considered a keystone species (WWF n.d.; Chopra & Singh 2016). In 2010, WWF India reported 60 dolphins in the main tributary and a total of 108 dolphins in its smaller tributaries (89 dolphins in Chambal, 8 in Ken, 6 in Betwa and 5 in Sind). In the past decade, the population has continued to decline, which is a key indicator of the poor health of the Yamuna's ecosystem (Indian Institute of Technology [IIT] 2012; IUCN n.d). In addition, the Yamuna Riverkeeper has stated poaching and illegal fishing taking place in the mid-lower stretch of the Yamuna are major drivers for the rapid decline of the River Dolphin.

Source: Gowri Subramanya/Unsplash

Threats to the Yamuna

As a direct result of rapid urban population growth, industrialisation and inadequate infrastructure, the water quality of Yamuna has been deteriorating at alarming rates causing the lower stretch to be drained and filled with agricultural, industrial and domestic effluents (Ali et al. 2001). Whilst industries situated on and near the banks of Yamuna River have been reported by the Central Pollution Control Board for discharging untreated wastewater into the river, there has been no major reform. These industries and factories include paper, sugar, tannery, steel plants, distilleries, textiles, leather, chemical, pharmaceutical, oil refineries, thermal power plants and many others (Sharma & Chaudhry 2015). Due to the increase in anthropogenic pressure, the Yamuna's degradation has been likened to a sewage drain.

Delhi extracts the least amount of water from the river, however, 95% of Yamuna's pollution comes from untreated domestic and industrial wastewater through Delhi's seven major drains; namely, Najafgarh, Yamunapur, Sen Nursing Home, Barathpula, Maharanibag, Kalkaji and Tuglakabad (Sharma & Chaudhry 2015). The major sources of pollution from NCT are untreated domestic wastewater, untreated industrial effluents, poor sanitation practices by residents, diffuse pollution (agricultural runoff, dead body dumping and cattle washing), untreated pesticides, religious activity and immersion of idols. Aggrawal (1996) states that "The River Yamuna is so polluted in Delhi that beyond Okhla Barrage, it hardly supports any form of life." Along with organic matter and nutrients, several pesticides and heavy metals have been found at extremely high levels.

Water Quality

The major decline in various species' populations is a strong indicator of Yamuna's River health. In India, the Central Pollution Control Board (CPCB), the Central Water Commission (CWC), the Delhi Pollution Control Committee (DPCC) and the State Pollution Control Board (SPCB) regularly monitor the Yamuna for water quality samples at 19 locations along its main tributary (Sharma & Kansal 2011). Untreated domestic and industrial waste are the major reasons for the decline in Yamuna's water quality. To monitor these discharges, the government bodies test the water quality from the twenty-eight major drain outfalls into the Yamuna. The organic pollution level increases significantly in Delhi and the biochemical oxygen demand (BOD) level does not meet the stipulated standard for the Class C category till the confluence of the Chambal River (Chopra & Singh 2016). The same stretch of the river shows fluctuations in dissolved oxygen (DO) level from nil to well above saturation level. This reflects the presence of organic pollution load and prevalence of eutrophic conditions. Bacteriological contamination is significantly high in the entire Yamuna River stretch (Chopra & Singh 2016; CPCB 2005; DPCC 2020).

Amongst the heavy metals, Cadmium, Nickel and Lead are scantily present in the river, whereas, Zinc, Iron, Chromium and Copper are highly present. Among the pesticides, BHC (benzene hexachloride) was present in significant amounts, whereas other monitored pesticides e.g. Aldrin, Dieldrin, endosulfan and DDT were not traceable. The highest detectable presence of pesticide in the river is during the non-monsoon period when the main river stream shrinks significantly, and the riverbed is used for farming purposes, therefore, contributing to the pesticide residue in the water (CPCB 2005; Chopra & Singh 2016).

From the latest water quality report from the Yamuna monitoring in February 2020 (Table 1), the presence of BOD and faecal Coliform bacteria were alarmingly high indicating the continuous discharge of domestic waste, causing further deterioration of the river health and threats to its native species (DPCC 2020).

Table 1 Water Quality of River Yamuna in Delhi (February, 2020)

S. No	station code	Station Name	Dissolved Oxygen (mg/l)	pH	Conductivity (μmhos/cm)	BOD (mg/l)	Fecal Coliform (MPN/100 ml)	Total Coliform (MPN/100 ml)
WATER QUALITY CRITERIA			> 5 mg/l	6.5-8.5	-	< 3 mg/l	< 500 MPN/100ml	-
1	1120	YAMUNA AT PALLA	8.4	7.6	668	7.4	930	79×10^2
2	1121	YAMUNA AT NIZAMUDDIN	ND	7.1	1152	20	49×10^5	79×10^5
3	1375	YAMUNA AT OKHLA BRIDGE (INLET OF AGRA CANAL) KALINDI KUNJ	ND	7.1	808	16	23×10^5	46×10^5
4	1812	RIVER YAMUNA AT OKHLA AFTER MEETING OF SHAHDARA DRAIN (OKHALA D/S)	ND	7.2	1528	82	7×10^6	17×10^6
5	2057	AGRA CANAL, MADANPUR KHADAR (BADARPUR)	ND	7.1	897	25	49×10^5	49×10^5

River Management Initiatives

The Yamuna River has been degraded through the decades due to constant pressures to support the human population density. In 1977-78, Central Pollution Control Board (CPCB) initiated a study to assess the river health of the Yamuna, the study indicated the major causes of pollution were the discharges of domestic wastewater into the river and the remaining pollution is contributed by industries and agriculture. Based on these findings, the Government of India (GoI) decided to take up water quality restoration measures known as the Yamuna Action Plan (YAP) under the mega project of the Ganga Action Plan (GAP) phase-II. This was a bilateral project between GoI and the Government of Japan (GoJ) with GoJ providing loan assistance of ¥17.7 billion for implementation of YAP in December-1990. YAP was formally launched in 1993 and is now referred to as YAP phase I (YAP I). Subsequently, the work continued with the launch of YAP phase II (YAP II) in the year 2001 (CPCB, 2006). YAP focused on constructing Sewage Treatment Plants (STPs), pumping stations to treat the river and standard parameters were set to ensure the water quality is maintained. The YAP aimed to achieve clean water by March 2020, however, the water quality standards of the Yamuna remain poor and have not met the set standards yet. The Yamuna Riverkeeper, Minakshi Arora hopes that the GoI will shift priorities from economic development to environmental protection and carry out a transparent river management approach.

PERIYAR

EXPERT SPOTLIGHT

Dr.Venkatesh Dutta *Advocate for Southern Indian Waterkeeping, Gomti Riverkeeper*

Venkatesh is the Gomti Riverkeeper based in Lucknow, India, and has contributed to significant changes in public discourse, law, and policy for sustainable water resource management in India. His main research interests include river restoration, land-use planning along with zoning regulations, environmental impact assessment, urban policies and sustainable cities. He is actively engaged in educating students across the world to create awareness about water health and sustainability. His passion for the Indian rivers has been a valuable resource to understand an overview of the comparative differences between North and South Indian environmental resource management. Recently, he delivered two talks during the "Sustainability Exchange Programme – International Certificate Course on Water and Health for Sustainability" held from 18th to 20th November 2019 and organized by the Centre for Environment Education (CEE), University of Lucknow (Institute of Wildlife Sciences) and Western Sydney University, Australia. He has presented several invited lectures at universities and institutions of repute outside India since 2005 in the UK, USA, Sweden, Belgium, France, Germany, Russia, Greece, Italy, Brazil, Kuwait, Dubai, Luxembourg, Hungary, Switzerland, Nepal, etc.

"Ponds have dried up and perennial rivers have become seasonal. Everywhere we are dehydrating the ecosystem just to keep our economy hydrated. We must respect the ecological resilience and integrity of the watersheds and river basins across the globe." -Dr. Dutta, Gomti Riverkeeper

Dr. Sunny George *Director of the SCMS Water Institute, Kerala*

Dr. Sunny George is a limnologist of international repute and the Director of the SCMS Water Institute. He has special expertise in standardizing and fine-tuning several laboratory level concepts and ideas and converting them into socially relevant projects and programs. He has more than 20 years of experience in research, consultancy and implementation of development projects and has worked in several European Universities and Institutes. In 2012 he was selected by the U.S Government as a member of the Indian Water Mission to the United States. Key water policy is being drafted in a joint initiative between the Cochin Municipal Corporation and the SCMS Water Institute in order to develop a water policy under the purview of the National and State Water Policies. This water policy would be the first-ever initiative of this nature launched by any corporation in the country. The water policy being developed is anticipated to assist Kochi Corporation to improve its delivery mechanism and to coordinate and integrate water-related services to the community.

"Water, in any form, is the elixir of life on earth, may it be the waterfall in the rainforest, snow in a mountain, or even the raindrop on the leaves in our garden." -Dr. Sunny George

Source: India, 2018

Background

The Periyar River is primarily located in the state of Kerala with a small section reaching within Tamil Nadu. It is the longest river in Kerala and the state belongs to one of the highest monsoon rainfall regions in India, alongside northeast India (Sudheer et al. 2019). The Indian state of Kerala is located in the southernmost part along the west coast of India and is confined between the Western Ghats in the east and the Arabian Sea in the west (Nair et al. 2014). Stretching 244 km in length (Figure 4), the river originates from the Sivagiri hills of the Western Ghats and flows through the districts of Idukki and Ernakulam before joining the Arabian Sea at Cochin (Earth5R 2020). It is the largest basin in Kerala with a catchment area of 5398 sq km and acts as the main source of drinking water supply to the Cochin Corporation, Aluva, and Paravur towns (Jeberlin, Sheeja & Karuppasamy 2015; Sudheer et al. 2019).

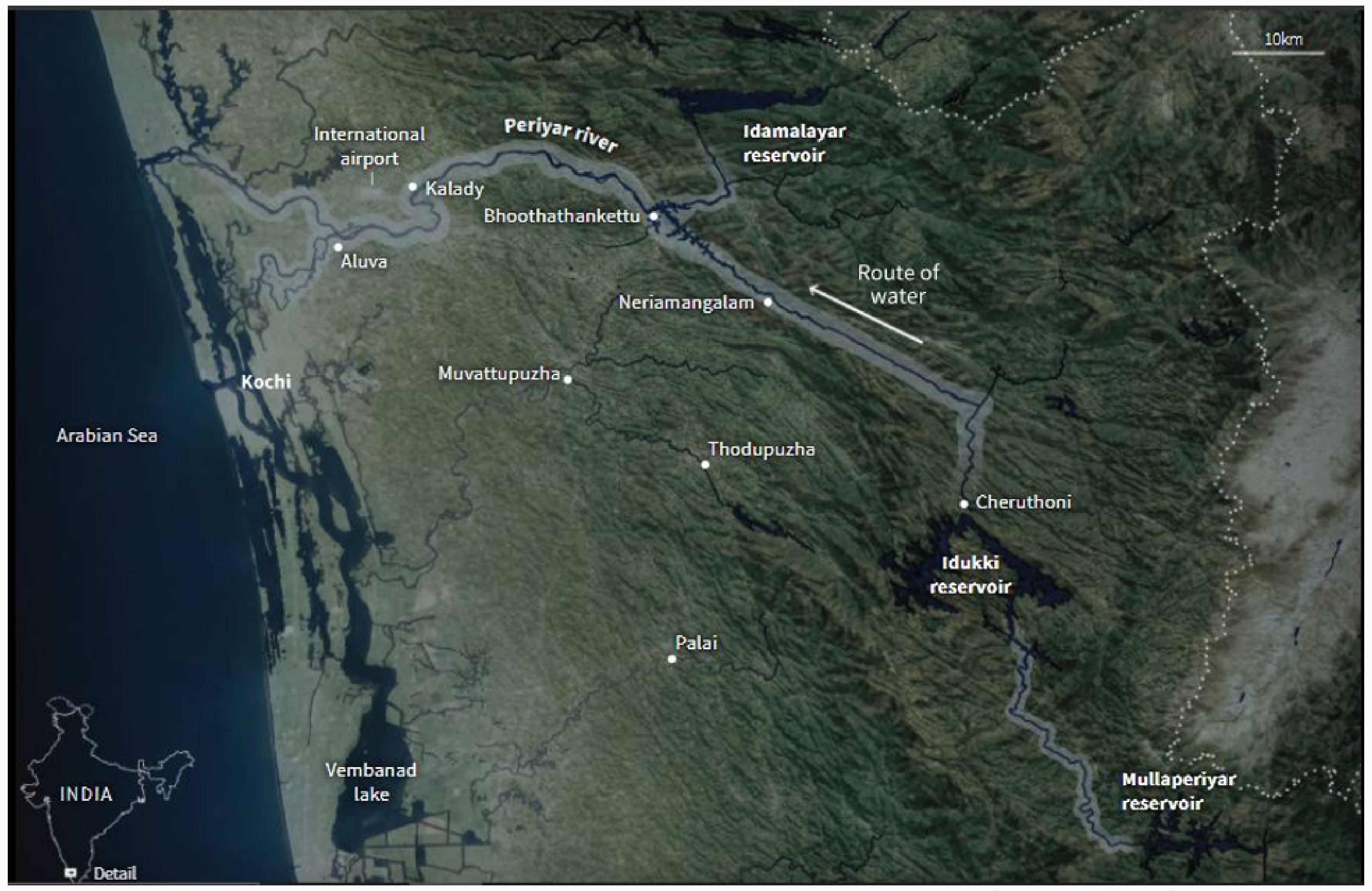


Figure 4. Periyar River (Reuters 2020)

The major tributaries are Mullayar, Cheruthoni Aar, Muthirapuzha, Perinjankutty Aar, and Idamalayar (Figure 5), with the general drainage pattern of the basin is dendritic in nature, spreading out with a wide network of smaller streams from tributaries. The mainstream of the river divides at Alwaye and finally concludes at the Arabian Sea through two different estuaries: the Kodungallur–Azhikode and the Cochin estuary (Sudheer et al. 2019). The wetland system of Vembanad, located in the river basin, is the largest of its kind on the west coast of India. The region enjoys a tropical humid climate, with marked wet and dry seasons and variable rainfall across the basin. The basin receives large amounts of rainfall, with upstream parts of the basin (in Idukki district) recording a mean annual rainfall of 3677 mm, whereas the downstream parts (in Ernakulam district) experiences a mean annual rainfall of 3360 mm (Shyam 2013; Singadurai 2013; Thomas & Prasanna Kumar 2016). In part due to its geography and climate, nearly 80% of the total area situated in the high ranges are susceptible to erosion and landslides (Annual report 2010). Early inhabitants of the upper catchments of the Periyar River basin are the indigenous people; namely, the Mannans, Uralis, Paniyas, Malayars, and Malampandarams (Latha & Vasudevan 2016).

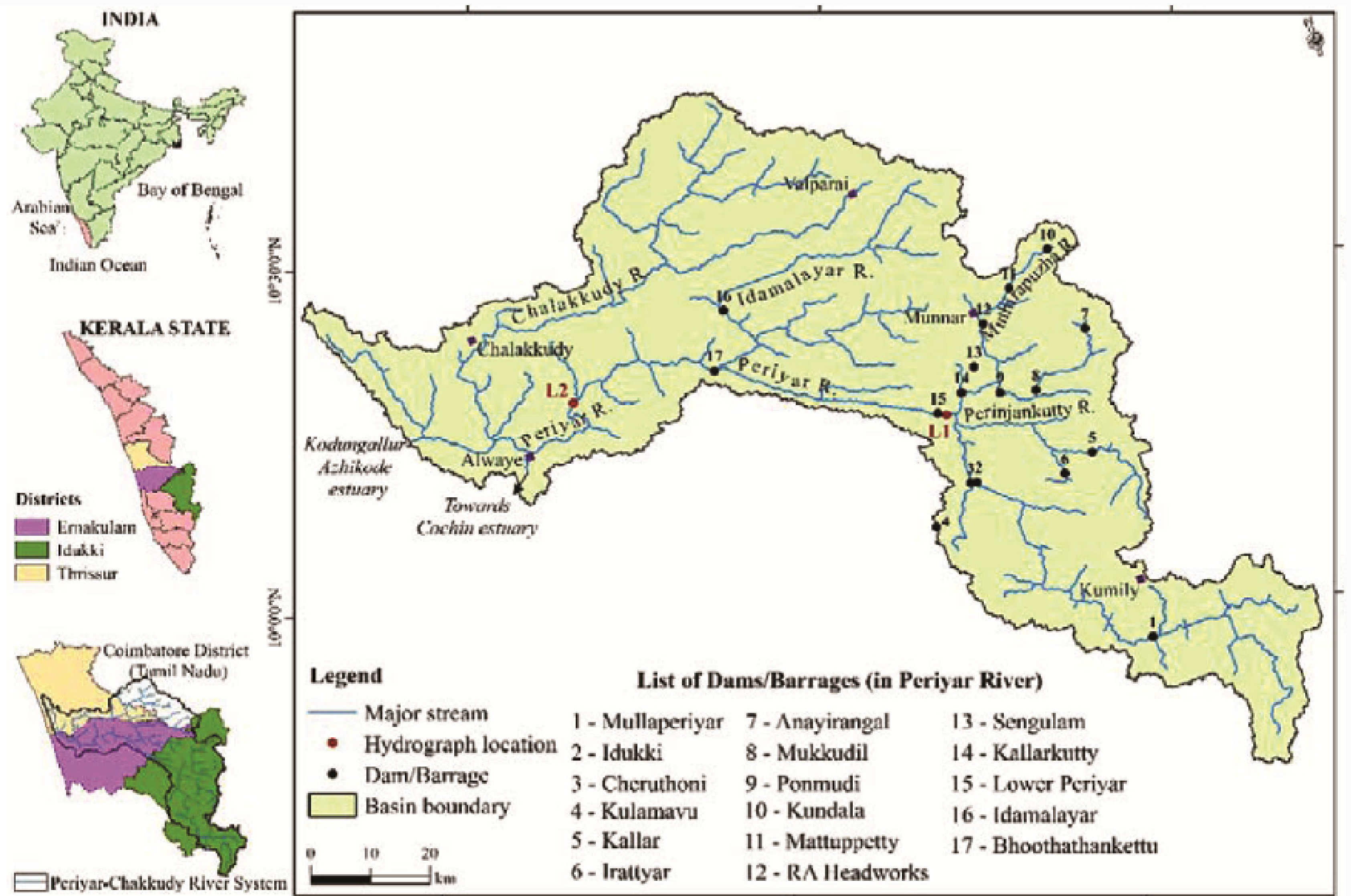


Figure 5. Periyar River Basin (including Chalakkudy River System) (Sudheer et al. 2019)

