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Public health and water quality management in low-exposure stormwater schemes: A critical review of regulatory frameworks and path forward

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ABSTRACT

An international review of stormwater regulation and practices, especially for low-exposure, landscape irrigation schemes in urban environments, was undertaken with a view to identifying what could be used in Alberta, Canada. A general lack of clear guidance and regulation to manage stormwater quality and potential public health risks was identified, which could be hindering the uptake of stormwater schemes generally. Particular data gaps and weaknesses identified include nominal and event performance of treatment barriers for the main acute hazards, enteric viruses and protozoa, which impacts on the ability to quantify risks and appropriately manage stormwater uses. Building on an interest to utilize stormwater for water-sensitive urban design and the Australian risk-management approach for water reuse, further guidance for the development of a risk-based regulatory approach to stormwater schemes is proposed. Using the principles of Water Safety Plans we propose a performance-based validation approach, involving the development of site-specific stormwater use management plans (SUMPs) that integrate monitoring and auditing protocols.

1. Introduction

1.1. Context for innovation in stormwater management

Water management in face of climate change and global population growth calls for technological and institutional innovation: sufficient freshwater volumes of adequate quality (fit-for-purpose) need to be secured to meet a variety of uses while supporting economic development as well as ecosystems' health (Schewe et al., 2014). This urgency is even more obvious in urban and *peri*-urban environments that are experiencing rapid growth and continued environmental degradation worldwide. By 2050, 70% of the global population is projected to live in urban settlements (Lüthi, Morel, Tilley, & Ulrich, 2011). Australia, the most urbanized country, for example, has recently experienced, through the "Millennium Drought", the social and economic consequences and stress of water shortages associated with traditional reliance on climate-vulnerable surface water supply sources (Brown, Deletic, & Wong, 2015). In turn, major cities in Brazil (Pagotto et al., 2014) and in the southern US (Jones & Hunt, 2010) have and expect future significant drought periods. Given the uncertain availability of traditional water resources due to highly variable rainfall patterns, urban water security requires innovative strategic planning. Resilience can be built through the diversification of water sources and supply schemes, sometimes referred to as the portfolio management approach to urban water supply. Integrating alternative water sources at a range of application scales into such a portfolio combining supply and demand management options can increase flexibility and adaptability of the community water system, and reduce reliance on traditional sources of drinking water (Howe, Mukheibir, & Gallet, 2013). Through such an approach, the augmentation of large-scale water supply schemes from traditional sources like dams and water transfers and the construction of desalination plants can be deferred or avoided.

Alternative water sources include treated and recycled wastewater, blackwater, greywater, stormwater, and rainwater. These sources can all be economically harnessed through more or less

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decentralized schemes serving non-potable uses, from the household level to the scale of a large residential development (Mainali et al., 2014). Although a few examples of potable reuse schemes exist, alternative sources more commonly substitute high-quality potable water for a range of uses that involve a lower level of human exposure/risk from water, and therefore require a lower water quality: this is the emerging approach of fit-for-purpose water supply (summarized e.g. in Bichai & Smeets, 2015).

Technical challenges related to the variable quality and flows of stormwater in comparison with wastewater, and its limitations in terms of reliability and availability as a resource especially in dry periods, may have favored greater progress in wastewater reuse, especially in water-scarce regions, where wastewater irrigation has been widely used for many years (Jiménez & Asano, 2008). Yet, in addition to augmenting the water supply capacity of a city, alternative sources often bring additional environmental benefits into urban settings, such as flood management. It is the case of stormwater harvesting, increasingly approached through what is termed Water Sensitive Urban Design (WSUD) (Brown, Jackson, & Khalifé, 2010). While the traditional approach to stormwater management has long favored its rapid conveyance away from human settlements to prevent flooding and protect buildings, the emerging paradigm involves the design and integration of drainage features that minimize impervious cover, maximize rainfall infiltration or capture at the source, promote evapo-transpiration, and, ultimately, attempt to restore natural flow regimes in urban environments (Roy et al., 2008). In the WSUD approach, drainage objectives are combined with the treatment of stormwater, in order to protect receiving water ecosystems from runoff pollution and erosion, and in some cases, to use it as a freshwater resource, most commonly for irrigation purposes (Dobbie & Brown, 2012).

