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Managing the public health paradox: Benefits and risks associated with waterway use

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Abstract

Engaging with waterways affects our health and wellbeing. This engagement can be direct and intentional, such as when swimming, kayaking or engaging in conservation practices; indirect and intentional, such as when picnicking with water views; or incidental, such as when cycling on riverside bike paths. In the subtropical climate of the Moreton Bay catchment these activities are popular year-round. These forms of engagement can benefit our physical, mental and social wellbeing, and contribute to our cultural identity and sense of place. Conversely, there are health risks associated with waterway use, including exposure to waterborne pathogens, cyanobacterial toxins, dangerous aquatic animals and submerged objects. Whether our interactions with waterways enhance our health and wellbeing or constitute a health risk depends on a wide range of factors and management decisions. In the context of the waterways within Moreton Bay, this paper discusses ways of optimising opportunities for water users while managing public health risks, and how to evaluate the effectiveness of interventions through the use of environmental health indicators.

Keywords: recreational water, ecosystem health, wellbeing, DPSEEA, indicators

Introduction

'Healthy waterways, healthy people'— the connection is intuitive. Images of clear, blue rivers, lakes, waterfalls, beaches and oceans feature in tourism brochures as a backdrop to vibrant backpackers engaged in exciting water sports or families relaxing alongside tranquil water bodies. From the upper reaches of tributaries in sub-catchments of the Brisbane River through to Moreton Bay, this region provides a diverse range of water-based environments that impact on the health and wellbeing of individuals and communities. The state or condition of these aquatic environments and how we interact with them (directly and indirectly) are critical factors that determine whether health outcomes are positive or negative (1). Degraded, polluted waterways can result in adverse health outcomes due to direct exposure to pathogens or toxins or by providing habitats for disease vectors such as mosquitoes (2, 3). On the other hand, healthy waterways can be 'health-promoting' by providing locations suitable for swimming and other forms of physical activity, as well as spaces for stress relief, relaxation and social interaction (4). The aim of this paper is to consider the risks and health benefits associated with waterways in general, with a specific focus on the Moreton Bay region. It conceptualises the relationships between waterways and human health by drawing on trans-disciplinary constructs and international frameworks.

The complexity and richness of the relationships between waterway health and public health warrant a deeper analysis. The intrinsic and reciprocal relationships between human and ecosystem health were synthesised through the Millennium Ecosystem Assessment (MEA), framed around the construct of ecosystem services (5). The MEA describes ecosystem services as the benefits we acquire from ecosystems, which include our waterways. These services can be 'provisional' (e.g. providing fresh water and food), 'regulatory' (e.g. regulating water purification, climate and diseases), 'cultural' (e.g. being a medium for recreational, aesthetic, spiritual, cultural heritage and educational pursuits) or 'supportive' (e.g. cycling of nutrients). Human wellbeing is intrinsically linked to ecosystem health through the benefits arising from meeting our basic resource needs, social relations and access to resources that will mediate the security of health and sustained quality of life, including food and water security. Thus, protecting the health of waterways has both intrinsic value to these ecosystems and reciprocal value to public health.

Utilising ecosystem services at unsustainable rates will not translate to proportionately larger public health benefits. Similarly, when an ecosystem service is scarce, any small decrease 'can substantially reduce human wellbeing' (5 p.49). While better access to ecosystem services has provided human societies with the means to improve health and wellbeing, society may be forcing irreversible changes and damage to these ecosystems. For example, although societal factors such as changing demographics, economic policies, governance frameworks, scientific and technological developments, and cultural and religious choices can improve human health, they can also become indirect drivers of significant pressures on ecosystems. Detrimental changes to ecosystems have resulted from intensive land use, the introduction of exotic species or extinction of native species, inappropriate technologies, excessive use of chemicals, over-harvesting and over-consumption.

Human health cannot be isolated from the health of ecosystems. Nine categories of indicators of health outcomes related to wetland[1] ecosystem services have been identified by Horwitz and Finlayson (1): (i) contributors to hydration and safe water, (ii) contributors to nutrition, (iii) sites of exposure to pollution or toxicants, (iv) sites of exposure to infectious diseases, (v) settings for mental health and psychosocial wellbeing, (vi) places from which people derive their livelihood, (vii) places that enrich people's lives, and enable them to cope and help others, (viii) sites of physical hazards, and (ix) sites from which medicinal and other products can be derived. It is, however, restrictive to consider that ecosystems deliver only a one-way service and that only humans benefit from a healthy ecosystem—this risks ignoring the reciprocity of the human–ecosystem relationship and the human contribution

[1] Wetlands are defined broadly by the Ramsar Convention on Wetlands to include rivers, lakes, marshes, rice fields and coastal areas (6).