Uses of the River

The Periyar River plays a vital role in the economy of Kerala, reflected by the fact that nearly 25% of the industries in Kerala are situated along the Periyar river basin (Earth5R 2020). At present, the state has installed hydropower plants with a total capacity of more than 2000MW including 12 major projects, among which seven projects are installed in the Periyar basin with a total installed capacity of 1233 MW (Abe 2014). Idukki dam, located in the Periyar River, is one of the highest arch dams in Asia and the third tallest arch dam supporting an installed capacity of 780MW in Moolamattom (nearly 65% from the state's hydropower generation) (KSEB 2020). Periyar is a well-known tourist spot as it spans between the two mountains - Kuravanmala (839m) and Kurathimala (925m) with a wide-spread view of beautiful, wooden valleys and meandering streams (Figure 6). The river basin also plays a significant role in irrigation and domestic supply whilst also supporting a rich fishery and major agricultural crops such as rice, coconut, areca nut, banana, rubber and vegetables. The upstream region is well-known for its plantation of tea, coffee, cardamom, and rubber (Latha & Vasudevan 2016). The total wetlands out of the river catchment area is estimated to be over 39,000 hectares, 16,600 of which is a garden of arable land area of 16,600 hectares. The City of Kochi's drinking water supply comes from Aluva located in the upstream region of the Periyar River. Another key use of the river basin is transportation, where inland passage is navigated through Cochin backwaters and lower reaches of Periyar using boats owned by both government and private agencies. The Periyar offers a smooth and comfortable journey for passengers when compared to the busiest roadways in the Cochin area.

More downstream, the river meanders through Malayattoor, Kalady, and Alwaye—which are holy places of worship, attracting up to 50 million pilgrims annually (Smakthin et al. 2007). For centuries Kerala residents have practiced shifting cultivation, collected fish, honey, and other forest produce to support their living, and their lives have been inevitably intertwined with the flow and health of the river. These features are the reasons for which the river has been named as the "Lifeline of Kerala''. (Earth5R 2020).

Figure 6 Idukki Dam, Source: Reuters 2020

Biodiversity

Known as the 'Great Escarpment of India', the Western Ghats of India is a UNESCO World Heritage Site and a biodiversity hotspot. The Western Ghats is not only one of 36 biodiversity hotspots, but also one of eight "hottest" of its class because of the incredible biological diversity exhibited (Myers et al. 2000; UNESCO 2020). Of a total of 39 World Heritage Sites in India, which include national parks, wildlife sanctuaries, and reserve forests, 20 are in Kerala. These sites however are widely threatened by human activities and invasive species (Dahanukar et al. 2004; Arunkumar & Manimekalan 2018). Tropical evergreen and semi-evergreen forests constitute 74.6% of the total area, followed by moist deciduous forests coverage of 12.7%, eucalyptus 7.1% and grasslands 1.5% of the area (Thomas & Prasanna Kumar 2016). The world-famous Periyar reservoir in the Periyar Tiger Reserve (PTR) is defined as wet evergreen forests, which extend further west into the Pamba basin and south into the forests of the Achankovil Division (Figure 7).

Figure 7. Periyar Tiger Reserve (PTR) (Earth5R 2020)

Figure 8. Keystone & Charismatic species of Periyar River. (Clockwise from top-left) Nilgiri Tahr, Spotted Deer, Mugger crocodile, the Great Hornbill, Bengal Tiger, Indian Rock Python, Asian Tusker Elephant, and Indian King Cobra

Up in the Shola grasslands of the river basin are found endemics like the Nilgiri Tahr (Hemitragus bylocrius) and the endemic orchid Habenaria periyarensis. PTR is also one of the most ecologically diverse regions in India, where the 3800 species of angiosperm plants of Kerala, 1966 are found within the reserve (Latha & Vasudevan 2016). Apart from this, the reserve also contains an estimated 323 species of birds, 38 species of fish, and 44 species of reptiles including the Mugger Crocodile, various species of turtles, Indian Rock Python and the Indian King Cobra. One of the most charismatic animals found in the river basin is the national state bird of Kerala, the Great Oriental Hornbill (Buceros bicornis), a species that has defined many different indigenous and modern cultures (Figure 8).

Periyar is a prime Asian elephant country and large herds are often sighted at the lake fringes. There is an estimated population of 900-1000 animals which likely overlaps with the population in the adjoining forest areas and is very well noted to have a high proportion of large tuskers in comparison to other Indian populations (Latha & Vasudevan 2016).

Thattekad Bird Sanctuary is an evergreen low-land forest located between the branches of Periyar River and is well noted by famous ornithologist Salim Ali's times to be a haven for the Ceylon frogmouth, an endemic bird. The Vembanad lake, into which Periyar drains into along with five major rivers, is a wetland assigned international importance under the definition of the Ramsar Convention for the conservation and sustainable use of wetlands (Figure 9). It is home to more than 20,000 waterfowls, the third-largest such population in India (Latha & Vasudevan 2016).

The river basin is well-known for its fisheries, where a total of 84 fish species are known to occur in the entire course of Periyar many of which are endemic. A high percentage of diet overlap exists between native fish species such as Tor khudree, Gonoproktopterus curmuca, Lepidopygopsis typus, and exotic species like Tilapia (Oreochromis mossambicus) and Common carp (Cyprinus carpio) (Latha & Vasudevan 2016).

Figure 9. Vembanad lake, Kerala (Wallpaperflare 2020)

Threats to the Periyar

The Greater Kochi Area (GKA) ranks 24th (with a Comprehensive Environmental Pollution Index score of 75.08) amongst the critically polluted areas (CPA) in the country (Divya et al. 2011). The lower reaches of the Periyar are heavily polluted due to the industrial discharges in the Eloor industrial zone into the river (George, S, pers. communication, 02 October 2020). The industries located in the lower reaches of Periyar consume 189,343 cubic meters of water from the river on a daily basis and discharge approximately 75% as wastewater, along with a large number of effluents and pollutants (Figure 10). The tail of Periyar has been labeled "a cesspool of toxins", being host to alarmingly high levels of deadly poisons like DDT, Hexa, and trivalent Chromium, Lead, and Cyanide [Sreelakshmi & Chinamma 2018; Earth5R 2020]. The river directly receives civic effluents from the townships of Malayattoor, Kalady, Perumbavoor, Neriamangalam, Aluva and Parur, in which none of these local bodies possess proper sewage treatment facilities. In the case of Cochin Corporation, the sewage treatment system is inadequate and the untreated organic and inorganic refuse is discharged into the river's backwaters (George, S, pers. communication, 02 October 2020).

A major developmental trend in all the rivers within the Western Ghats is the construction of dams. The existing hydroelectric projects such as Idukki and the four proposed projects in the Periyar will cause additional fragmentation and water flow disruption in what is an already significantly fragmented main river, contributing to the significant flooding to primary forests.

Figure 10. Industrial belt (Deccan Chronicle 2019)

Intensive agricultural practices along the river banks and watershed areas have been polluting the river water with huge amounts of pesticides and fertilizers from surface runoff, especially during the monsoon season. In addition, loosening surface soil and removal of vegetation from the catchment area; such as the common practice of sand mining, generates cascading problems related to soil erosion, siltation and landslides. According to an ecological and environmental management report, the quantity of sand that could be extracted safely is 19,178 tonnes annually, but the actual quantity that is being removed is more than 30 times this amount (Pratapan 1999).

Water Quality

Periyar River is one of the most polluted rivers in India. The river receives nearly 260 million litres of effluents per day from the industrial belt through illegal discharge pipes (KSPCB 2014; Stringer, Labunska & Brigden 2003). There are over 250 industries operating along the riverbanks, including prominent names such as Fertilizer and Chemicals Travancore Limited (FACT), Hindustan Insecticide Limited (HIL), Indian Rare Earths Limited, etc (Stringer, Labunska & Brigden 2003; Greenpeace 2003). As development has progressed over the years, Periyar pollution has become the root cause of many social and environmental issues. In the Kerala floods of 2018 – which affected nearly 5 million people – the waste chemicals from the river that had overflowed into the residents and nearby low-lying areas caused additional damage such as corrosion, soil and crop contamination and chemical fungal growth (Earth5R 2020).

Table 3. Test results (Lakshmi & Madhu 2014)

Parameters	Ph	DO mg/l	Cond mS/cm	NO_3-N mg/l	COD mg/l	SO_4 mg/l	Cl mg/l	F mg/l	Phe mg/l	TDS mg/l	Fe mg/l	Ca mg/l	Mg mg/l	TH mg/l
Sample No														
S1	6.2	6.97	4.34	0.33	289.1	3.2	27.08	0.21	0.57	3674.8	0.4	3.2	2.9	17.64
S2	6.0	5.82	10.30	0.56	844.0	39.26	128.0	0.26	0.10	4694.5	0.4	6.4	7.0	46.07
S5	5.8	5.89	0.35	0.67	249.8	10.11	74.33	0.25	0.12	10135.7	1.5	7.0	8.30	76.47
S8	5.9	5.98	122.48	0.46	447.4	47.50	195.3	0.21	0.08	410.6	0.43	10.22	16.5	93.96
S11	5.9	6.35	125.23	0.41	345.6	39.54	232.8	0.28	0.17	368.12	1.51	10.15	14.34	84.71
S14	5.1	3.2	129.3	1.43	380.0	292.98	445.37	0.36	1.07	805.57	2.06	40.88	61.107	3244.5
S15	5.9	4.12	139.73	0.61	321.2	68.84	246.90	0.29	0.53	509.74	1.07	18.16	17.18	110.67
S16	5.9	5.31	142.98	0.763	379.4	184.48	404.43	0.36	0.75	582.23	1.54	10.94	36.50	217.64

According to the water quality assessment conducted by Lakshmi and Madhu (2014), the overall water quality index of the Periyar river was calculated as 24.76 which is categorized as "poor" water class (index value between 0-45). The samples were collected in 16 point locations from both banks and from the middle of the river starting from Edamula upstream to the Eloor Ferry joining the estuary (Table 2) (Lakshmi & Madhu. 2014; Panigrahi & Pattnaik 2019). From the test results shown in Table 3, it could be seen that the water quality index in the downstream area is observed to be even further reduced and the river water showed a slightly acidic nature throughout the sampling points (Lakshmi & Madhu 2014). The discoloration of Periyar water and fish deaths through hypoxia have been a serious issue for the last couple of years. A decrease in dissolved oxygen level has caused fish-kills more than 25 times in the past two years (Deccan Chronicle 2019; Earth5R 2020).

Table 2. Water Quality Index at different sites (Lakshmi & Madhu 2014)

Serial No	Sampling Points	Water Quality Index
S1	Edamula	33.88
S2	Pathalam Bund 1 North	25.72
S5	Pathalam Bund 2 South	27.52
S8	Sudchemi	24.81
S11	Pallikadavu	24.38
S14	Kuzhikandam	19.25
S15	Eloor Ferry (R)	25.75
S16	Eloor Ferry (L)	22.0
Overall water Quality Index		**24.76**

River Management Initiatives

The Periyar River has witnessed frequent incidents of colour change, fish kill, and foul odour along the Eloor-Edayar industrial belt and environmental organizations have long been demanding strict monitoring from the Pollution Control Board (George, S, pers. communication, 02 October 2020). A new display board at FACT Junction helps inform the public in real-time to observe for themselves the parameters of air and water quality in the area (Deccan Chronicle 2019; Earth5R 2020). The Pollution Control Board has sent notices to the companies with directives to install treatment plants or close down the worst offending factories. Ecological and conservation progress has been made, where 'The Total Ecosystem Restoration Project for Periyar' was a project built towards restoring the health of the river via largely conservation actions such as habitat maintenance works, increased wildlife promotions and greater park ranger recruitment. The administration of Kerala along with the district administration have made an advanced pollution monitoring committee along with civic bodies. The committee consists of experts, representatives of local bodies and factories, and NGOs brought together to address the collaborative task of tackling the 'wicked' environmental problems facing the Periyar (George, S, pers. communication, 02 October 2020). Furthermore, the Periyar River Action Plan has been drafted by the Kerala State Pollution Control Board (KSPCB) in order to address the persistent public health issue of Kochi city's extremely poor drinking water quality (Earth5R 2020; George, S, pers. communication, 02 October 2020).

Source: Dreamstime, 2018

EXPERT SPOTLIGHT

Au Shion Yee *Chairperson Asian Development Bank-Staff Council, Philippines*.

Shion is a Senior Water Resources Specialist currently working with the Manila-based Asian Development Bank's (ADB) East Asia Department responsible for leading design, processing and implementing of loan projects and technical assistance programs in the People's Republic of China and Mongolia. He joined ADB in 2015 as the urban and water sector focal point in ADB's Independent Evaluation Department responsible for water sector project and country program evaluations in South Asia, with a focus on Sri Lanka's water and sanitation sector.

"Yangtze River is the Mother River of China and is the largest river system in China. On the one hand, it contains globally significant biodiversity hotspots. But on the other hand, it's also facing a lot of challenges due to the nature of urban development." - Au Shion Yee.

Prior to joining ADB, he worked on a range of water infrastructure policy and strategic planning roles in the Queensland Government and in consultancy, including most recently leading the Asset Efficiency and Optimization program at Seqwater, responsible for strategic asset management planning and policy development for a range of bulk water supply infrastructure in southeast Queensland. He has a PhD in Resource Economics from Central Queensland University, and holds qualifications in Civil Engineering and Business Management from the University of Queensland.

Background

The Yangtze River is the longest river in Asia and the third-longest in the world behind the Nile and the Amazon respectively. It is the home to 400 million people or nearly one-third of China's population and is stretched over 11 provinces and municipalities of Qinghai, Tibet, Sichuan, Yunnan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu and Shanghai, passing through prominent cities of Chengdu, Chongqing, Wuhan, Nanjing, and Shanghai (WWF 2020). The total catchment area is 1.8 × 10^6 square km, comprising one-fifth of China's land territory (Chen et al. 2017). The river originates from Qinghai–Tibet Plateau and runs west to east for approximately 6,300 km and finally concludes into the East China Sea (Figure 12). The river is divided into upper, middle, and lower reaches. The upper stream is home to the famous Three Gorges Dam and runs 4,504 km in length above Yichang with a catchment area of 1 × 10^6 square km; the middle reaches runs between Yichang and Hukou for 955 km and has a catchment area of 6.8 × 10^5 square km, and finally the lower reaches is 938 km in length with a catchment area of 1.2 × 10^5 square km starting from Hukou (Yu & Lu 2005; Wang et al. 2016).

There are more than 10,000 tributaries in the Yangtze River system. Among them, there are 437 rivers, each with a catchment area of more than 1,000 square km, and 22 rivers, each with a catchment area of more than 10,000 square km (Wang et al. 2016). Several large interior lakes, such as Lake Chao Hu and Lake Taihu in association with many tributaries, drain into the reach (Chen et al. 2001) (Figure 11).

The river empties into the East China Sea at the estuary, which is characterized by three bifurcations and four outlets into the sea and a complicated temporal and spatial salinity distribution (Mao et al. 2001)Plateau lakes in the upper basin are mainly freshwater lakes, with some saltwater, whereas lakes in the middle and lower basins are completely absent of any saltwater (Yu & Lu 2005). The mean annual runoff of the Yangtze River is 9.6 × 10^11 cubic m, constituting one-third of the total amount discharged into the sea by Chinese rivers and ranking fourth in the world. The river basin plays a key role in the Chinese cultural development, and the Three Gorges Dam which separates the Sichuan Basin in the west from the lowlands of Eastern China to the east, has shaped significant economic and geomorphological values (Durgham University 2016). Nearly half of China's 55 ethnic minority groups, such as Tibetan, Zhuang, and Qiang people, live along the bed and have long learned to derive a sustainable livelihood from the natural resources of the forest, river, and wetlands (WWF 2020).