Securing adequate capacity of water supply in the long term is recognized as a critical factor to sustain economic development, environmental health and livability of cities. Nonetheless, the crucial role that public water services have played historically in improving human health and hygiene in urban environments should not be overlooked. The introduction of alternative sources and the delivery of fit-for-purpose water quality require mechanisms to ensure that public health protection is maintained, if not improved, as cross-connections between fit-for-purpose pipes and drinking water pipes have been reported to lead to disease outbreaks or customer concerns (Anonymous 2003; Storey, Deere, Davison, Tam, & Lovell, 2007). Such mechanisms should be embedded in regulation and best practice guidance in order to foster the development of these new schemes without compromising public health. However, as assessed in the present review, clear guidance and regulatory approaches have not yet been established in most parts of the world.

The World Health Organization (WHO) recommends the use of Water Safety Plans (WSPs) and Sanitation Safety Plans (SSPs) to provide a risk management framework to manage safe water from source to human exposure. For example, a WSP involves a site-specific assessment to identify local hazards in water, from the watershed to the consumer, as well as risk control measures, leading to the development of monitoring and management plans. Further guidance on WSPs/SSPs can be found in the latest version of the WHO drinking water guidelines (Bartram, 2009; WHO, 2011) and guidelines on wastewaters (WHO, 2015). The benefits of WSPs in drinking water systems have been shown through improved regulatory compliance, microbial water quality, and public health (Gunnarsdottir, Gardarsson, Elliott, Sigmundsdottir, & Bartram, 2012). While the approach has only recently been extended to wastewater management and reuse, through Sanitation Safety Plans (SSPs), it is consistent with the harmonized approach originally proposed through the 2001 Stockholm Framework (Fewtrell & Bartram, 2001), which encompassed all waters (including drinking water, wastewater, and recreational water).

In the risk-based management approach, however, questions arise regarding the explicit choice of a tolerable risk-based target, the efficacy of contaminant removal barriers, and the effect of system failures on health (Bichai & Smeets, 2015). Currently these safety plans are implemented via a semi-quantitative approach based on available literature and experience, as well as on local-workers' knowledge. However, with new water supply schemes from alternatives sources, experience and data are scarcer, hence very conservative assumptions may be used. Yet, being overly conservative towards public health protection entails higher costs and environmental impacts due to over-engineered systems or may completely discourage the industry from innovating with alternative water supply schemes. Therefore, objective, science-based risk quantification is needed to support decisions impacting risk-management measures. Quantitative Microbial Risk Assessment (QMRA) is a method that is used to estimates the microbial risks associated with human exposure to water through any route. Furthermore, it can be integrated into the WSP approach, as recommended by WHO (2016) and recently developed for decentralized reclaimed water uses in the U.S. (Sharvelle et al., 2016).

Stormwater harvesting schemes for landscape irrigation are increasingly part of the Canadian province of Alberta's stormwater management and LID strategy. At the national level, however, Canadian guidance on Stormwater Management Planning (NRC-CNRC, 2005) does not address water quality requirements. Furthermore, stormwater management in Alberta is currently framed under provincial guidelines (Protection, 1999; Government of Alberta, 2013), which, when accounting for water quality, only refer to physiochemical parameters and indicator concepts for the protection of water bodies and/or recommend design consideration for BMPs. Hence, human pathogen-specific parameters are not addressed in these Canadian guidelines, and this review was undertaken in part to address due diligence for the safe use of stormwater in Alberta.

In addition to microbial contaminants and to (commonly regulated) nutrients and suspended solids, stormwater may also carry inorganic and organic chemicals, hydrocarbons, pesticides, heavy metals, and potential endocrine disruptors, usually at low levels due to high dilution (Victoria Department of Health, 2013). Untreated stormwater may contain such chemical contaminants at levels comparable to that of treated sewage (Wong et al., 2012). Even though some level of chemical risk may potentially be posed when using stormwater, high exposures are highly unlikely with landscape irrigation, as contact volumes are typically low and exposure is sporadic; hence, microbial risks (also including their cyanotoxins and endotoxins) are the focus of this paper.

1.2. Challenges in stormwater regulation

In this paper, the current state-of-the-art in stormwater management was assessed regarding international regulation and practices, especially for low-exposure, landscape irrigation schemes in urban environments. Gaps and weaknesses were identified, as a lack of clear guidance and regulation may hinder the expansion of stormwater schemes and prevent their multiple environmental benefits. By nature, stormwater schemes tend to fall between areas of traditional environmental regulatory bodies, which may explain the void or blur in their regulation. As societies innovate, the building of additional new rules and regulation across different jurisdictions may actually make the process too difficult and hinder uptake. Therefore in this review of stormwater management regulation, we propose to step back to understand and clarify the intent of stormwater regulation. In addition, the risk-based management approach is put forth as a means to provide a framework and path forward to implement effective regulatory