(improvement, maintenance, degradation) to the health of the ecosystems described by Horwitz & Finlayson and Comberti *et al.* (1, 7).

The relationships between human health and the ecosystem services provided by waterways are not linear and can be paradoxical. Depending on how they are managed, wetlands can either enhance or diminish human health via effects on their ecological functioning and ability to provide the various ecosystem services from which we benefit (8). For example, trade-offs are made when engineering works carried out to regulate rivers for flood mitigation in order to protect lives and property in a way that may diminish some of their other intrinsic ecosystem services. On the other hand, river reaches could be managed in a way that enhances their aquatic ecosystem health by slowing down the water and creating habitats using large woody debris, but at the expense of safe swimming or boating. A framework for making these trade-offs and paradoxes explicit was first presented in Horwitz & Finlayson (1) and adapted slightly in Finlayson & Horwitz (6). This defined four possible relationships to consider when relating the condition of ecosystem services and human health:

- Double dividend – improved health outcomes and enhanced or maintained ecosystem services;
- Environmentalist's or Wetlands paradox – a degraded ecosystem which provides positive health outcomes (e.g. draining wetlands or applying pesticides to control disease vectors);
- Paradox of the health imperative or Health paradox – a maintained or enhanced ecosystem can pose negative human health consequences (e.g. protected wetlands providing ideal mosquito breeding sites); and,
- Unhealthy wetlands – a poor human health outcome associated with degraded wetlands.

These relationships are depicted in Figure 1.

Wise stewardship of places such as Moreton Bay and its catchment should aim for the double dividend of healthy people and healthy wetlands. This requires an understanding of how these complex relationships operate and change across the catchment and sub-catchments of Moreton Bay and over time. As a starting point, this would require multiple measures of both aquatic ecosystem health and human health and wellbeing so that these trade-offs could be made explicit.

Health benefits and risks associated with the use of waterways

The use of natural waterways provides health benefits yet presents potential health risks. The health benefits of water-based recreation are widely accepted (2, 4, 9). It is also well established that exposure to poor quality recreational waters can result in negative outcomes for human health (10, 11). These health risks and benefits derive from exposure to environmental health determinants that are physical, microbial, chemical, psychological or social. Table 1 summarises both the health risks and benefits associated with using waterways under these five categories of health determinants. In order to maximise their public health benefits, waterways must be managed such that human exposure to hazards is minimised without placing undue restrictions on waterway use (2).

Human health

Ecosystem services		**Poor health outcomes**	**Improved health outcomes**
	Enhanced or maintained	+ – Paradox of the health imperative	+ + Double dividend (healthy wetlands, healthy people)
	Degraded	– – Unhealthy wetlands	– + Analogous to the 'Environmentalist's paradox'

Figure 1. Four relationships possible when considering the condition of ecosystem services and human health (1 p684).

Physical hazards present the highest health risk to recreational water users (10, 12). Incidents of drowning, major impact injuries, and slip, trip and fall injuries can result in death or permanent disability. As a result, recreational water management programs should consider the physical characteristics of a beach or other water environment, including water depth and turbidity; swimming zone topography; presence of breaking waves, currents and rips; and local and foreign hazards such as coral reefs or floating debris (12). The risk of these hazards may be compounded by exposure to solar radiation, heat and cold (12). In addition to natural hazards, incidents of violence from other people may result in physical harm (e.g. muggings in remote or poorly lit areas).

The health benefits associated with physical aspects of waterways are probably the most intuitive. At the most basic 'sustenance' level, waterways provide food (via wild-caught and farmed seafood and crop irrigation) and sources of raw water for drinking. During extreme climatic events, such as the Brisbane flood of 2011, waterways can protect lives and property through peak discharge attenuation (22). Even small urban creeks within built environments can reduce the urban heat-island effect considerably (13, 23). The 'everyday health dividends', on the other hand, are the physical health gains derived through a wide range of recreational and sporting activities such as swimming, surfing, fishing, kayaking and walking along trails near waterways (4). In addition, these outdoor activities provide the co-benefit of vitamin D being synthesised in our bodies in sufficient amounts.