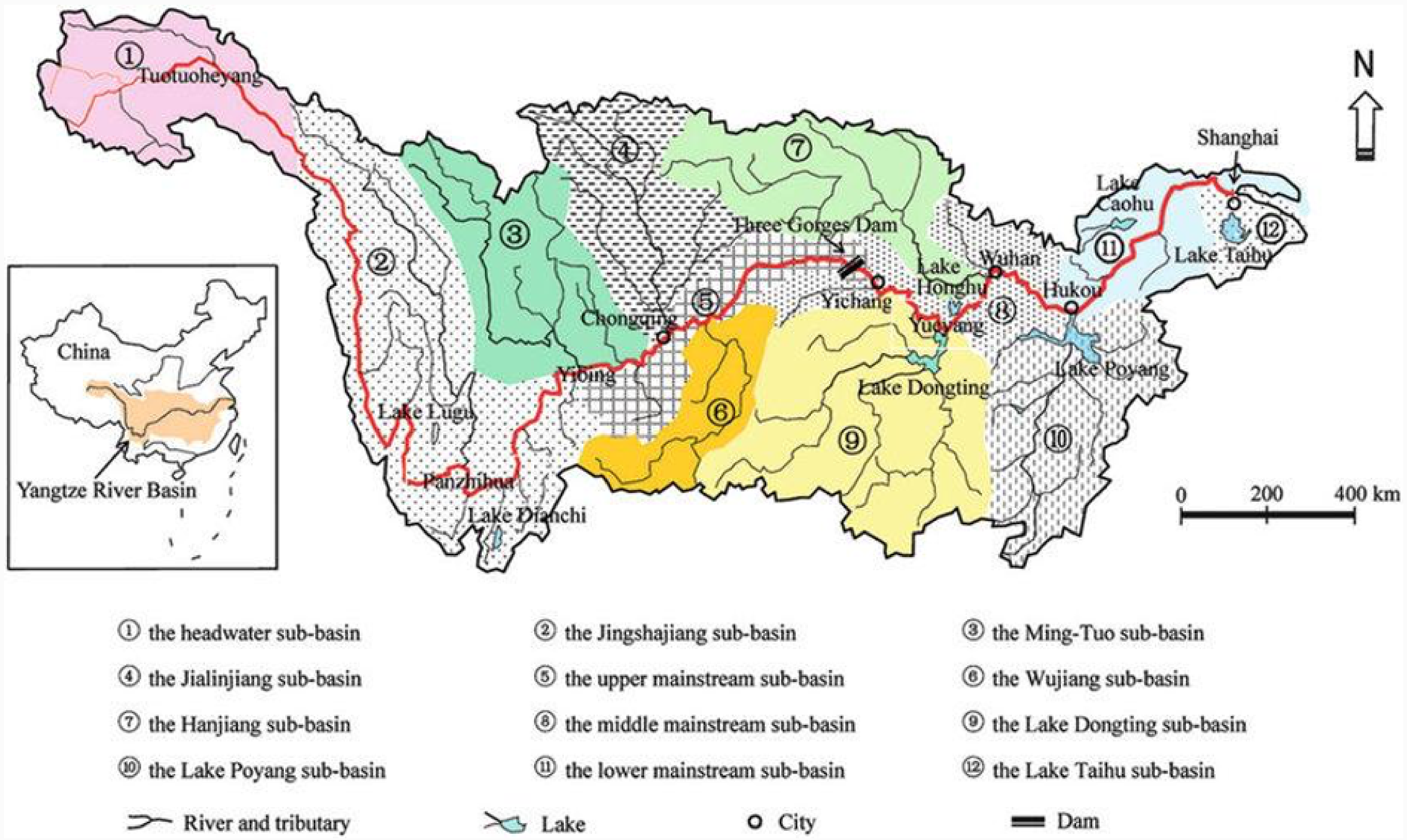


Figure 11. Yangtze river basin (Fu et al. 2005)

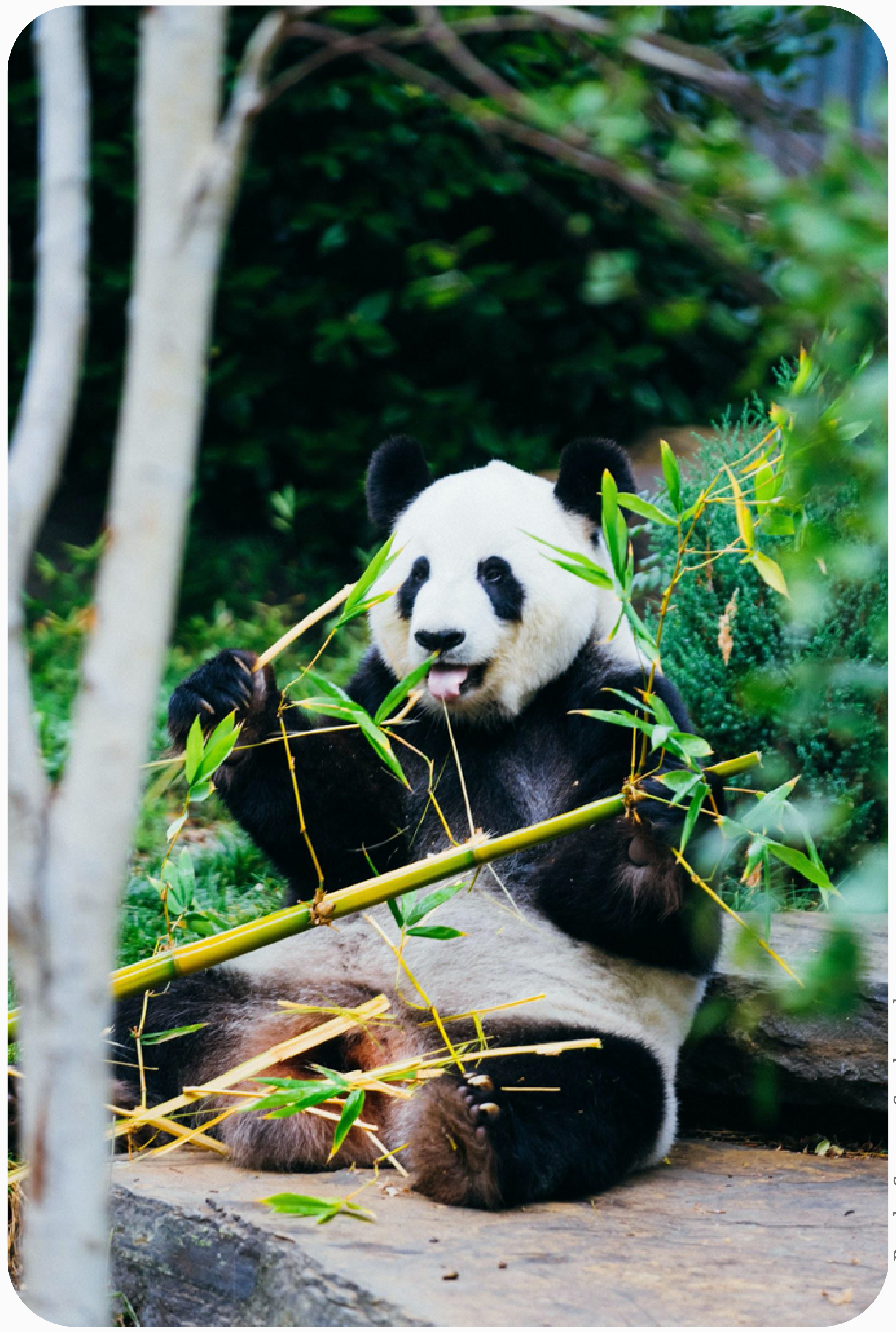
Uses of the River

The Yangtze River is one of the key geographic, ecological, cultural, and economic features of China and for these reasons, it is known as the “Mother of Rivers” (Qu et al. 2015; Zhao et al. 2019). Today, the Yangtze is by far the world's busiest inland waterway for freight transport, shown wherein 2011, the river carried 40 % of the nation's inland waterborne freight (Yang & Wang 2017). According to the China statistical yearbook and China city statistical yearbook, the Yangtze River economic belt’s (YREB) GDP reached 37.3 trillion Yuan in the year 2017 (CWR 2019; Cai & Fangyuan 2020). The Three Gorges Dam was built to be a clean, large scale alternative to coal-fired power stations, where current widespread power shortages caused by bad weather and limited coal supply are underscoring China’s need for more electricity to fuel its fast-growing economy (Yue & Chen 1998).

It is the world's largest capacity hydroelectric power station and was built to provide hydroelectric power, flood control, and greater navigation access to the Yangtze River in central China (López-Pujol & Ren 2009) (Figure 12). The dam has 34 generators: 32 main generators, each with a capacity of 700 MW, and two plant power generators, each with a capacity of 50 MW, making a total capacity of 22,500 MW (Aucker 2009; Yardley 2007). Annual electricity generation in 2015 was 87 TWh, which is 20 times more than the Hoover Dam, USA.

Figure 12. Three Gorges Dam (Gan 2020)

The prosperous Yangtze River Delta is estimated to generate as much as $USD 3.35 trillion, some one-quarter of China's total GDP (Pittock & Xu 2010; EY 2020; Cai & Fangyuan 2020). The agricultural civilization that originated in the Yangtze River Basin is an important part of Chinese historical development. Being one of the world's most famous crop origin centers, the Yangtze River Basin is rich in agricultural innovation, breeding many cultivated plants most notably many species of modern White Rice (Yao & Chen 2018). The Yangtze basin contributes nearly half of China's crop production, including more than two-thirds of the total volume of rice as well as other key crops such as cotton, wheat, barley, corn (maize), beans, and hemp (Yao & Chen 2018; WWF 2020).



Panda, Source: Stocks, n.d.

Biodiversity

The Yangtze region is home to a stunning array of other wildlife (Figure 13), including the elusive Snow Leopard, the iconic Giant Panda and beautiful pheasants in all colors of the rainbow (WWF 2020). With a combination of high nutrients and suitable water-thermal conditions, a unique and diverse biota has evolved in the Yangtze River and its adjoining lakes. The region is known to support 400 waterbird species, 378 species of fish, more than 280 species of mammals, 145 species of amphibians, and 166 species of reptiles (Wang et al. 2016; Huang & Li 2016; WWF 2020). The Central Yangtze River and lakes are also known to be important wintering and stopover sites for large numbers of migratory birds, including an estimated 95 % of the world's Siberian crane population (Zhao et al. 2012).

Only in the forests of the upper Yangtze in Sichuan Province can one find the beloved Giant Panda, which has been WWF‘s symbol since the organisation was formed in 1961 (WWF 2020; Yee, AS, pers. communication, 12 October 2020). The Yangtze finless porpoise, the only creature of this type in the world, lives solely in the middle and lower reaches of the Yangtze River, with a wild population estimated at less than 1000 individuals (WWF 2020).

Unfortunately, during the past several decades, loss of biodiversity in the Yangtze River Basin has been accelerated by a series of direct and indirect effects of human activities and environmental changes, e.g., disappearance, shrinkage, and fragmentation of habitats for fish spawning, feeding, and migration, overfishing, water pollution, and invasion of exotic species (Xie & Chen 1999; Xie et al. 2007; Wang et al. 2016).

Figure 13. Keystone & Charismatic Wildlife species of Yangtze. (Clockwise from top-left) Snow Leopard, Rafetus Softshell Turtle, Baiji Dolphin, Finless Porpoise, Siberia Crane, Chinese Paddlefish, Panda and Chinese Sturgeon

The basin has an ecological problem that includes the functional extinction of critically endangered and mythically important species such as the Yangtze River Dolphin "Baiji" (Lipotes vexillifer), Yangtze Giant Softshell Turtle (Rafetus swinhoei) and Chinese Paddlefish (Psephurus gladius) (Zhang et al. 2020), as well as dramatically reduced populations of endangered Chinese Sturgeon (Acipenser sinensis) and Yangtze finless Porpoise (Neophocaena asiaeorientalis asiaeorientalis) (Chen et al. 2017).

Threats to the Yangtze

Although the above significance of the Yangtze river basin has numerous advantages, its key utilities pose a serious threat to the environment and ecological resilience of the system. The Yangtze (Changjiang) River floodplain is considered to be one of the most important key ecosystems in not only China but the entire world. However, the growing population and rapid economic development along the river basin have posed serious threats to the health of the basin (Figure 14). Over the last 50 years, the human population has more than doubled, leaving a huge impact on the river's health and wellbeing. The economic boom caused by the rapid industrial development and urbanization is taking a huge toll on the biodiversity and ecosystems in this region (Lui & Diamond 2005; Chen et al. 2017; Chen et al. 2016).

Figure 14.Urbanization (WWF 2020)

Figure 15. Overfishing (WWF 2020)

Unsustainable harvesting, such as overfishing (Figure 15), is the most pervasive threat to the Yangtze's fish populations, contributing to the endangerment of 86.2 % of the listed species, followed by habitat loss/degradation (43.1 %), water pollution (30.8 %), and biological invasion (27.7 %) (Yee, AS, pers. communication, 12 October 2020). Damming and other hydraulic constructions have been evaluated to be the most significant threats to natural habitat and ecology (Huang & Li 2016). The embankment construction along the river's main stem has stabilized the river regime resulting in serious channelization. The lake area shrinkage in the Jianghan and Dongtinghu plains in the mid-Yangtze is mainly due to land reclamation and sedimentation. During the period between the 1930s and 2000s, the lake area has been gradually reduced in increments (Du et al. 2011; CWRC 1999; Wei et al. 2007).

Degradation of lakeshores has resulted in the deterioration of aquatic and terrestrial vegetation along shorelines, the diminution of capabilities to intercept external pollution and loss of lake-ecosystem integrity (Wang et al. 2016). Another major threat since the 1980s is the gradual increase of unauthorized sand mining. Concurrently, ship traffic increased into the thousands of vessels that impose negative effects on the river floodplain ecosystem species (Wang et al. 2016). A gradual increase in the discharge of wastewater and sewage in the Yangtze River basin has been seen since the 1970s from 9.5 x 10^9 mt/year to 4.4 × 10^10 mt/year in 2012 (MWR 2004-2013).

Water Quality

As stated above, the basin supports one-third of the country's population and acts as a key economic source for the country (Yee, AS, pers. communication, 12 October 2020). Because of population and economic demands, there is a huge pressure on the river basin in terms of wastewater discharge (Dudgeon 2010; Huang & Li 2016) as nearly half of China's wastewater discharge is being received by the Yangtze. Another major pressure is caused by the point-source discharge of sewage and industrial waste (which measures nearly 4 times-fold the global average), this is compounded by nitrogen runoff along with phosphorus and pesticides from agricultural development (Xue et al. 2008; Lui & Diamond 2005). According to the Chinese Ministry of Environmental Protection (MEP 2017) annual reports, the river basin's water quality has been deteriorating gradually over the past years, especially in the lower Yangtze region and in smaller tributaries (Xue et al. 2008). Overall, the MEP annual report (2017) shows that among all the 510 water sections under the national monitoring program, 2.2% met Grade I standard, 44.3% met Grade II standard; 38.0% met Grad III standard; 10.2% met Grade IV standard; 3.1% met Grade V and 2.2% were inferior to Grade V standard (Table 4). Compared with that of MEP (2016), the percentage of water sections meeting Grade I was down by 0.5 percentage point; Grade II down by 9.2 percentage points; Grade III up by 11.9 percentage points; Grade IV up by 0.6 percentage point; Grade V down by 1.4 percentage points and those inferior to Grade V down by 1.3 percentage points (MEP 2017).

Table 4. Average concentration of Primary Pollutants in Yangtze river in 2017 (MEP 2017)

Region	Indicator	Average concentration (CO: mg/m^3, others: $\mu g/m^3$)	Increase from 2016 (%)
The Yangtze River Delta	$PM_{2.5}$	44	-4.3
	PM_{10}	71	-5.3
	O_3	170	6.9
	SO_2	14	-17.6
	NO_2	37	2.8
	CO	1.3	-13.3
Shanghai	$PM_{2.5}$	39	-13.3
	PM_{10}	55	-6.8
	O_3	181	10.4
	SO_2	12	-20.0
	NO_2	44	2.3
	CO	1.2	-7.7

The water quality problems in the river drainage include: (a) nitrogen and phosphorous (nutrients) which drives the eutrophication linked issues such as harmful algal blooms; (b) biodegradable organic pollutants including chemical oxygen demand; (c) heavy metals such as Copper, Zinc, Lead, Arsenic and others; (d) persistent organic pollutants (POPs), which include pesticides and polychlorinated biphenyls (PCBs); and (e) pharmaceuticals and personal care products, such as antibiotics (Chen et al. 2017; MEP 2016). These water quality problems are severe in both the Yangtze River mainstem (e.g., below Hukou) and associated lake areas (e.g., Taihu Lake) throughout the lower reaches. From a basin-wide perspective, smaller tributaries have more severe water quality deteriorations because of their limited flows and closer proximities to pollution sources (MEP 2017). Due to higher flows and volumes, water quality in most reaches of the Yangtze River mainstem exceeds the national criteria and standards, despite this the total wastewater discharge to the river has continued to increase and water quality and biodiversity are under increasing pressure (Chen et al. 2017).