Table 1. Health risks and benefits associated with the use of waterways.

Type of health determinant	Health risks associated with waterways	Health benefits associated with waterways
Physical	Injuries sustained during recreational activities (e.g. jetski collisions, sunburn, trip hazards, drownings, and bites/stings from dangerous aquatic organisms) (12) High turbidity due to high sediment loads can increase the likelihood of physical injuries due to poor visibility, while also reducing the efficacy of UV disinfection of microbial contaminants (12) Personal security risks (e.g. muggings in poorly lit areas) Deterioration of water quality or water sites may impede participation in physical activities (8)	Improved physical health (e.g. through use of walking trails and water sports such as swimming, surfing, fishing and wading) (4) Buffering from extreme events (e.g. flooding) (6) Climatic regulation, mitigating the heat-island effect (13) Benefits of moderate sunlight exposure (e.g. vitamin D synthesis) (12) Provision of food and water (5)
Microbial	Ingestion of waterborne pathogens (e.g. *Cryptosporidium, Giardia, Campylobacter* spp.) and adenoviruses in water contaminated by sewage and/or stormwater (12, 14) Infection by water-based pathogens (e.g. Leptospires and *Naeglaria fowleri*) (12, 14) Infection by pathogens spread by insect vectors that breed or bite near water (e.g. Ross River virus infection) (12) Pathogens associated with engineered water systems including water parks (e.g. *Pseudomonas aeruginosa*) (15)	Bioregulation of pathogens via predation/competition (12) Sequestration of pathogens by natural vegetation (16) Protection against conditions fostering pathogen growth through intact riparian zones (e.g. increased sediment, temperature and nutrient levels) (12)
Chemical	Exposure to cyanobacterial toxins (e.g. *Lyngbya majuscula*)(17)	Reduced exposure due to pollutant filtration by wetlands (18)
Psychological	Loss of relaxing/stress-reducing aesthetics (6) Solastalgia – existential distress caused by environmental deterioration or loss (19)	Improved psychological health (2) Nature contact is associated with reduced mental ill-health (e.g. stress, anxiety and depression) and promotion of wellbeing (20).
Social	Loss of sense of place and/or cultural identity (2) Deterioration of water quality or water sites may impede opportunities for social interaction (2)	Improved community cohesion (21) Enhanced sense of place (21)

Microbial hazards, particularly pathogens, are of high public health concern. Pathogenic bacteria, viruses, protozoa and helminths have the potential to cause a wide range of acute, delayed, chronic and fatal health conditions (12). Major point-sources of such pathogens include faecal pollution from wastewater treatment plants, sewer overflows and industrial effluents (2). Non-point sources include water runoff from surrounding landscapes, defective sanitation systems (e.g. onsite septic systems), as well as agricultural run-off and faecal pollution from bathers, wildlife and domestic animals (14). Human faecal pollution is considered to pose substantially higher health risks than other animal wastewater (24, 25), particularly due to potential exposure to human enteric viruses (25). Globally, epidemiological evidence shows that gastroenteritis (with symptoms such as diarrhoea and vomiting) is one of the most common diseases caused by a range of human pathogens via exposure to contaminated waters (2, 14). Routine microbial water quality monitoring of recreational waters in Moreton Bay by local authorities is generally limited to faecal indicator bacteria (Enterococci). Regular exceedances of recreational water guidelines (e.g. where 200–499 Enterococci CFU/100 mL triggers additional investigation and ≥500 Enterococci CFU/100 mL triggers temporary site closure for recreation, CFU – colony forming units) occur particularly after heavy rainfall (26). While these data are not generally available to the public, the general advice provided on the Healthy Waterplay website is to avoid swimming during, and at least one day after, heavy rain in open waterways and beaches, and for at least three days within confined bays and estuaries (27). Brisbane City Council is one of the authorities that does publish its microbial water quality data (28). Despite these exceedances, epidemiological evidence of outbreaks of gastro-intestinal illness associated with recreational use of these sites is lacking.

Not all microbes in and around water are harmful. Recent developments in metagenomics have unveiled the importance of microbial biodiversity by allowing us to profile the bacterial communities associated with specific aquatic environments. Studies conducted by Beale et al (29) in variably polluted reaches of the Brisbane River have used metagenomics to better characterise the responses of bacterial communities to contaminants. Research in this emerging field suggests that diverse bacterial communities play a crucial role in ecosystem health resilience and the recovery of areas following pollution events (30, 31). This resilience and recovery may play a factor in regulating which water-based recreational activities can resume and when following pollution incidents.