River Management Initiatives

In light of the serious challenges presented by industrialisation such as environmental pollution and ecosystem degradation, the Chinese government has been advocating and working to advance ecological civilisation (Yee, AS, pers. Communication 12 October 2020), which draws upon the ancient Chinese notion of "unity of nature and man" and "follow nature's course". The philosophy of ecological civilisation was enshrined in the year 2018 and was embedded in the master blueprint of national development in China. In the year 2010, the China National Biodiversity Conservation Strategy and Action Plan (2011-2030) was formulated to prioritize the actions for biodiversity conservation. Since 2015, China has conducted wildlife surveys and monitoring through major biodiversity conservation projects, logging more than 2.1 million entries (PRC 2020). Between 2009 and 2019, China asserts that it topped the world in forest resource increase with a total of 71.307 million hectares of land afforested. This work is complemented by satellite data that showed a significant increase in the green space between 2000 and 2017. China is the largest contributor to the greening of the global landscape and has continued to step up oversight and investigation of illegal activities such as overfishing. Starting on January 1, 2021, a ten-year fishing ban will be imposed on the mainstream and key tributaries of the Yangtze River as well as major lakes connected to it to provide time and space for the rehabilitation of its ecosystem, hence protecting the gene bank of biodiversity (PRC 2020).

Both the 12th Five-Year Plan (2011-2015) and the 13th Five-Year Plan (2016-2020) identify the further development, application, and monitoring of eco-compensation as a high priority to achieving the broader “ecological civilization” agenda goal (Lopez 2017).

The Yangtze River (YR) Masterplan framework is an Asian Development Bank (ADB) assisted framework for the PRC’s YREB is key to helping the country achieve its goals of inclusive and sustainable growth. It outlines a comprehensive cross-sector approach to address complex socio-ecological challenges across the basin with water quality being one of the key areas that are targeted (Yee, AS, pers. Communication, 12 October 2020). The plan identifies targets relating to water quality, forest cover, and other factors that need to be addressed within a specific timeframe. Under the overall masterplan, individual provinces need to work at the local level through programs and initiatives towards achieving the basin targets (Yee, AS, pers. Communication 12 October, 2020).

EXPERT SPOTLIGHT

Paul Gallay *Hudson Riverkeeper, Lecturer for Earth Institute at Columbia University*

Paul Gallay is the Hudson Riverkeeper and President of the Riverkeeper Organisation. An attorney and educator, Paul has dedicated himself to the environmental movement since 1987 when he left the private practice of law and went to work for the New York State Attorney General. In 1990, Paul began a ten-year stint at New York's Department of Environmental Conservation, where he brought hundreds of corporate and government polluters to justice. As the Hudson Riverkeeper, Paul has successfully helped drive $2.9 billion US dollars in infrastructure funding and new controls on toxins in drinking water. The Riverkeeper Organisation has been a success story for environmental conservation, partnering with more than 120 stakeholders. In addition, Paul is also a respected and beloved lecturer at Columbia University.

"Our job is to make sure we foster a returning respect for the natural world, as there is a thriving ecosystem that needs our help"

– Paul Gallay, Hudson Riverkeeper

Waterkeeper Alliance is growing exponentially with more than 350 Waterkeeper Organizations and Affiliates already patrolling and protecting waterways in 48 countries, on 6 continents. The Waterkeeper movement is the largest and fastest-growing non-profit solely focused on water. The Waterkeeper Alliance has critically assessed and developed a strategic business plan for the next 20 years, the organisation's main aim is to have a community-based Waterkeepers safeguarding every waterway in the world.

Mary-Beth Postman *Waterkeeper Alliance, Deputy Director and Secretary to the Board of Directors*

Mary-Beth Postman plays an important role in the formation of the Waterkeeper Alliance and currently serves as the Deputy Director and Secretary to the Board of Directors at the Waterkeeper Alliance. Mary-Beth has fought and advocated for local communities globally to protect and preserve the quality of life for over 25 years.

Marc Yaggi *Waterkeeper Alliance, Executive Director*

Marc Yaggi is the Executive Director of the Waterkeeper Alliance. Marc has dedicated his entire career to environmental advocacy and has been instrumental in expanding the Waterkeeper movement around the world for nearly 20 years.

Source: Carson Vara/Unsplash

Background

The Hudson River was named after Henry Hudson, who accidentally discovered the river in 1609 whilst finding a short route to India from Europe. At that time, there were approximately 10,000 Native Americans residing on both sides of the river. The tribes were part of the Algonquin Confederacy which included the Delaware, Mohican (aka Mohegan) and Wappinger Tribes (Riverkeeper, n.d.). Before the 16th century, the Native American Tribe, Lenape, named the river Mahicantuck (muh-he-kun-ne-tuk) which means “the river that flows two ways” (Henshaw, 2011). Hudson River is not just like any other river as it is a unique tidal estuary where saltwater from the ocean combines with freshwater from the northern tributaries (Riverkeeper, n.d.).

The vast majority of the Hudson River is located in New York State, United States, with the exception being its final segment, where it forms the boundary between New York and New Jersey for 21 miles (34 km). The Hudson originates in several small postglacial lakes in the Adirondack Mountains near Mount Marcy (5,344 feet [1,629 metres]), the highest point in New York, and flows 315 miles (507 km) through the eastern part of the state (Figure 16) (Henshaw, 2011). Lake Tear of the Clouds is regarded as the source of its main headstream, the Opalescent River (Henshaw, 2011; Riverkeeper, n.d.).

Figure 16 Hudson River Basin (Britannica, n.d.)

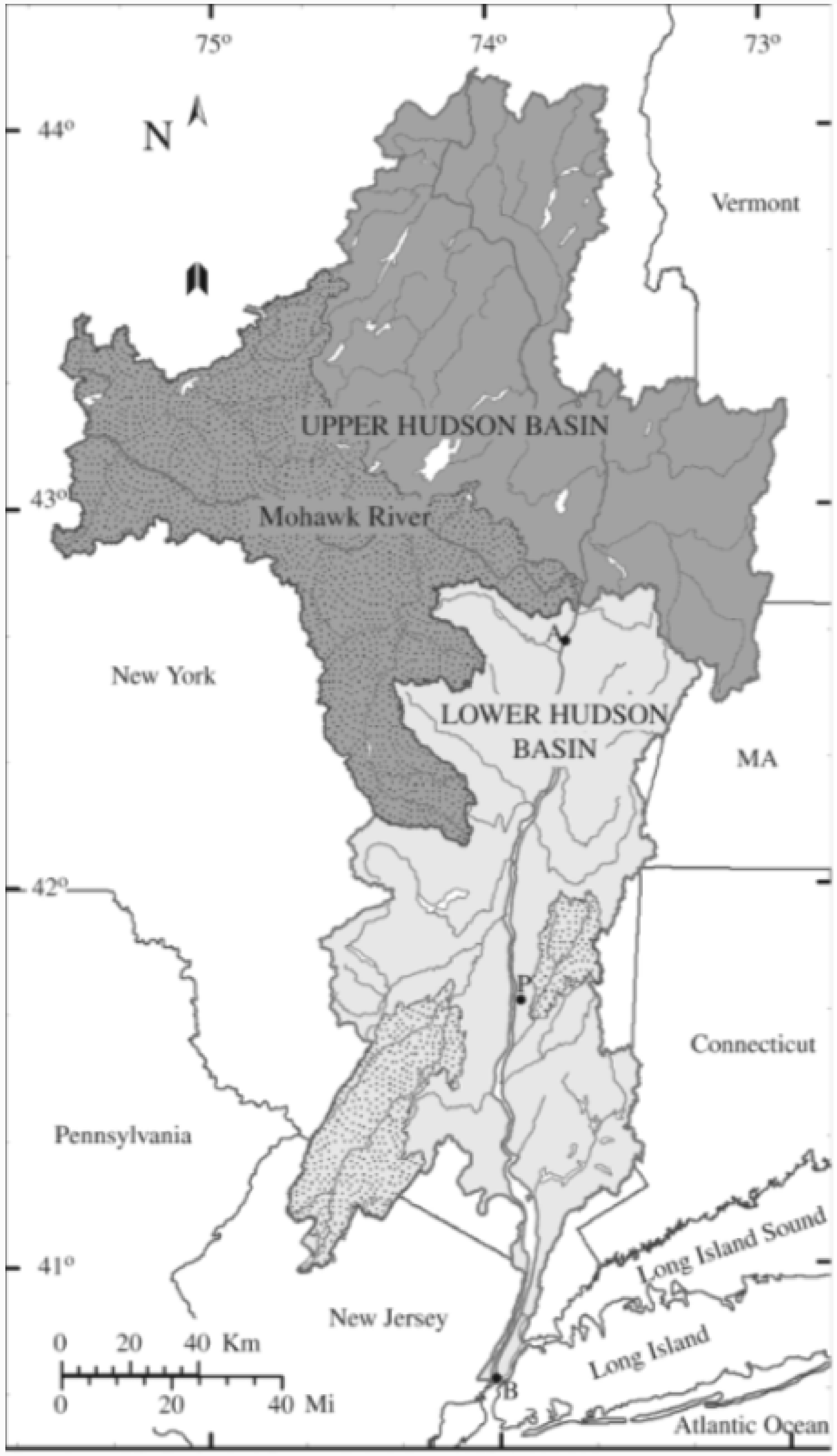


Figure 17 Watershed of the Hudson River Basin (Henshaw, 2011)

The Hudson is usually divided into two main segments: Upper Hudson and Lower Hudson (Figure 17) (Henshaw, 2011). Originating from the mountains and flowing downwards towards the sea, the Hudson hosts more than 60 tributaries, the most notable being the Mohawk River (Riverkeeper, n.d.). The lower Hudson is mainly a tidal estuary, meaning it ebbs and flows with the ocean tide, it supports a biologically rich environment, making it an important ecosystem for various species of both saltwater and freshwater aquatic life. For many key species, it provides critical habitats and essential spawning and breeding grounds (Riverkeeper, n.d.).

Uses of the River

For thirteen thousand years, Native American tribes have lived along the Hudson River; Lenape in the southern and coastal portion, and Mahicans north of the Hudson Highlands. These tribes mainly fished the water, hunted in the nearby forests and created river-related cultures (Henshaw, 2011). The European settlers mainly utilised the river and its catchment for fur trade, land clearance for homestead and pastures, and keeping of cattle (Henshaw, 2011).

Through the decades, the Hudson River was used for transportation and this led to industrial development such as textile, lumber mills, automobile industries in the Hudson basin (Harmon, 2004). With more than a hundred industries being developed in the Hudson river basin, the nearby towns began to evolve and give rise to the mega-city of New York with a core city population of more than 8 million and a metro population of over 19 million (Taillie et. al., 2019). To support the growing population, the Hudson River has been utilised for drinking water and recreational purposes such as swimming, boating and recreational fishing (Brooks et al., 2019; New York State Department of Environmental Conservation [NYS DEC], n.d.). Nearly 60 % of the water supplied in the basin is for commercial or industrial use. Several reservoirs within the Hudson river basin contribute to the New York City water-supply system, which supplies water for its population (United States Geological Survey [USGS], 1992). It is estimated the Hudson River Estuary also brings in about $USD 4.4 billion in tourism economy to the United States of America (USA) (Riverkeeper, 2017).

The Hudson river basin currently supports major construction, manufacturing, transportation, healthcare, power and automobile industries. However, due to the presence and abundance of such industries, polychlorinated biphenyls (PCBs) and other toxic contaminants that have been constantly dumped into the river, treating the Hudson River as the ‘region’s sewer’ (NYS DEC, n.d.; New York State Department of Labour, 2019; Riverkeeper, n.d.). New York State is currently undergoing restoration efforts to ensure that the water in the river and its tributaries can be used as source waters for drinking water and are safe to support water recreational activities (Brooks et al., 2019).

Source: Hudson River Foundation, n.d.

Biodiversity

The river basin homes an immensely rich array of biodiversity (Figure 18); Of New York State's total species, 87% of birds are present in the basin, 85% of the state's amphibian population, 73% of its reptiles, and 92% of its mammals (NYS DEC, 2015). The Hudson River and its watershed is home to 221 species of fish. As stated by the Hudson Riverkeeper, Paul Gallay, the Atlantic Sturgeon (Acipenser oxyrhynchus oxyrhynchus) and Short-nose Sturgeon (Acipenser brevirostrum) are the major keystone species of the Hudson River, with the Atlantic Sturgeon serving as the mascot for the Global Waterkeeper Alliance. The sturgeon is also considered the most speciose group of 'living fossil' fishes but their population has been depleting from the world (Bemis et al., 1997).

The majority of the Atlantic Sturgeon population in the world is found in the Hudson, young Atlantic Sturgeon became scarce from the later 1980s through the mid-1990s due to overfishing for caviar and meat (NYS DEC, 2015). Currently, the Atlantic Sturgeon has been listed as 'Critically Endangered' in the International Union for Conservation of Nature (IUCN) Red List. However, the State of New York and Not-For-Profit organisations like the Riverkeeper and Waterkeeper Alliance have taken initiatives to stop overfishing and help conserve the sturgeon population in the Hudson River. Sturgeons born after the fisheries closed have started to spawn and there have been more sightings of young sturgeons since (NYS DEC, 2015; Milman, 2019).

Figure 18 Biodiversity of Hudson River. (Clockwise from top-right: Bald Eagle, American Black Bear, River Otter (top), American Beaver (bottom), Moose (top), Striped Bass (bottom), Peregrine Falcon (top), Ospreys (bottom), Atlantic Sturgeon)

Striped bass (Morone saxatilis), another keystone species to the Hudson River that is most popular amongst anglers, has been depleting in population. Annual monitoring conducted by the Department of Environment and Conservation has revealed below-average production of young striped bass in recent years. However, due to pressure from environmental organisations, the State of New York has implemented tighter fishing regulations and ‘Catch-and-Release’ Fishing in Upper and Lower Hudson (NYS DEC, 2015; NYS DEC, 2020). Riverkeeper Organisation has worked on removal of out-dated dams and industries, this has helped with spawning habitat and increasing the dimensioning of fish species population (P. Gallay 2020, pers. Comm. 7 October).

The Hudson is home to many bird species as well, the Bald Eagle (Haliaeetus leucocephalus) known as the National Bird of The United States of America, can be frequently sighted along the river basin (NYS DEC, 2015). Peregrine Falcon (Falco peregrinus) and Ospreys (Pandion haliaetus) have started to nest on the river bridges and have been sighted more frequently in recent years (NYS DEC, 2015; NYS DEC, 2020). Around New York harbor, herons (Ardeidae) and ibises (Threskiornithinae) have become a star attraction during ecotours (NYS DEC, 2015). In addition, the Hudson Valley hosts the two distinct megafauna species of Moose and American Black Bear. Moose play a critical part in shaping the vegetative landscape and the Black Bear serves as the Hudson ecosystem’s top terrestrial predator (Quigley & Hornocker 2001). The Hudson’s river systems and tributaries are also home to the North American River Otter and Beaver, who both play a significant role in ecosystem maintenance through predation and dam building respectively (Quigley & Hornocker 2001, NYS DEC, 2020).

Threats to the Hudson

Over 100 years, the Hudson River has been used for multiple purposes to benefit the human population and industrial pollution has been one of the major reasons for the depletion of the river’s health. For nearly 30 years ending in the late 1970s, the General Electric Company (GE) discharged approximately 1.3 million pounds (590,000 kilograms) of polychlorinated biphenyls (PCBs) into the Hudson River (United States Environmental Protection Agency [US EPA], 2016). PCBs have remained in river sediments and their presence has been found to be extremely harmful by causing depletion of fish species, as well as being a probable cause of cancer in humans (US EPA, 2016).

The rise in sea-levels due to climate change has been a threat to the Hudson River and the habitats surrounding it. The highest water level ever recorded was more than 11 feet (3.35 meters) above the mean sea level during Superstorm Sandy in 2012 (NYS DEC, 2015). In addition to the destruction, the storm surge continued up the Hudson, wreaking havoc in low-lying communities. Another issue caused by climate change is the increase in temperature and warming of the river. In July 2011, the river reached a temperature of 30 degrees Celsius, a new unprecedented high; a longer record at Poughkeepsie’s water treatment plant also shows a clear trend of rising water temperatures (Figure 19) (NYS DEC, 2015). Climate change effects on the Hudson River have been destructive to the human population surrounding it and harmful to the aquatic population residing within.

Water Quality

The toxic industrial pollution, urban/stormwater runoff, sewage discharges and climate have been the major threats to the Hudson River. Human influence and activities have been pervasive, causing further depletion and degradation of the river. The Hudson estuary is typically cloudy with sediment eroded from the watershed and lifted off the bottom of tidal currents (NYS DEC, 2015). This turbidity can be exacerbated by dredging, boat traffic, and runoff from bare cropland and construction sites. High turbidity in the Hudson River denotes lower concentrations of dissolved oxygen, as less sunlight is available for photosynthesis by aquatic habitats, causing degradation to its aquatic life (NYS DEC, 2015).

A recent water quality study by the Riverkeeper Organisation, Columbia University New York, Queens College and Columbia University's Lamont-Doherty Earth Observatory found that although the Hudson River is safe for swimming at most locations, overflows of sewage water and remains of toxic contaminants make the water unsafe (Riverkeeper, 2017).