Chemical hazards in our waterways can present health risks under certain exposure scenarios. Actual levels of health risk are determined by the characteristics of the chemical, exposure routes and pathways, the nature and magnitude of exposures, and the characteristics of the individuals and populations exposed (32). Chemical toxicants can enter waterways rapidly via a massive influx (chemical spill) or very slowly and imperceptibly over time via complex pathways. The former often triggers a public health response that minimises exposure and therefore the health risk, whereas the latter can lead to chronic, biomagnified exposures via the food chain (18). At commonly observed concentrations, chemical hazards in recreational waters typically pose a lesser threat to public health compared with the other types of hazards. This is because the health risks associated with chemical hazards (e.g. pesticides and polycyclic aromatic hydrocarbons) are often a result of chronic or high levels of exposure that are not likely to occur via recreational activities due to dilution and limited durations of exposure (12).

Toxins produced by cyanobacteria can adversely affect health through dermal contact or accidental ingestion or aspiration of water (12). In Moreton Bay, regular annual blooms of the nuisance and potentially harmful cyanobacterium *Lyngbya majuscula* have been studied extensively (17, 33). Several key toxins have been isolated and characterised from these blooms and anecdotal evidence of toxic incidents reported; however, only limited epidemiological data are available linking toxins and severe skin symptoms among exposed recreational users coming into contact with blooms (17). Most documented cases of human illness associated with cyanobacterial toxin exposures, however, have been associated with drinking water (12). Health risks from cyanobacterial toxins in recreational waters are likely to increase given the widespread nature of the hazards in combination with rising global temperatures, agricultural nutrient run-off and population growth (34–36).

Perceived health risks from chemicals in waterways need to be managed alongside actual health risks. This can present a challenge as illustrated by a recent, locally relevant example. Contamination of waterways (including several sites in Moreton Bay) by a particular group of persistent chemicals known as per- and poly-fluoroalkyl substances (PFAS) has recently triggered high levels of community concern and regulatory attention (37, 38). A recent accidental release of these chemicals via a spill of firefighting foam by an airline into Moreton Bay, along with historical, long-term industrial/commercial use of PFAS has led to potential exposure routes being identified and public health advisories being released (37). Factors such as involuntary, past exposures for particular affected communities via contaminated groundwater, high levels of ongoing media coverage, scientific complexity and uncertainty about long-term health effects have all contributed to elevated levels of perceived risk (38).

In contrast to the psychological risks posed by concerns generated by contaminants entering waterways, 'blue' environments can be a key contributor to people's psychological wellbeing (9, 20). For example, research from New Zealand has shown that higher levels of blue space visibility within a person's local urban area is associated with lower psychological distress (39). Further, non-coastal blue spaces, such as rivers, have also been shown to have health-enhancing aspects serving as therapeutic landscapes (20). Research investigating UK census data found that people living closer to the coast were more likely to report a good status of health (4). Given that approximately 85% of Australians live within 50 km of the coastline, these findings are especially interesting (40). With Brisbane, the Sunshine Coast and the Gold Coast being the major population hubs in South East Queensland (SEQ) (40, 41), coastal lifestyles are clearly valued by residents and research is beginning to emerge about how people interact with and what they value about these landscapes (3, 21). Furthermore, research from the UK also showed that the positive health effect can be more pronounced in deprived areas (4), indicating that blue environments may serve as an important instrument for tackling health inequalities. Urban blue environments may be of critical importance for buffering the stress- inducing characteristics of city living and living in areas of socio-economic disadvantage. Programs addressing place-based disadvantage in

SEQ, such as the 'Logan Together' partnership (42), could benefit in the future from more-explicitly nature-based interventions. Water environments such as riverside parks, lakeside trails and beaches provide important settings for people to come together with family, friends and neighbours or as part of larger organised community events. This is evident by the number of popular waterway themed festivals and events that occur in both SEQ (e.g. Riverfire in Brisbane, Lines in the Sand festival on North Stradbroke Island) and across Australia.