The main criteria set by EPA (part of the Clean Water Act[CWA]) is monitoring Entero (Enterococcus), a group of fecal indicator bacteria or fecal and total coliform, to ensure the Hudson River was safe for recreational purposes. With Entero as an indicator, three ways to measure water quality were determined: Beach Action Value (BAV), Geometric Value (GV) and Statistical Threshold Value (STV) (Appendix 3) (Brooks et al., 2019;

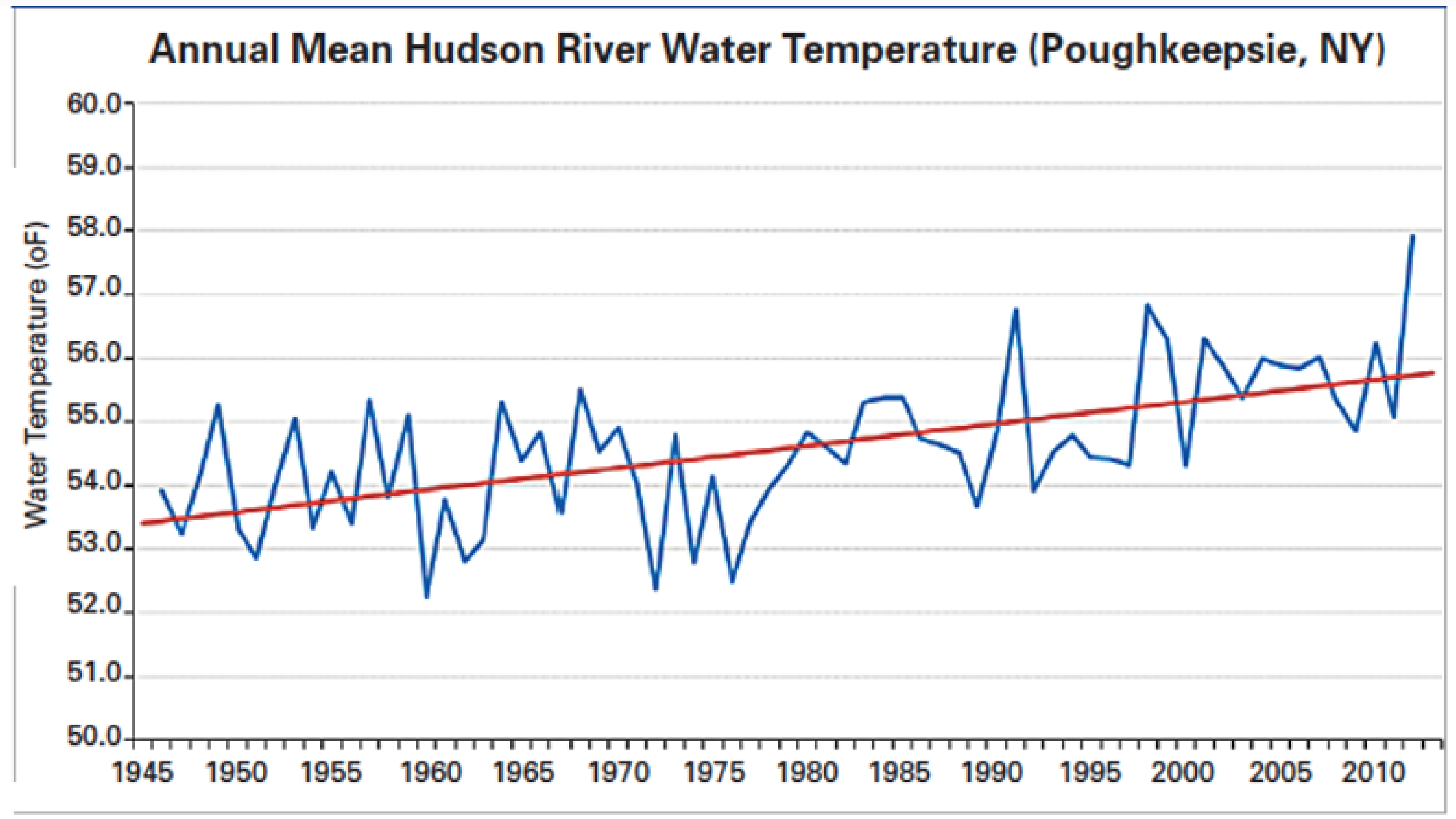


Figure 19 Annual Mean Hudson River Water Temperature at Poughkeepsie, NY. Data compiled by David Seekell et al., 2011 (NYS DEC, 2015)

Other serious issues threatening the health of the Hudson are sewer overflows and stormwater runoff. During rainstorms, the combined sewer overflow (CSO) exceeds the capacity of the receiving treatment plant, causing the untreated sewage water to flow into the Hudson River, damaging the fish population and degrading the water quality (NYS DEC, 2015). From New York City's total land area of 300 sq.m., substantial amounts of stormwater runoff from the city's impervious pavements end up in the Hudson. Stormwater runoff in the Hudson River has resulted in increased loadings of sediment, nutrients and salt to the river's tributaries, and led to unstable stream channels, erosion and degraded habitat (NYS DEC, 2015).

Riverkeeper, 2017). The Riverkeeper study indicated that the water quality of the river was best in the Mid channel, away from the shore, the water quality near the city and village waterfronts were affected by street runoff and sewer overflows, and the most polluted water was found in the tributaries, mainly due to rain and increase in CSOs (Riverkeeper, 2019).

A study carried out by Taillie et al. (2019), used five indicators throughout the New York Harbour including total nitrogen (TN), total phosphorus (TP), dissolved oxygen (DO), chlorophyll a (Chla) and water clarity (Secchi disk depth). The study indicated the Hudson River and its tributaries had intermediate water quality, however, high nutrient levels (TN and TP) were found throughout but water clarity, DO and Chla were variable (Figure 20).

Organisations such as Riverkeeper and Waterkeeper Alliance with dozens of their partners have achieved remarkable achievements in improving the quality of water by carrying out research projects and advocating for the river. However, to improve water quality, action needs to be taken by federal, state and local levels to increase and prioritise infrastructure investments (Riverkeeper, 2017).

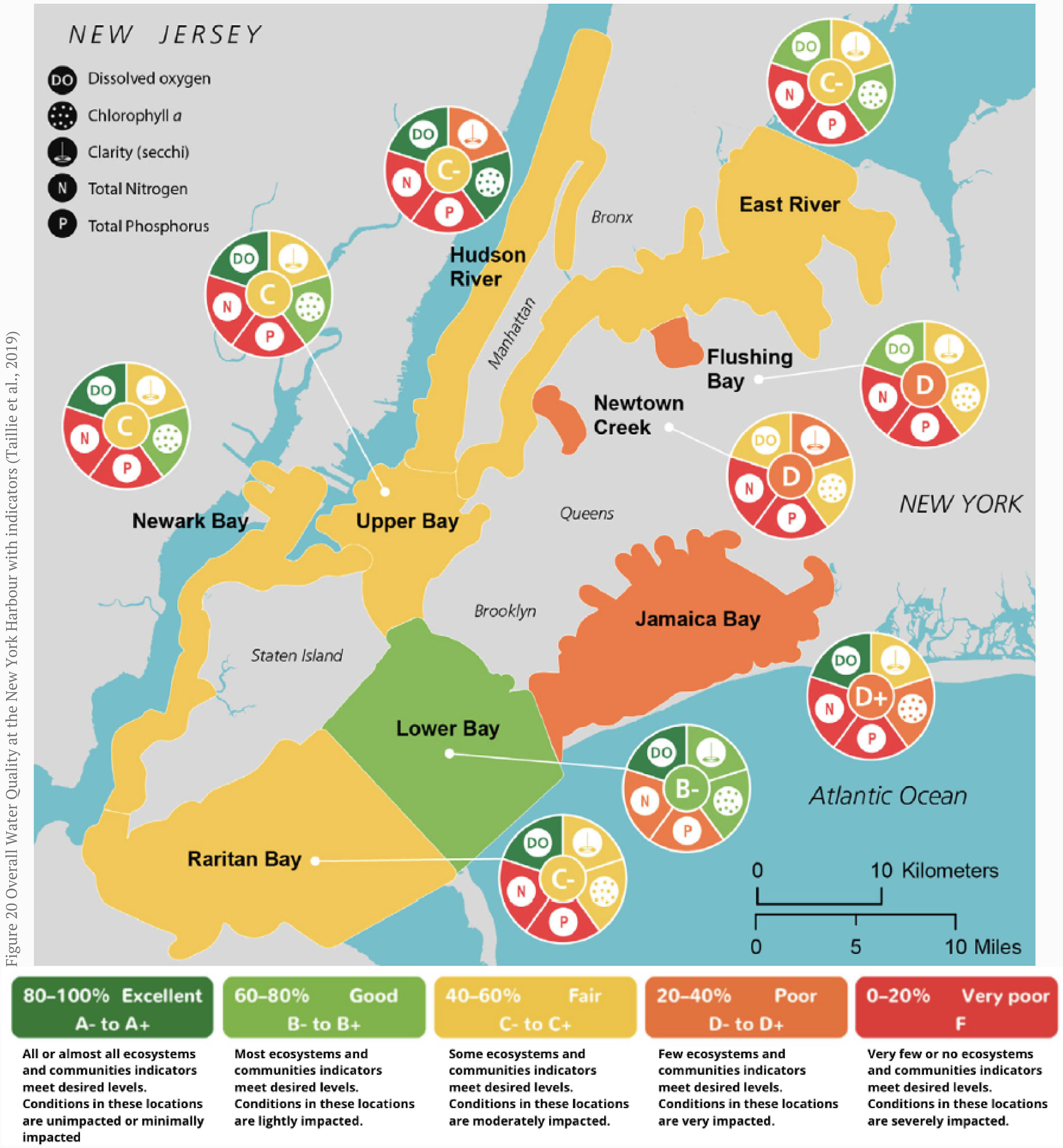


Figure 20 Overall Water Quality at the New York Harbour with indicators (Taillie et al., 2019)

River Management Initiatives

Humans have been affecting the Hudson River's natural resources for nearly four centuries, with the most profound human influences occurring during the last 150 years at the start of industrialisation. The Pure Waters Bond Act passed by New York State voters in 1965 and the federal Clean Water Act (CWA) of 1972 were significant milestones in cleaning up a river that in many places was little more than an open sewer. Since then, the Hudson has become a regional asset, with its waters attractive to boaters, anglers, and swimmers as well as to fish, birds, and wildlife. Meanwhile, the Hudson River Fishermen's Association (HRFA) was formed in March 1966 as an organisation to track down polluters and bring them to justice. The HRFA continued to fight for the protection of the Hudson under the CWA and finally, in 1986 the HRFA and Riverkeeper aligned under the Riverkeeper name to continue their advocacy for the river. In 2015, The federal Microbead-Free Waters Act was established to protect water quality for people and animals by banning cosmetics that contain synthetic plastic microbeads that are a source of pollution and accumulate toxins.

Paul Gallay has also stated that the Riverkeeper Organisation and Waterkeeper Alliance along with their stakeholders have successfully won the lawsuit against Indian Point, a three-unit nuclear power station, saving 1.2 billion fish larvae which would be lost from normally from water harvesting used to cool the reactors. In spite of these successes, significant threats and problems remain.

The Department of Conservation, New York State, established the Hudson River Estuary Action Agenda (2015-2020) that was created by the Hudson River Estuary Program which aims to clean water, build resilient communities and vital estuary ecosystems. The Riverkeeper Organisation along with the Waterkeeper Alliance has continued to advocate and develop river management strategies to protect the Hudson.

Source: Riverkeeper Org., n.d.

HAWKESBURY NEPEAN

EXPERT SPOTLIGHT

Sue Martin *President & Public Officer for Australian Association for Environmental Education: NSW, Hawkesbury-Nepean Riverkeeping Advocate*

Sue Martin is an accomplished education professional, passionate about the environment and engaging communities. She has driven engagement and dialogue for various communities within local government, schools and natural resource management sectors. She also has experience for more than a decade as a Sustainability Learning Officer at St Ignatius College and EcoLearn Consulting at Kenthurst. Sue has been the National Director at Catholic Earthcare Australia, promoting dialogue, education, advocacy and action for ecological conversion and care, and is a trained Climate Reality Leader and Presenter for Climate Project Australia.

Sue strongly believes "*change starts locally*", she chairs the Cattai Hills Environment Network and is the President of the New South Wales Chapter of the Environmental Education Professional Association. She is currently working as an Ecology Project Officer and aiming to build a 'Hawkesbury-Nepean River Waterkeeper Alliance' in association with the Global Waterkeeper Alliance and support from local, state agencies and the federal government.

Sue envisions that the establishment of the Hawkesbury River Waterkeeper Alliance (HRWA), would provide a platform for the community to voice their concerns about development projects threatening the river health of the Hawkesbury-Nepean River Catchment (HNRC). which would align the interests of the stakeholders involved in the protection of HNRC.

Background

The Hawkesbury-Nepean River (HNR) is one of the most important river systems in Australian state of New South Wales (NSW) with a catchment area of more than 22,000 sq. kilometres, making it one of the largest coastal basins in NSW (NSW Department of Environment, Climate Change & Water [NSWDECCW], 2010; NSW Department of Planning, Industry and Environment, 2018). The catchment includes the coastal reaches from Turimetta Headland to Barrenjoey near its mouth, and catchments for Warragamba, the Upper Nepean and the Mangrove Creek dams serve as the main water-supply reservoirs for the Sydney metropolitan area (Figure 21) (DPIE, 2018)

The river system flows from south of Goulburn to Broken Bay, approximately 480 kilometres in distance which makes it the longest coastal catchment in NSW (Western Sydney University [WSU], 2017). The Hawkesbury-Nepean River System is a combination of two major rivers, the Nepean (178 km) and the Hawkesbury River (126 km) along with major tributaries including Avon, Cataract, Colo, Cordeaux, Coxs, Grose, McDonald, Wollondilly, Warragamba and Wingecarribee rivers (Figure 21) (NSW Government, 2010; DPIE, 2018). There are a significant number of creeks that are a part of the Hawkesbury-Nepean Catchment including Berowra, Bundanoon, Cascade, Cattai, Cowan, Mangrove, Sooley, South and Mooni Mooni creeks (DPIE, 2018)

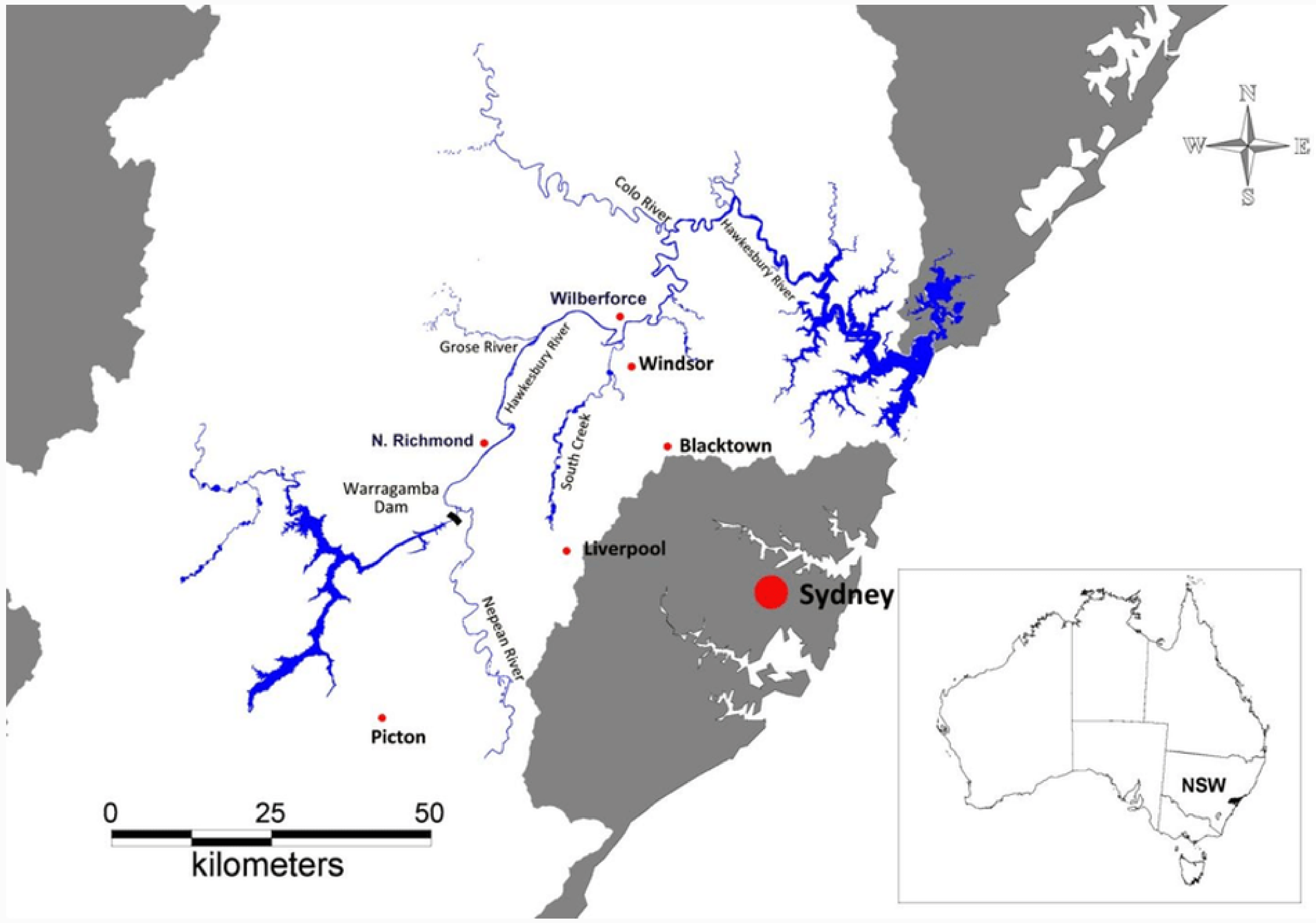


Figure 21 Hawkesbury - Nepean River Catchment (Pinto & Maheshwari, 2015)

The Hawkesbury-Nepean catchment has been a major source for drinking water, irrigation and agricultural uses to support the population of Sydney. However, the growing population and human settlement have caused degradation to the river's health (WSU, 2017). While the basin is considered unregulated, the catchment is heavily controlled by five major dams and various major weirs which retain the river flows for anthropogenic uses and activities (DPIE, 2018). These major water storages and reservoirs include Warragamba, Mangrove Creek, Nepean, Lyell, Avon, Cataract and Cordeaux (Figure 22) (DPIE, 2018).