Degraded blue environments can negatively impact a person's sense of wellbeing by causing distress or creating a sense of loss (2, 6). This environmental distress, captured by the term solastalgia, is produced by environmental change impacting on people while they are directly connected to their home environment (19). As waterways face increasing pressures, signs of degradation can become more obvious and frequent, particularly under projected climate change scenarios. It is therefore likely that communities that witness algal blooms, fish kills, pollution of their local water environments or climate change impacts may be vulnerable to solastalgia. Similarly, communities may lament over the loss of coastal ecosystems to land reclamation works, canal estate developments and rising sea levels. As traditional custodians of the land, Indigenous communities in Moreton Bay are particularly vulnerable to experiencing a strong sense of personal loss in the face of environmental degradation (43). Once waterways become degraded it can also deter people from visiting and valuing them, decreasing their opportunities for social interaction.

Conceptual frameworks for managing waterways for health

Environmental health, as a discipline, recognises the importance of quality physical environments in protecting health and promoting wellbeing. Moreover, it recognises the complex, reciprocal relationships between human and ecosystem health and advocates for policies that aim to achieve the 'double dividend' of enhanced ecosystem services and improved health outcomes (1). The development of effective policies and interventions in this cross-sectoral domain, however, is often constrained by factors such as segregated governance structures and inadequate linkage across sectors of the abundant data being routinely collected about natural resources, planning, environmental management, health and social services. This 'Data Rich, Information Poor Syndrome' (DRIPS) was recognised by intergovernmental agencies around the time that the milestone United Nations Conference on Environment and Development was held in Rio de Janeiro in 1992. Two integrative frameworks were developed to evaluate and track environmental performance and to connect measured changes in environmental quality with their causes and consequences. The development and adoption of the DPSIR (Driver, Pressure, State, Impact, Response) framework was promulgated by the Organisation for Economic Cooperation and Development (OECD) (44), while the DPSEEA (Driving force, Pressure, State, Exposure, Effect, Action) framework, was developed jointly by the World Health Organization, The United Nations Environment Program and the United States Environmental Protection Agency to make the pathways between environmental changes and human health outcomes more explicit (45). Both frameworks are designed to facilitate decision-making that considers not only the 'higher order' or distal determinants of environmental quality, but pathways through which society is impacted by enhanced or degraded environments. Bowen et al. (46) present a thorough overview and comparison of the DPSIR and DPSEEA frameworks, using international case studies to highlight their differences. Scotland's Good Places, Better Health Policy initiative in 2008 is featured as the most wide-ranging and inclusive case that shows the value of the DPSEEA framework as an auditing and communication tool among a broad range of policy constituencies and stakeholder groups (46).

Metrics or scorecards can be useful to monitor and communicate the effectiveness of our investments in waterway management. An important caveat here is that rigour around what we are actually measuring with such metrics is critical, as any deficiencies can easily be carried through to oversimplified, but popular messaging. In SEQ, the ecological condition of waterways has been assessed and rated through the internationally acclaimed Ecosystem Health Monitoring Program (EHMP) coordinated by Healthy Land and Water since 2000 (47). An overall Environmental Condition Grade (A–F) is assigned to each of 18 catchments based on a synthesis of 25 indicators reflecting key freshwater and estuarine aspects of the waterways. In response to the need to develop additional metrics to capture the social and economic values associated with waterways, the 5-star Waterways Benefits Rating was developed by Healthy Land and Water and added to the annual report cards in 2015 (47). The 1–5 star rating is based on the following six components:

1. Community satisfaction with local waterways;
2. Appropriate access to local waterways;
3. Personal benefits residents derive from using local waterways;
4. Community motivation to use and protect waterways;
5. Economic benefits generated through recreation; and,
6. Contribution relevant catchments make to providing clean low-cost drinking water.

This Waterways Benefits Rating is designed to gather data that would help us better understand how social and economic benefits may be affected by changing environmental conditions; however, it has some shortcomings with respect to capturing the inherent and complex linkages between humans and ecosystems being discussed in this paper.