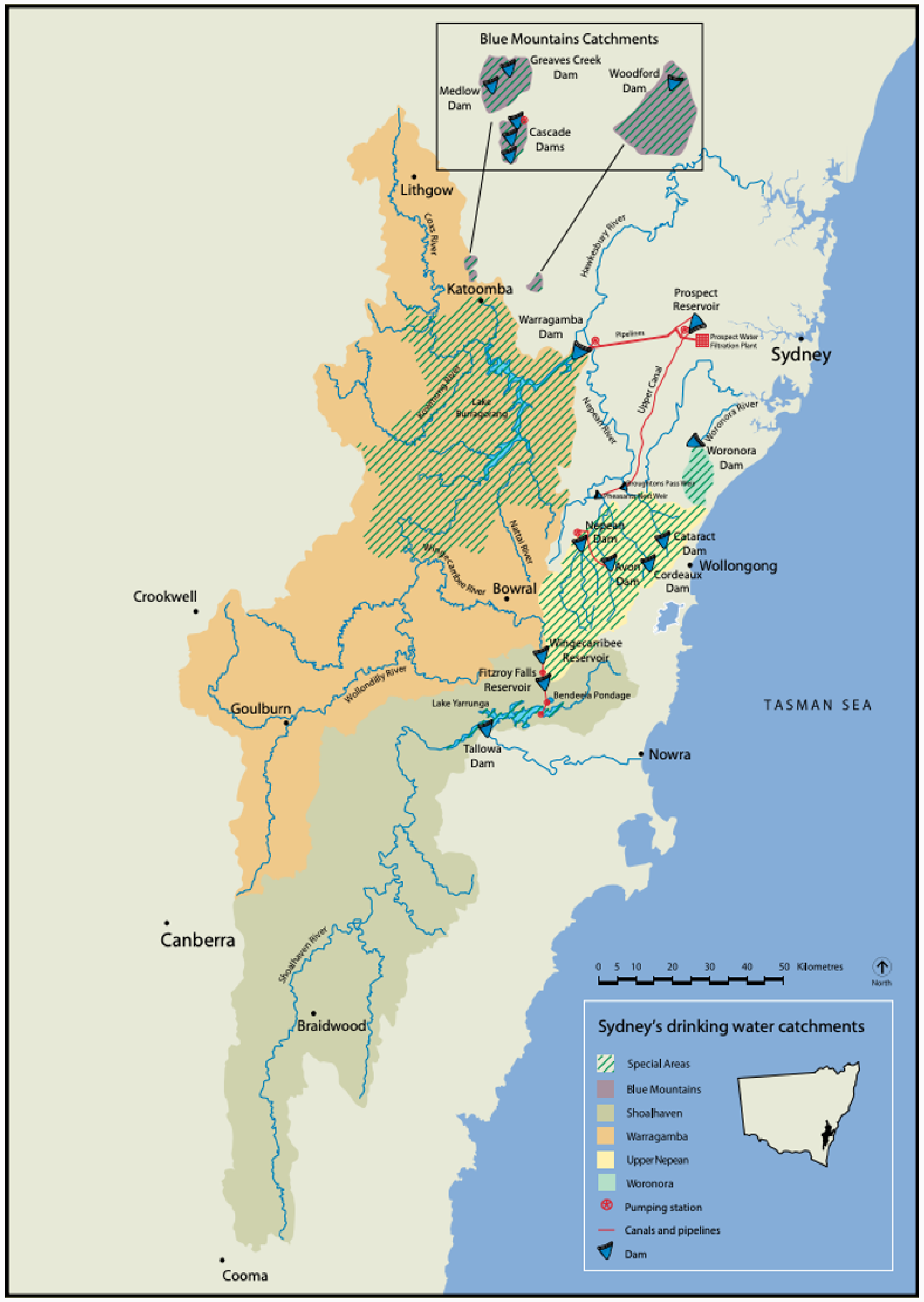


Figure 22 Hawkesbury - Nepean Water Catchments and Dams (Water NSW, 2015)

Uses of the River

The traditional name in the Aboriginal Dharug Language for the Hawkesbury River was published as “Deerubbun” in 1870. The two main Aboriginal tribes inhabiting the HNR Catchments were the Wannungine of the coastal area on the lower reaches (below Mangrove Creek) and the Darkinung people, whose lands are extensive on the lower Hawkesbury to Mangrove Creek, upper Hawkesbury, inland Hunter and lower Blue Mountains (Attenbrow, 2002; 2010). The land adjacent to the Hawkesbury River was occupied for many thousands of years by the Darkinjung, Dharug/Darug, Eora, and Kuringgal Aboriginal peoples who used the river as an important source of food and a place for trade (Attenbrow, 2002; 2010).

The Dharug tribe are the traditional custodians of the land on the south bank of the Hawkesbury River. The river and its nearby lagoons were a focal point for communities to collect food such as fish, eels, shellfish and water birds (Attenbrow, 2002; 2010). The Dharug people also grew vegetables along the riverbanks throughout the year. The surrounding bushlands were places where the Dharug hunted and trapped animals (Attenbrow, 2002; 2010).

The Hawkesbury-Nepean River Catchment was also one of the first areas chosen for settlement by the early European settlers in late 1700s in Australia and since then it has been relied upon to meet the needs of the growing population (Pinto & Maheshwari, 2015). Depending on boundaries, the catchment is estimated to provide 97% of the fresh drinking water for more than 5.3 million people living in the Greater Sydney region (WSU, 2017).

The Sydney Water Corporation are the major users of the HNR catchments along with the local councils of Hornsby, The Hills, Northern Beaches, Hawkesbury, Ku-ring-gai, Central Coast (DPIE, n.d.). The land use in HNR catchment includes heavily peri-urbanised and industrialised areas, as the catchment is primarily used for its recreational, tourism and agricultural activities (Pinto & Maheshwari, 2015; Baginska et al., 2003). The catchment attracts more than 10 million visitors annually, generating over $60 million annually in tourism and recreation (Hawkesbury Nepean Catchment Management Authority [HNCMA], 2007).

The HNR system supports a $259 million agriculture industry as well as the aquaculture industry that provides Sydney’s population with fresh produce all year round (WSU, 2017). In addition, the HNR also supports extensive underground mining, manufacturing and processing industries located in the catchment (WSU, 2017). The rivers supply 80% of the sand and gravel used in Sydney’s construction industry with an estimated annual worth of $100 million. Nearly 23% of NSW’s electricity is generated through the large dams located within the HNR Catchment (HNCMA, 2007). Other uses of this catchment include commercial fishing and oyster industries, and recreational activities such as boating, kayaking, water skiing and canoeing (DPIE, n.d.)

Biodiversity

The Hawkesbury-Nepean River catchment contains a vast diversity in its flora and fauna species (Figure 23) with nearly 71% of the catchment comprising national parks, nature reserves and state recreation areas (Hawkesbury City Council, 2020). Some of the most famous and World Heritage National Parks include Blue Mountains National Park, Yengo National Park, Wollemi National Park, Dharug National Park and Cattai National Park (Hawkesbury City Council, 2020). Along the Hawkesbury-Nepean River, Forest red/blue gum (Eucalyptus tereticornis) is the most dominant tree (Hawkesbury City Council, 2020).

The HNR Catchment comprises a vast range of aquatic and riparian vegetation, supporting a diverse range of aquatic species including over 50 species of fish. Sue Martin has stated that the Australian Bass (Macquaria novemaculeata) is a keystone and native flagship fish species of the Hawkesbury-Nepean River (WSU, 2017). However, the total number of native fish species have declined in population due to the introduction of new species (invasive species). Important indigenous freshwater species listed as threatened include Macquarie perch (Macquaria australasica) and the Australia grayling (Prototroctes maraena). The catchment also includes two key threatened estuarine species, the Black Cod (Epinephelus daemelii) and the Green sawfish (Pristis zijsron), the decline of the fish populations is mainly due to a large uptake in commercial and recreational fishing (NSW Department of Primary Industries (NSWDPI, 2006)

Figure 23 Biodiversity of the Hawkesbury-Nepean River. (Clockwise from top-right): Koalas (top), Platypus (bottom), Australian Bass (top), Macquarie perch (bottom), Brush-tailed Rock Wallaby (top), Tiger Quoll (bottom), Glossy Black Cockatoo (top), the Green and golden bell frog (bottom), Green Sawfish)

The HNR Catchment is also home to an array of aquatic macroinvertebrates including insects, prawns, crayfish and freshwater mussels. Over 60 species of frogs have been identified in the region including threatened species such as the Giant Burrowing Frog, the Green and Golden Bell Frog and the Giant Barred Frog (NSWDPI, 2006).

Two of the most charismatic species of the HNR Catchment include Australian icons; the Koala (Phascolarctos cinereus) and the Platypus (Ornithorhynchus anatinus). There have been numerous sightings of the koala, mostly near the Nepean and Avon River dams. Whilst the koala population has been quite persistent despite the fires in the HNR Catchment, National Parks and Wildlife Services (NPWS) has been developing future mitigation strategies to protect the population (NSW National Parks & Wildlife Services [NPWS], 2017). Recent platypus studies in the Hawkesbury-Nepean River reflect that the population is scarce and human modifications to its habitat with dams and weirs showed a massive decline in its population (WSU, 2017). After three years in 2020, researchers from Western Sydney University (WSU) and Cattai Hills Environment Network (CHEN) identified a healthy platypus population closer to the urbanised area of the HNR Catchment through Environmental DNA (eDNA) water sampling (WSU, 2020).

One of the major threats to the biodiversity of the HNR Catchment is the invasive species such as feral cats (Felis catus), feral pigs (Sus scrofa), European red foxes (Vulpes vulpes), rabbits (Oryctolagus cuniculus), black rats (Rattus rattus), fallow deer (Cervus dama), Rusa deer (Cervus timorensis) and feral goats (Capra hircus) (NPWS, 2017). These invasive species not only prey on the threatened species population but can also affect water quality through erosion and sedimentation by introducing pathogens into the river system (NPWS, 2017).

Threats to the Hawkesbury-Nepean

The Hawkesbury-Nepean River system has been under constant pressure from human-induced pollution which has caused significant changes to the pristine, riverine habitat, water quality and aquatic flora and fauna (Recher et al., 1993). To support the growing population, the natural vegetation in and around the HNR catchment has been cleared for housing, agriculture and growing manufacturing and professional industries (WSU, 2017). By 1998, more than 25% of the catchment area was cleared for agriculture and small-scale production, the remaining forested landscape is still under constant threat from land clearance to accommodate and support the booming western-Sydney population (Recher et al., 1993; Pinto & Maheshwari, 2015).

Source: Dan Himbrechts, 2019

Water Quality

The chemical and nutrient runoff from residential, agricultural and industrial areas are one of the major threats to the HNR system. In particular, chemicals such as heavy metals and pesticides and nutrients such as nitrates and phosphates cause eutrophication that could lead to harmful algal bloom (WSU, 2017). Surface runoff from small-scale production and animal farms in peri-urban regions have contributed to more than 40-50% phosphorus loads and nearly 25% nitrate loads in the river catchment (Markich & Brown, 1998; Pinto & Maheshwari, 2015). There are 20 sewage treatment plants situated in the Hawkesbury-Nepean River Catchment which all discharge significant amounts of tertiary treated municipal wastewater into the river. (Howard, 2009; Pinto & Maheshwari, 2015). Overflows from household septic systems have led to an increase in biological pollutants in the river system resulting in the depletion of river health (Björklund, 2009; Thoms et al., 2000; Pinto & Maheshwari, 2015).

Another major threat to the HNR Catchment is the changes in water flow regulation through 22 large dams and 15 weirs causing a further increase in nutrient levels and decrease in dissolved oxygen leading to siltation and weed by the riverbanks. The major dam, Warragamba holds about 2.057 x 109 m3 of freshwater, which is directly captured from the catchment (WSU, 2017; Turner and Erskine, 2005). Based on the Hawkesbury River Waterkeeper Alliance's Report (2020), other threats to the HNR Catchment and Hawkesbury Watershed include an increase in land fragmentation due to hobby farming, retention of water on sites in small dams (ponds) and land clearing activities leading to erosion issues.

The major threats facing the HNR system include growing human population, habitat degradation, regulation of river flows, agricultural and industrial waste, all of which have been depleting the water quality of the HNR System (DPIE, n.d.). The water quality of HNR is monitored regularly through Real-Time Data (RTD) at 32 sites by numerous government agencies namely the Sydney Catchment Authority, Bureau of Meteorology, Department of Primary Industries, Hornsbury City Council and Manley Hydraulics Lab (NSW Government, 2010; WSU, 2017). For inflow streams, water storages and water filtration plants across the HNR Catchment, water quality monitoring is undertaken by Water NSW (NPWS, 2017).

There are 15 wastewater treatment plants (WWTPs) and one Advanced Water Treatment Plant (St Marys AWTP) that has been operating in the Hawkesbury Nepean Catchment, directly discharging untreated water into the river catchment for more than 25 years. A study by Sydney Water (2017), determined the short term and long term effects of wastewater discharge (Table 5). Between 1992 and 2017, the total nitrogen load discharged from Sydney Water's inland WWTPs decreased by 76% and the total phosphorus load decreased by 94% whilst the population grew by 73% over the same period in the Hawkesbury-Nepean River catchment (Sydney Water, 2017). However, in terms of short-term trends, there has been an overall increase in the total nitrogen load discharged to all five sub-catchments, and total phosphorus load to four sub-catchments with the exception of the Lower Nepean/Upper Hawkesbury River sub-catchment since 2011 (Sydney Water, 2017). There is a lack of water quality data on the current state of the Hawkesbury-Nepean River Catchment.

Table 5: Summary of long-term and short-term trends in WWTP nutrient loads of Hawkesbury-Nepean's five river catchments (Sydney Water, 2017)

Parameters	Upper Nepean	Lower Nepean and Upper Hawkesbury	South Creek	Cattai Creek	Berowra Creek	Total
Long-term period	1992-2017	1992-2017	1992-2017	1992-2017	1992-2017	1992-2017
Total nitrogen load						
Total phosphorus load						
Short-term period	2008-2017	2011-2017	2011-2017	2009-2017	2005-2017	2011-2017
Total nitrogen load						
Short-term period	2009-2017	2011-2017	2011-2017	2011-2017	2005-2017	2011-2017
Total phosphorus load						

Legend

- Insignificant trend in nutrient load
- Significant decreasing trend in nutrient load
- Significant increasing trend in nutrient load

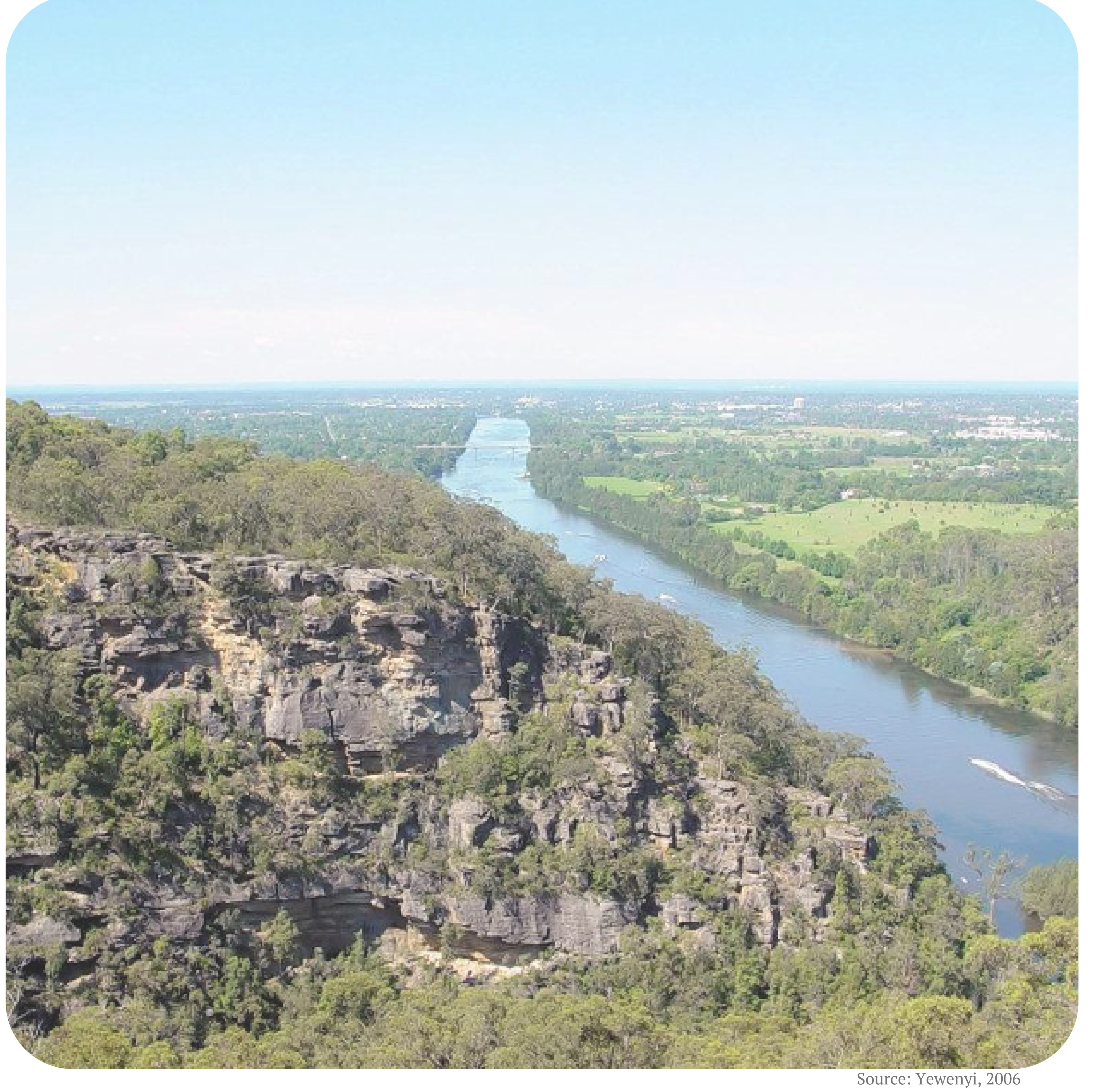
In terms of heavy metals, Copper, Lead and Zinc concentrations have been found to be extremely high in the Peachtree Creek and the Nepean River due to industrial and sewage waste. Meanwhile, the concentration of Cadmium, Cobalt and Iron were high at the Nepean and Avon Dam (Simonovski, et al., 2003). Mining activities in the HNR Catchment have also caused a decline in the water quality through elevated levels of salinity, low pH and elevated metals load (Sullivan et al., 2014; Wright et al., 2011).

Based on a recent study by water expert Dr. Ian Wright, from 90 water samples, approximately 6% of the water samples were contaminated at an extremely hazardous level, through this study, Dr. Wright claims that the NSW government has failed its duty of care and has stated that "It is unacceptable that microbial data is regularly collected, and at times hazardous levels of faecal bacteria are detected, [and] the results are not shared with potentially vulnerable river users." (Hair, 2019). One of the limitations of water quality sampling and analysis in the Hawkesbury-Nepean River is that it is generally undertaken monthly, so that short-term changes may not be easily detected without further additional investigation. It also means that it may take many years before trends in water quality become evident in the routine monitoring program (NSW DECCW, 2010).

River Management Initiatives

Similar to many other catchments, a major threat to the Hawkesbury-Nepean has been anthropogenic activities, especially the increase in urbanisation in the Western Sydney region. The New South Wales (NSW) Government established the Hawkesbury-Nepean Catchment Management Authority (HNCMA) under the Catchment Management Authorities Act 2003 to promote improved natural resource management at a catchment level. The HNCMA continued to work with multiple community groups such as Landcare to improve the river health of Hawkesbury-Nepean until 2018. The abolishment of HNCMA is a key challenge in the river management initiatives and since then the Hawkesbury-Nepean River Catchment has been managed by the Department of Environment, Climate Change & Water and City Councils surrounding the catchment.

Simultaneously, In 2011 the Waterkeepers Alliance granted status to a Hawkesbury River Waterkeeper with the Hawkesbury Environment Network Alan Midgley, PhD candidate in Western Sydney University's School of Science and Health serving as Riverkeeper. Alan performed this role for the duration of his studies and patrolled the river and catchment between Wisemans Ferry and the mouth of the Grose River until 2015. The role of the Hawkesbury Riverkeeper was to provide independent and scientifically informed monitoring of river health and assists with community-based responses and remediation. Sue Martin aims the establishment of a new Hawkesbury River Waterkeeper Alliance who would create a community-led group focused on the HNR and create opportunities for stakeholder collaborations on both a council, state and federal level for the betterment of the river catchment.



Source: Yewenyi, 2006

EXPERT SPOTLIGHT

Andrew Kelly *Yarra Riverkeeper, Member of Birrarung Council*

Andrew Kelly is the Yarra Riverkeeper and has been the spokesperson for the river since November 2014, succeeding the founding Riverkeeper, Ian Penrose. Together Ian and Andrew have built the Yarra Riverkeeper Association (YRKA) with a reputation for both on the groundwork of environmental stewardship and water quality protection, as well as advocacy and educating the public. Andrew regularly features in news articles, radio and podcasts as Melbourne's foremost expert on the Yarra and frequently contributes his passion and expertise to strategic planning and policy development panels. In addition, he serves as the organisation's figurehead on a global scale, contributing to the International Network of Rivers and Global Waterkeeper Alliance. A true advocate, he sits on the Birrarung Council, an expert panel of stakeholders dedicated to being the 'voice of the Yarra'.

"We have to speak for the river, as the river can't speak for itself"-Andrew Kelly, Yarra Riverkeeper.

Andrew has a passion for writing and he continues to run a secret life as a children's picture book author. He has recently published the book Wilam: a Birrarung Story, which was written in partnership with Aboriginal Wurundjeri Elder, Aunty Joy Murphy. Andrew has been deeply involved with the mission of conservation and environmental protection, leading the charge on environmental progress and facilitating large scale community events. His aspirational vision for the future Yarra is to create opportunities to reconnect the Yarra corridor landscapes along the basins up to the forest catchment. Andrew is all about community engagement and he believes that the communities play a vital role in rescuing the Yarra's future.

He hopes to observe more wildlife involvement in the river like dolphins and seals as he believes that they would create a powerful connection within the community. His organisational vision for YRKA is to find the right balance between socio-economic development and environmental values in such a way that it retains the organization's original grass-roots purpose. He aims for YRKA to act as a platform to pave the way for the river and the wildlife forms to flourish.

Dr. Teresa Jane Mackintosh *Waterwatch Coordinator, Customer & Strategy, Melbourne Water.*

Dr. Teresa Mackintosh is a Waterwatch Coordinator with Melbourne Water, Australia, where she runs the Platypus and Litter Action program. Her role includes working with various stakeholders, including state government, local government, community groups and schools. Originally from the UK, Teresa's background is in Aquatic Ecology. She received a First Class Honours in her undergraduate degree in Environmental Science, before gaining a Distinction in her Masters of Aquatic Resource Management before coming to Australia to complete her doctorate. Her research at Monash University involved studying the biodiversity and ecosystem function of stormwater wetlands, which specifically focussed on how heavy metals affect these processes. She has presented her research to both an international and national audience and published four peer-reviewed articles in international journals and a book chapter.

"My main interest is to make science understandable and accessible to the general community and providing opportunities for people to become involved in citizen science projects to monitor and record the health of Melbourne's Waterways."

-Dr. Teresa Mackintosh, Melbourne Water.

Before working at Melbourne Water, Teresa was the Science Officer for the Werribee River Association, which hosts the Werribee Riverkeeper, John Forrester. Teresa's work with the Association involved running a project to map pollution in the Werribee River. The project included engaging and training the general community to collect water quality data and conduct ecological monitoring. She also has experience in consulting, working for other state government agencies and also has her own environmental consultancy business, Aqua Terra Ecology.

Background

The Yarra River, an iconic river in the south-eastern Australian state of Victoria and is recognised as one of Melbourne's most valuable natural assets alongside Port Phillip Bay. The river and its catchment supports around one-third of Victoria’s population and supplies approximately 70% of Greater Melbourne’s drinking water (Allinson et al. 2011; O’Bryan 2019). It traverses an enormous range of habitats from pristine forested catchments to a range of agricultural lands and dense urban areas (Barmand et al. 2020). Stretching 242 km in length, the Yarra starts its journey on the banks of Mt Baw Baw in the Yarra Ranges National Park and travels through the forests of the Yarra Ranges before ending its journey on the mouth of Port Phillip Bay at Newport (Figure 24) (MWC 2009). The Yarra River covers an area of over 4,000 sq. km including over 40 rivers and creeks which are of high social, economic, and environmental significance (MWC 2018a). The Upper Yarra segment, from the Yarra Ranges National Park to the Warburton Gorge at Millgrove, consists of mainly dense and extensive forested areas with a minimum human population. The Middle Yarra segment, from the Warburton Gorge to Warrandyte Gorge, is mainly rural floodplains and valleys with limited urban development. The Lower Yarra segment, downstream of Warrandyte, is mainly urbanised floodplains and has the poorest water quality. The annual rainfall of the Yarra River catchment varies from approximately 1,080 mm in the Upper Yarra area to about 615 mm in the Lower Yarra region (Ng et al. 2006; Melbourne Water 2019). The upper reaches of the Yarra is the source of Melbourne city’s high-quality drinking water, whereas the river quality has degraded in the Middle and Lower Yarra as a result of agriculture and urbanization along its corridor (Leahy 2005; Melbourne water 2010; Allinson et al. 2011).

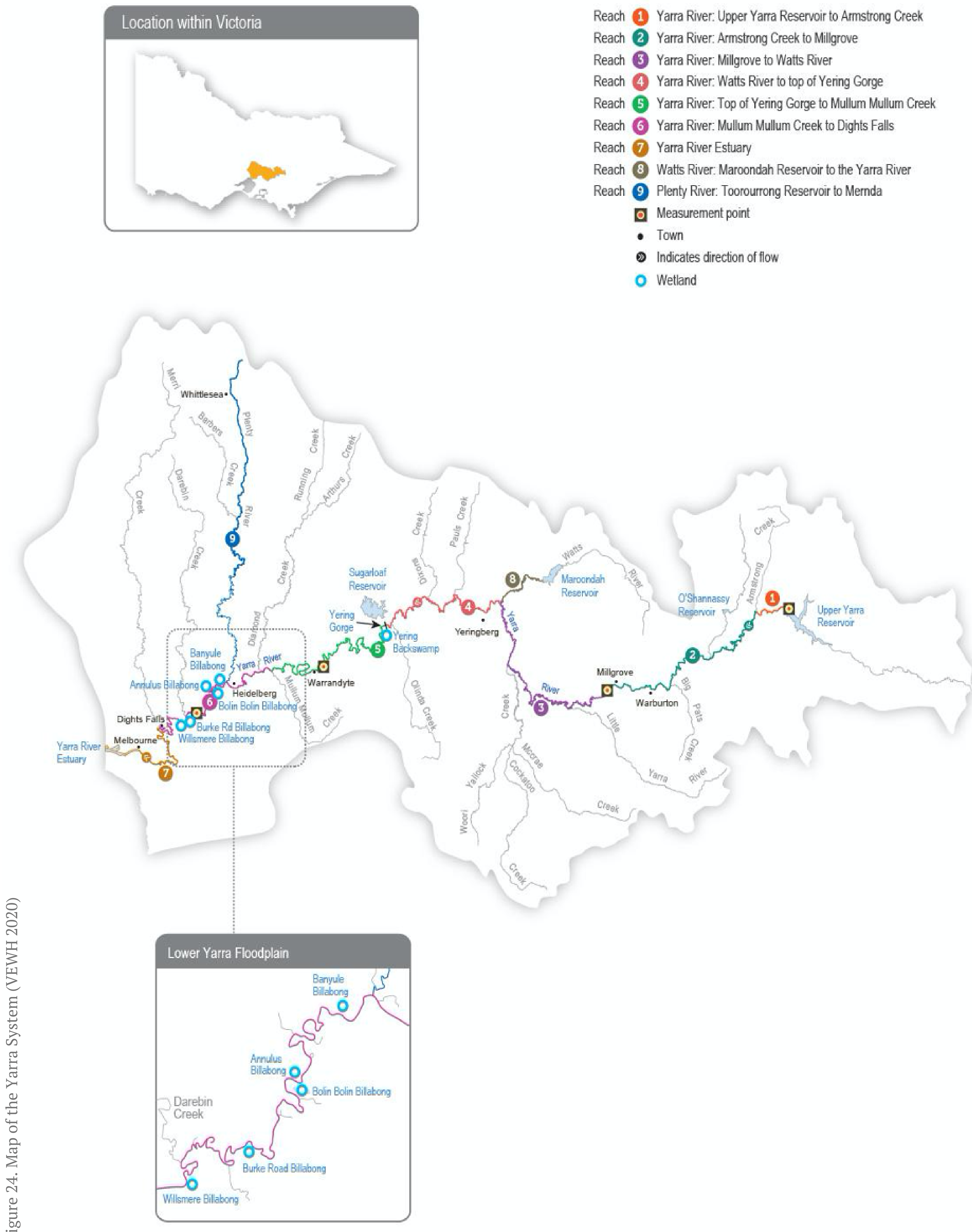


Figure 24. Map of the Yarra System (VEWH 2020)

Uses of the River

Waterways play an important role in the daily lives of Victorians. The Yarra River and its parklands system strongly link to Victorians' sense of health and wellbeing, providing places for cultural gatherings, recreation and contemplation (SoY 2018). Similarly, the Maribyrnong River, which spans 40kms serves a similar purpose for those in the western suburbs of Melbourne. Historically, the Indigenous community (the Traditional Owners) have held a particular existential significance, as well as economic and social values towards the Yarra (Parks victoria 2018; SoY 2018). The land surrounding where the catchment flows into Port Phillip Bay, including the Yarra Valley, is the traditional home to the Woiwurrung, Boonwurrung, Taungurong, Dja Dja Wurrung and the Wathaurung groups who form the Kulin Nation (DELWP 2016). They call the river Birrarung which means the river of "mists and shadows" and they have a spiritual connection to the Yarra's lands and waterway. In response to cultural and heritage reform, in 2017, the Victorian government has released the Yarra River Protection (Willip-gin Birrarung murron) Act 2017 (the Yarra Act) that treats the Yarra River as 'one living and integrated natural entity' which needs to be protected and preserved (O'Bryan 2019; Clark et al. 2018). The Act also recognises the traditional values of the Wurundjeri community and gives an independent voice to the river through its statutory advisory body, called the Birrarung Council (Eckstein et al. 2019).

The Yarra River is integral to Melbourne's identity and vital for the city's liveability. A total space of 7,795 hectares across the river corridor has been allocated to parklands and public open spaces for the recreational, social and physical wellbeing of residents. This in turn builds the resilience of the area's capacity to respond to pressures such as climate extremes. The Yarra River corridor is rich with wildlife and biodiversity, where the passage supports diverse life forms and it is uniquely important to the culture, values and practices of Aboriginal people. The Yarra River, its parklands and the surrounding areas are destinations for international and local tourists and visitors. Healesville Sanctuary, the Yarra Valley vineyards and Southbank Boulevard are some examples of key tourist locations (SoY 2018). The tourism industry has contributed to an estimated AUD$1.1 billion to the Yarra Valley and Dandenong Ranges economy (13.4% of gross regional product) and employed approximately 10,500 people (11.7% of regional employment) (Tourism Victoria 2015).

The Yarra River spanning between Warburton and Warrandyte has been identified as the Victorian Heritage River, meaning it has significant recreation, nature conservation, scenic and cultural heritage attributes (Melbourne Water 2019). Approximately 21 % of the river corridor retains its natural vegetation, 57 % is agricultural and 22 % is urbanised (MWC 2018b). The rural reach of Yarra supports strong primary production of agriculture businesses including nurseries, cut flowers, market gardening and dairy farming and fisheries commodities.

The lower rural reach is home to a high proportion of mixed farming and grazing as well as world-class vineyards generating a Gross Regional Product of AUD$574 million per year (SoY 2018; MWC 2018c). With an estimated annual benefit of AUD$730 million, the Yarra River and its corridor have provided a range of ecosystem services including recreational and amenity values (MWC 2018c). For decades, the river has been acting as a means of transport of goods and people. In modern times, the inner-city Yarra acts as a busy transport corridor providing access to Victoria Harbour and the Maribyrnong River, where the Yarra and its tributaries also provide trail paths for bicycle and pedestrian commuters. Up to 400,000 ML per year (long-term average diversion limit) can be harvested from the Yarra River system for consumptive use in Melbourne and surrounding areas (VEWH 2020).

The water released from the reservoirs such as the Upper Yarra Reservoir, O'Shannassy Reservoir and Maroondah Reservoirs supports the ecological processes and environmental outcomes in downstream river reaches and wetlands (VEWH 2020). The Yering Gorge water-supply catchment flows from the Upper Yarra dam wall through to Warrandyte where water is pumped directed from the river to Sugarloaf Reservoir and treated at Winneke Water Treatment Plant. This vital water line contributes to nearly 25% of Melbourne's total water demand and, during drought, supplies around one-third of the drinking water (SoY 2018).

Source: Anthony Despotellis

Biodiversity

The catchment is home to a wide range of plant and animal species including 25 unique vegetation communities, 252 bird species, 14 indigenous fish species and 38 species of native mammals, and biodiversity conservation infrastructure such a bird watching hides and man-made wetlands are a noted feature in many parts of the catchment (Barua et al. 2012; Melbourne Water 2010). The wildlife living in and around the Yarra River is diverse and it supports several native species who are entirely dependent on the Yarra's waterways for their continued survival (Adhikary et al. 2015). One-third of Victoria's animal species are found in the Yarra catchment, including Australian icons such as the Eastern-Grey Kangaroo, Koala, Echidna and Common Wombat (Figure 25). Compared with the lower sections, the middle and upper sections of the river provide better conditions for animals because of higher water quality, less erosion, and more continuous native vegetation and habitat (MWC 2009).