The DPSEEA framework offers an alternative, more robust approach to the development of metrics that link environmental conditions with human health and wellbeing within Moreton Bay. The first three elements (*Drivers, Pressures, State)* share perspectives with environmental protection and the protection of water-based ecosystems. This includes the large-scale social *Drivers* that lead to *Pressures* that can alter environmental *State* conditions. The framework then brings in the public health perspective by linking changes in the *State* of the waterways to *Exposure* routes and health *Effects*. The example illustrated in Figure 2 shows how the DPSEEA framework captures some of the links between environmental conditions and health in recreational waters that could be applied to Moreton Bay. Figure 2 also provides examples of metrics that could be monitored as indicators of changes over time. *Drivers* include population growth, changing land uses, as well as global patterns of energy use and climate change. For the *Driver* of population growth, another metric could be the proportion of Queensland's population growth that is concentrated in

SEQ (88.3% in 2016–17) (48). A significant amount of research has focused on both climate change impacts and adaptation strategies in southeast Queensland, including numerous projects under the auspices of the South East Queensland Climate Adaptation Research initiative (49). Metrics of *Pressures* could include sediment inputs due to bank erosion (influenced by land use) and sewage overflows triggered by extreme weather events within an undersized, aging sewerage infrastructure. To assess any changes to the condition of the recreational waterways, *State* indicators (i.e. observable and measurable measures of water quality such as those metrics incorporated into the EHMP and levels of faecal contamination) should be regularly monitored at the recreational water sites. The *Exposure* element of the DPSEEA framework is designed to capture how people are exposed to the '*State* of the environment' variables (e.g. water quality) that impact on their health and wellbeing status (*Effect*). Bowen *et al.* describe the *Exposure* attribute as one that reflects the 'vectors of risk exposure (either risk elevation or diminution) that emerge as a consequence of environmental change', and *Effect* as a measure 'of change in health resulting from changes in risk exposure' (46).

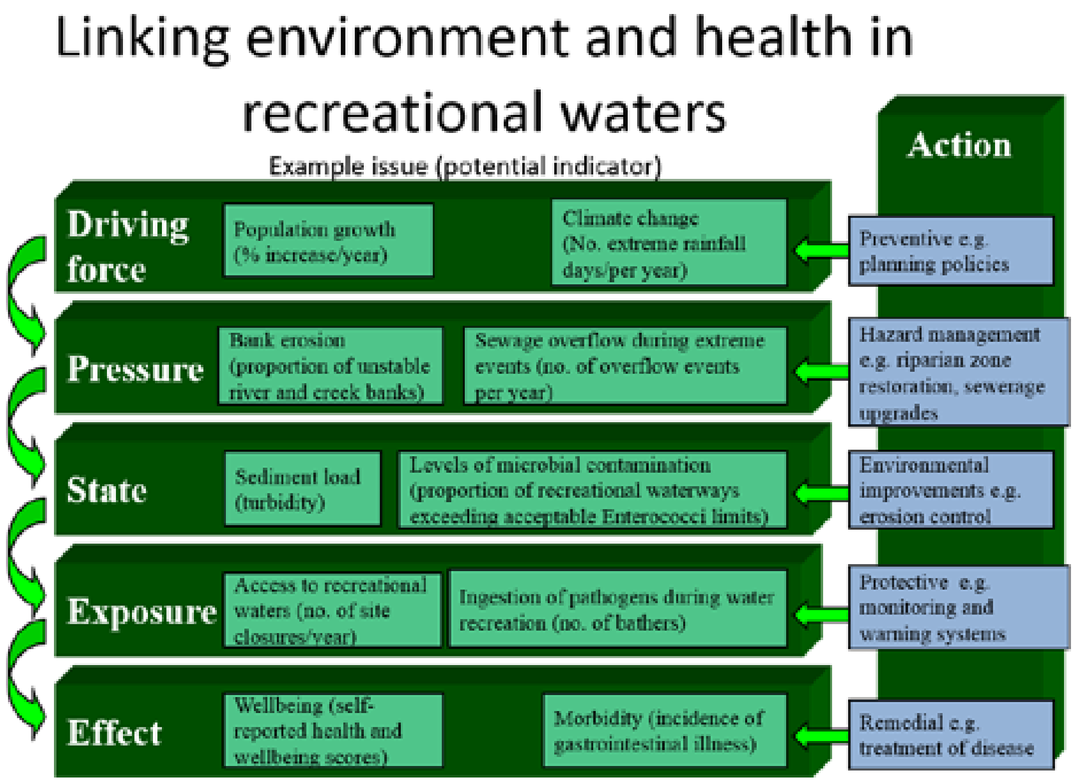

Figure 2. An illustration of how the Driving force, Pressure, State, Exposure, Effect, Action (DPSEEA) framework can be applied to the management of recreational waters.