Despite catchment changes, the aquatic and riparian habitat of the Yarra River is still of a high standard in many areas, supporting a diverse community of fish (DELWP 2016). Recent surveys show that the most common species present are the native Australian Smelt, Common Galaxias and Short-finned Eels (Anguilla australis), and Roach, which is an exotic fish. In addition, the iconic laughing kookaburra is abundant and other regionally significant bird species such as the White-faced Heron and Nankeen Night Heron are present along many stretches of the Yarra.

Figure 25. Key stone & Charismatic species of the Yarra: Platypus, Common Wombat, Eastern Grey Kangaroo, Short-Beaked Echidna, Helmeted Honeyeater, River Blackfish, Australian Grayling, Sugar Glider, Bottlenosed Dolphin, and Australian Fur Seal.

In addition, there are also notable bird species that are listed as nationally-threatened in the Yarra catchment including the Swift Parrot, Australasian Bittern and Helmeted Honeyeater (MWC 2018b). The unique monotreme and de facto animal mascot of Victorian Waterways, the Platypus, is found in rivers and creeks of the Yarra, and acts as a valuable indicator of the health of aquatic ecosystems (MWC 2009). Notable natives and introduced fish species in the Yarra River are River Blackfish (Gadopsis marmoratus), Spotted Galaxias (Galaxias truttaceus), Common Galaxias (Galaxias maculatus), Australian Grayling (Prototroctes maraena), Macquarie Perch (Macquaria australasica), and Tupong (Pseudaphritis urvilli) (Mackintosh 2019; Kelly A, pers. Communication, 07 October 2020). Billabongs are an important feature of the Yarra River floodplain between Millgrove and Yering Gorge and in the lower reaches around Banyule Flats near Heidelberg (VEWH 2020). In recent years, declining levels of dissolved oxygen have been considered a major risk to the ecological health of the Yarra River, with concern for the impact on nationally threatened species such as the Macquarie Perch, Murray and Australian Grayling and particularly the Platypus (Coleman et al. 2011).

Threats to the Yarra

Despite its ecological significance, the Yarra River corridor is exposed to a number of threats and pressures which include improper land-use patterns along the riverbank, invasive plants and animals, litter, water pollution (sewerage and stormwater), climate change and an increase in population. High plastic litter loads in rivers, including both macro and microplastics, are due to high levels of mismanaged plastic waste arising from population-dense river catchments (Schmidt et al. 2017). It is likely that the higher number of pollution reports along the inner city reach is due to the combination of higher population densities and more operational industrial sites located along the main Yarra stem (SoY 2018; Kelly. A, pers. Communication, 07 October 2020). The river catchment is experiencing extreme climatic stress, evident through increasingly frequent drought and flood incidents (MWC 2018a). Hydroclimatic projections for Victoria in 2040 and 2065 have predicted decreased rainfall events with increased evaporation due to the changing temperatures (Barua et al. 2012). This has further resulted in a change in fire regimes which has the potential to change species composition, vegetation coverage and fire fuel load (COAG 2012). This poses a severe threat to the creeks that run into the main Yarra River stem and the Yarra's wetlands, billabongs and estuary – all of which are important systems for drought refuge. Further, the change in land-use patterns due to human activities and major flood events has spread invasive terrestrial and freshwater plants and animals into the natural system (White et al. 2018). Such invasive species pose a major threat to biodiversity, ecosystem health, primary production and landscape aesthetics.

Water Quality

Water quality in the Yarra has been assessed by looking at both biotic and abiotic factors, which together form a suite of informative indicators for monitoring conditions. Melbourne Water has provided the water quality data from seven sampling locations (Table 6) which measure the parameters such as dissolved oxygen; electrical conductivity; pH; turbidity; nitrite/nitrate; ammonia; total nitrogen; filtered reactive phosphorus; total phosphorus; and E. coli as part of its river health and monitoring program. The data for the above parameters were collected on a monthly basis, between 2008 and 2017. These indicators were analysed using the State Environment Protection Policy (Waters) (SEPP (Waters of Victoria)) framework for Victoria's protection and management of water quality, within the Environmental Protection Act 1970. Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC) were used to analyse the test results where no SEPP values were available (Mackintosh 2019).

From the study conducted by Melbourne Water for the period 2008 and 2017 (Appendix 4), it is observed that the water quality in the Yarra River generally met SEPP (2018) guidelines for electrical conductivity, pH, and dissolved oxygen. However, many of the monitored sites exceeded the corresponding objectives for turbidity, total nitrogen, and total phosphorus. Nitrate and nitrite concentrations were higher than the ANZECC (2000) guidelines at all monitoring locations. It was evident from the report that the sites which met the water quality objectives were Millgrove and Launching Place as they are located in the upper reaches of the Yarra which encounters less anthropogenic activities (Goss 2003; Mackintosh 2019).

Table 6. Locations and water quality parameters provided by Melbourne Water (Mackintosh 2019).

Site Code	Location	SEPP Segment	Melways
YAYAR0855	Yarra River at McKenzie-King Drive, Millgrove	Rural	289 E4
YAYAR1040	Yarra River at Don Road, Launching Place (EPA 2916)	Rural	287 H6
YAYAR1569	Yarra River at Maroondah Hwy, Healesville (EPA 2904)	Rural	277 G7
YAYAR2151	Yarra River at Spadonis Reserve, Coldstream	Rural	274 E8
YAYAR2356	Yarra River at Kangaroo Ground-Warrandyte Road, Warrandyte	Urban Waters	23 F11
YAYAR3331	Yarra River at Chandler Hwy, Kew (Replaces MY01)	Urban Waters	45 B1
YAYAR3884	Yarra River at Princes Bridge, Melbourne	Upper Estuary	43 J9

Whereas, in the middle and lower reaches, turbidity, nitrogen, and phosphorus exceed SEPP objectives due to the change in land use dominated by agricultural and urbanisation (Mackintosh 2019). E. coli levels in the Yarra River catchment were higher than recommended levels for primary contact, at all sites. Possible sources of faecal contamination include agricultural runoff, domestic and wild animal waste, on-site septic systems, and stormwater runoff (Mackintosh 2019).

River Management Initiatives

In order to protect the river system, the Victorian Government released the Yarra River Action Plan in the year 2017 which addresses the need for the river to be managed as a living integrated entity with a voice; grounded by Traditional Owner values and perspectives; and underpinned by coordinated planning frameworks. In December 2017, the Yarra River Protection (Wilip-gin Birrarung murron) Act 2017 was passed by the Victorian Parliament to protect the Yarra River and it is the first legislation in Australia to be co-titled in a Traditional Owner language. The community's expectations for the entire length of the river are finely articulated in the Yarra River 50 Year Community Vision which was launched in May 2018 and is the first of its kind for an urban waterway in Australia. It formed a basis from which the overarching strategic framework to protect this waterway, the Yarra Strategic Plan is to be developed. The Draft Yarra Strategic Plan was released for public comment on 23 January 2020 which identifies immediate actions for the river, enables long-term collaborative management between agencies and Traditional Owners and guides local planning (Kelly A, pers. Communication, 07 October 2020). The draft has enlisted four 10-year performance objectives to deliver the community vision such as; a healthy river and lands, a culturally diverse river corridor, quality parklands for a growing population; and protecting the natural beauty of the Yarra River corridor (MWC 2020).

Source: Yarra Riverkeeper Association

Discussion

The six rivers discussed in this report are geographically distinct, with uniquely rich and diverse flora and fauna. However, the major and most common threats to these rivers have been anthropogenic activities. Through the decades, humans have been using rivers for their ecological benefits, which in turn has led to the depletion and degradation of their water quality. The six global rivers flow through major cities and support their respective populations and development through direct water consumption, transport and irrigation, etc. The expansion of urbanisation has led to an increase in impermeable surfaces that affects the natural waterways, where an increase in stormwater runoff has been a major threat to the water quality of these rivers, particularly observed in the Yarra, Yangtze and Hudson River. However, in the case of Indian Rivers, water quality is threatened by surface water runoff from agricultural fields containing high amounts of pesticide and toxic chemical compounds in the Yamuna and Periyar catchments.

The increase in population density in riverside major cities has been a challenge in terms of urban wastewater management. Through our comparative study, the disposal of untreated wastewater has been a common issue for all the six global rivers along with the disposal of industrial effluents leading to an increase in toxic and heavy metal contaminants. Urban wastewater management has become a common challenge because infrastructure development and regulations have not kept pace with such rapid population growth and urbanisation. For example, the North EastLink Project in Melbourne is a large-scale public infrastructure project that will provide economic benefits through a reduction in commuting time. However, it will also cause further degradation to the city's ecological significance due to an added large impermeable surface. Implementing Water-Sensitive Urban Designs (WSUD) in infrastructure development and regulation is a promising solution to tackle stormwater runoff and effluent disposal, minimising environmental degradation of these rivers.

Source: Cedric Dhaenens

The presence of multiple dams, reservoirs and weirs in the six rivers have also caused major negative impacts through the restriction of river flow, causing damage to the river habitat and destroying freshwater fisheries globally. The Waterkeeper Alliance adopted the "Free-Flowing Rivers Initiative" in 2018, which opposes the construction of new dams and diversions, strictly advocating the removal of dams wherever possible. Through stakeholder interview consultation which guided this report, the negative impacts of dams were strongly highlighted by the Hawkesbury-Nepean, Yamuna and the Yarra Riverkeepers respectively. The Yarra Riverkeeper Association has successfully advocated environmental flows to maintain the downstream river health and help mimic natural fluctuations in water flows. Similarly, the Yamuna, Hudson, Periyar, Yangtze and Hawkesbury-Nepean Riverkeepers have achieved significant advancement in improving the river's health through advocacy and being the voices of the river, as the rivers cannot speak for themselves. River Management Initiatives by the government and community-led groups have been key to ensure the projection of natural waterways.

Source: Yarra Riverkeeper Association

The Yamuna, Periyar and Hawkesbury Riverkeepers have faced challenges in terms of government support, however, through advocacy and stakeholder collaborations these riverkeepers have been working towards overcoming these challenges through community backing.

Regular monitoring and analysis on the water quality of the river is extremely crucial, as this would benefit the baseline core water values, the wildlife that inhabits the waterways and riverbanks and communities residing by the rivers. Due to the lack of information available on water quality and monitoring, the communities are often unaware of the depleting water quality and presence of harmful pollutants and contaminants. Educating the communities about the current state of their river will increase awareness and improve community engagement, citizen science and local stewardship for environmental protection, whilst at the same time mental and public health. In attempts to sensitise the community about the rivers and waterways, the concept of providing legal and cultural rights to the river has been emerging and the YRKA plans on discussing the rights of the river in the future through further legislative analysis, consultation and research. The YRKA is also currently working on its restoration guide and water quality report in collaboration with Melbourne Water to help drive ecological regeneration and water stewardship respectively.

In conclusion, the six global rivers are significantly important to their regions and whilst they might differ in certain geographical features, they are bounded by the common threats and negative impacts they face. Stakeholder collaboration and place-based initiatives by the Riverkeepers and the Waterkeeper Alliance is a way forward to protecting these rivers and their ecosystems. The Waterkeeper Alliance has grown exponentially with more than 350 Waterkeeper Organisations and Affiliations protecting waterways in 48 countries, on 6 continents. The Waterkeeper Alliance has future plans to intensively increase support for Waterkeepers globally, they have developed a strategic business plan over the next 20 years. In regards to their strategic plan, Marc Yaggi, Waterkeeper Alliance Executive Director, states that

“Executing this plan will allow the Waterkeeper Alliance to meet our natal vision of having community-based Waterkeepers safeguarding every waterway in the world. We will improve each local Waterkeeper’s capacity to effectively pursue the goal of drinkable, fishable, swimmable waters worldwide.”

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Appendices

Appendix 1: The catchment of Yamuna River (CPCB, 2006)

State/Territory	Total area in the Yamuna River Catchment (km²)	Area in the major sub-basin (km²)					
		River Hindon	River Chambal	River Sind	River Betwa	River Ken	Other Sub basin
Uttaranchal	3771	-	-	-	-	-	3771
Uttar Pradesh	70437	7083	452	748	14438	3336	44380
Himachal Pradesh	5799	-	-	-	-	-	5799
Haryana	21265	-	-	-	-	-	21265
Rajasthan	102883	-	79495	-	-	-	23388
Madhya Pradesh	140208	-	59838	25131	33502	21090	647
NCT – Delhi	1485	-	-	-	-	-	1485
Total	**345848 (100%)**	**7083 (2.0%)**	**139785 (40.5%)**	**25879 (7.5%)**	**47940 (13.9%)**	**24426 (7.1%)**	**100735 (29.1%)**

Appendix 2: State-wise land use pattern in Yamuna River Catchment (Government of India)

State	Area (% of total catchment)	Land use pattern			Land actually cultivated %	Land under habitational use %
		Non-arable land %	Forest land %	Cultivable land %		
Himachal Pradesh	1.6	25.0	59.4	15.6	14.2	1.5
Haryana	6.1	18.1	2.4	79.5	59.9	3.6
NCT – Delhi	0.4	51.0	1.0	48.0	46.5	43.7
Uttaranchal	1.1	5.0	22.0	23.0	14.3	1.6
Uttar Pradesh	20.4	14.5	3.9	81.1	68.0	5.1
Rajasthan	29.8	40.8	8.8	50.4	43.9	2.2
Madhya Pradesh	40.6	26.0	18.0	56	50.7	1.8
Total	**100.0**	**27.5**	**12.5**	**60.0**	**51.9**	**2.9**

Source: *Comprehensive plan of flood control for Ganga sub-basin and tributary River System, Ganga Flood Control Committee, Ministry of Water Resources, Govt of India*

Appendix 3: EPA Criteria for Hudson’s Water Quality (Riverkeeper.org)

Beach Action Value: If a single sample exceeds an Entero count of 60, swimming is not recommended. The percentage of samples that exceeded the Beach Action Value with bar charts.

Geometric Mean: A geometric mean (GM) is a weighted average of multiple samples. If the GM exceeds 30, water is not considered safe for swimming. The GM with proportional coloured bars to show which sites have the greatest and least “average” levels of contamination.

Statistical Threshold Value: If 10% or more of samples exceed 110, water is not considered safe for swimming due to the frequency of contamination events, even if “average” levels are low. The Statistical Threshold Value (STV) with numerals inside coloured icons to indicate the percentage of samples that exceeded this threshold.

The chart below shows the frequency and degree of contamination, as they relate to EPA criteria for safe swimming. The bars are colored red if “average” contamination exceeds the EPA-recommended threshold (geometric mean of 30). Each site is marked with a red stop sign if 10% or more of samples exceed the EPA threshold (statistical threshold value of 110).

NO.	SITE	%STV	GM
1	Hudson above Mohawk River	15	22.7
2	Mohawk River at Waterford	64	202.4
3	Hudson River above Troy Lock	42	105.6
4	Congress St. Bridge – Troy	25	64.2
5	Albany Rowing Dock	26	61.8
6	Dunn Memorial Bridge – Albany	36	71.9
7	Island Creek/Normans Kill	38	85.6
8	Bethlehem Launch Ramp	17	29.6
9	Castleton	23	28.3
10	Coeymans Landing	22	21.9
11	Coxsackie Waterfront Park	15	23.9
12	Gay’s Point mid-channel	17	12.9
13	Athens	13	36.5
14	Hudson Landing Ramp	13	26.1
15	Catskill Creek – First Bridge	22	19.0
16	Catskill Creek – East End	18	18.9
17	Catskill Launch Ramp	15	13.1
18	Inbocht Bay	7	8.7
19	Malden Launch Ramp	11	13.4
20	Esopus Creek West	16	21.6
21	Esopus Creek Entrance	18	19.6
22	Tivoli Landing	7	5.3
23	Ulster Landing Beach	6	6.9
24	Rondout – Eddyville Anchorage	16	29.1
25	Rondout – Kingston Public Dock	30	55.8
26	Kingston STP Outfall	29	75.7
27	Kingston Point Beach	7	7.3
28	Port Ewen Drinking Water Intake	5	4.3
29	Norrie Point Yacht Basin	19	22.7
30	Norrie Point mid-channel	4	2.9

Appendix 4: Summary comparison of SEPP and ANZECC water quality parameters.

Parameter	Data	SEPP Central Foothills and Coastal Plains (freshwater)	SEPP Central Foothills and Coastal Plains (estuaries)	ANZECC lowland rivers in SE Australian (freshwater)	ANZECC lowland rivers in SE Australian (estuaries)
Dissolved oxygen (%)	25th percentile	≥75	30	85	80
	Maximum	130	130	110	110
pH (units)	25th percentile	≥6.7	7	6.5	7
	75th percentile	≤7.7	8	8	8.5
Turbidity (NTU)	75th percentile	≤25	10	6-50	0.5-10
Nitrite/nitrate (NO_x)(µg/L)	Median			40	15
Ammonia (µg/L)	Median			900	910
Total nitrogen (µg/L)	75th percentile	≤1100	1000	500	300
Total phosphorus (µg/L)	75th percentile	≤55	90	50	30
E. coli (cfu/100ml)	Median			150	1000