While these definitions cater for both the positive and negative linkages between environmental quality and public health, in practice there is a paucity of routinely collected data that could be used for reliable *Exposure* or health *(Effect)* metrics. If we wanted to focus on health risks of recreational *Exposures*, biomarkers could be used to indicate exposure and models could be used to estimate likely numbers of pathogens ingested by recreational water users; however, these approaches are usually only applied in site-specific health risk investigations. On the other hand, focusing on the health-promoting exposures brings additional challenges, as reported benefits are typically narrative. To capture information on both health risks and benefits, it would therefore be best to combine metrics derived from measurements, where applicable, with stakeholder narratives to gain a more holistic understanding of the linkages. This approach is espoused by Waltner-Toews & Kay (50).

The 5-star Waterways Benefits Rating incorporated into the Healthy Land and Water annual report card brings us one step closer to capturing these positive benefits within Moreton Bay and its catchments. Unfortunately, neither the environmental *State* data relevant to public health (e.g. faecal indicator monitoring) nor the perceived benefits data (e.g. Waterways Benefits Rating) can be geo-referenced directly to EHMP monitoring sites. Using integrated frameworks such as DPSEEA could help us get the best value out of our ecosystem health monitoring and modelling efforts in Moreton Bay by shedding light on the structure of the complex interrelationships between human and ecosystem health.

The *Action* element of the DPSEEA framework captures the potential for multi-tiered management responses aimed at improving environmental and health conditions. A unique strength is that it shows how *Actions* can target multiple points in the DPSEEA pathway and be coordinated across policy sectors. It also facilitates the consideration and integration of more progressive, holistic management strategies such as health-based targets for drinking water management (51), water-sensitive urban design (52) and effects-based management (48, 53). The benefit of these strategies is that they shift environmental management from a regulator-driven, compliance approach to an environmental and community values-driven approach. This does not preclude using traditional tools such as zoning reviews, impact assessments, riparian zone restoration programs, environmental licensing regulations, health protection actions, and policy and clinical responses to the health outcomes. The merits and practicalities of using these approaches in Moreton Bay are currently being explored by a range of stakeholders, including water utilities, councils, researchers and consultants.

Integrative frameworks such as DPSEEA are designed to capture the complexity of the systems they represent. For example, a network of linkages is more likely to represent an issue of concern in Moreton Bay among a mixed group of stakeholders than a single cause–effect pathway. Importantly, DPSEEA can and should be applied flexibly and the stakeholders can begin to populate the elements of the framework from different starting points to promote a better, shared understanding of the integrity of the system as a whole.

Health effects too, are not limited to ill-health and an ongoing challenge when investing in ‘livability’ within catchments is how to capture the positive health and wellbeing contribution of our waterways. Several research projects in Moreton Bay are collecting valuable, in-depth empirical data that could populate parts of the DPSEEA framework. For example, several investigative approaches (microbial source tracking, epidemiological and quantitative microbial risk modelling) are being used by Kozak *et al*. to better characterise the potential health risks associated with exposure to diffuse and point-source polluted recreational waters (54, 55). Another project by Cleary *et al*. seeks to understand the role that ‘nature connection’ (the feelings, beliefs and behaviours that people have towards nature) plays in supporting mental health and wellbeing (56).

Variants of this particular conceptual model continue to evolve as our understanding grows. For example, the eDPSEEA ('ecosystem enriched DPSEEA') model, developed by Reis *et al*., extends the *State* element to incorporate the *State* of the ecosystem services, as well as positive and negative feedbacks between a wide range of the model's components. Using eDPSEEA facilitated better engagement with stakeholders and drew out the wider potential implications of reduced amenity on human wellbeing (57).

Conclusions

In striving for improved health outcomes and ecosystem services in Moreton Bay, we will inevitably come up against trade-offs or paradoxes. We need to better understand the science and social values behind these paradoxes to improve the alignment of environmental and public health strategies in order to maximise the gains from both public and private investment in them. Framing complex environmental health issues in Moreton Bay using models such as DPSEEA would provide the backbone of a more rigorous approach for linking existing data, identifying gaps and collecting relevant additional evidence to facilitate more effective actions at multiple levels and across several policy sectors. Combining emerging scientific tools and technologies with the narratives of stakeholders offers exciting new avenues to guide adaptive strategic management of Moreton Bay. The double-dividend of enhanced ecosystem services and improved human health outcomes is a worthwhile goal.

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