# Peak health and the need for more sustainable urban water systems

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## ABSTRACT

Large centralized urban water services in developed countries like the USA still provide significant environmental impact via loss of ecological water services, energy use, loss of nutrients from agricultural production, and eutrophication issues. Current climate models predict that many regions will generally be increasingly more water stressed as well as prone to intense storm events, further exacerbating the negative effects of centralized water services. As a consequence of many interacting factors based around energy/water use and social inequity, Peak Health may have already been reached in the USA, with life expectancies equal to that of Cuba (75 years). From a global perspective, rapidly developing regions, most of which are in water scarce regions, make water-based sanitation unsustainable if not impractical. Hence there is a need to rethink how water services can be obtained for the health of developed and developing regions by lowering our environmental footprint as well as empowering individuals/communities to control their water/sanitation services in a health-promoting environment. Examples include net energy production from organic components along with nutrients returned to agriculture, particularly phosphorus that has known stores of available rock phosphate to only last 60-150 years. From a public health perspective, aging water mains and their vulnerability to intrusions by fecally-contaminated waters is a rising issue; all the more reason to consider an alternative approach to water distribution and handling of associated wastewater streams rather than rebuilding more of the same problem. Most interesting is that the single largest cause of waterborne illness identified in the US (legionellosis) is not of fecal origin, nor currently regulated in most parts of the world. Legionellosis is due to the growth of a pathogen (*Legionella pneumophila*), which may largely be an in-premise (building) issue rather than the distribution system *per se*. Hence *Legionella* and other similar indigenous pathogens that grow in pipe biofilms are not necessarily the responsibility of the distribution system provider. As we move to greater reliance on reclaimed waters, fit-for-purpose, the long-term ramifications of fecal and indigenous pathogen issues should be considered within a broader sustainability assessment if we are to further improve public health. A framework for a way forward is described.

## INTRODUCTION

During the past century, the treatment and distribution of drinking water along with the collection, treatment, and discharge of wastewater have significantly contributed to the extremely high quality of life enjoy in developed regions, in terms of public health and aquatic ecosystems. The introduction and implementation of rapid sand filtration and chlorination of drinking water during the first half of the 20$^{th}$ century has probably been the most important public health intervention in reducing infant mortality and extended people's lives, and is still cost beneficial for today's developing regions (Hutton *et al*. 2007). Nonetheless, significant questions are being raised as to whether our centralized engineered approach to water services are the most sustainable from the point of energy use, ecological service provision and human health protection – key issues considered in this paper for urban water sustainability.

A problem in some developed regions is that we are in danger of losing the public health, economic, and aquatic ecosystem health gains that we achieved during the last century because of a myriad of interacting factors. Economically, countries like the United States have been living off excess capital of their buried water infrastructure and treatment works providing drinking water and wastewater services as almost a "free good." In contrast, a number of European cities have been completely replacing old pipe infrastructure so avoiding potential health issues, but is that the only solution? There are certainly options like slip linings, *in-situ* reconstruction etc. (DeSilva *et al*. 2005) but in essence all of these solutions assume the current paradigm is sustainable in its broader meaning to society.

Secondly, from an ecological perspective population growth in many urban areas can not continue to be met by withdrawing increasing amounts of water from, and disposing of wastewaters to, the environment. On a global scale the ecological services we rely upon are already largely overstretched (Millennium Assessment Board 2005). This will only be exacerbated by population growth being highest in regions of the world most water stressed (WHO 2008b), including developed countries (Anon 2008).

Thirdly, climate change is an overarching factor that will, if not already (WSAA 2008), require the water industry to adapt its processes in order to treat 'new' drinking water sources as tradition sources become scarcer and highly variable in quality and quantity (Anon 2002; Campbell-Lendrum and Woodruff 2006; Barnett *et al*. 2008; Smith *et al*. 2009). Wastewater utilities in developed regions are already dealing with receiving streams than can no longer assimilate the wastes being discharged to them. Concurrently, there are land use and demographic shifts taking place within various states further exacerbating water supply availability and quality issues, as well increasing the occurrence of waterborne diseases (Rose and Dreelin 2008). Related to the concern of global warming is the cost of energy and greenhouse gas emissions. In the United States for example, the water industry is the third largest consumer of water (behind agriculture and power plant cooling water usage), directly accounting for approximately 5% of the total electricity production. Further, more than 10% of a US utility's total operating cost is for energy, with direct US water and wastewater energy usages of 300-3800 kWh/MG[1] and 800-3500 kWh/MG respectively (Carlson and Walburger 2007). These estimates however do not include embodied energy in our infrastructure and systems. When the major embodied energy components are included, it can been seen from Table 1 that significantly more energy is used, and that relative differences with increasing treatment can be better quantified. For example, simply adding activated sludge secondary treatment doubles energy requirements to that of primary wastewater treatment, and distributing tertiary-treated disinfected recycled non-potable water to domestic customers quadruples overall energy use. Other interacting effects, such as eutrophication potential and health effects, have also been considered using LCA and risk assessments (see Malmqvist *et al*. 2006; Lundie *et al*. 2008), but the focus for this symposium session is on emerging health (and related energy) issues associated with distribution systems.

**Table 1 – Typical energy use (including embodied) and relative contributions for various wastewater treatment steps and distribution to customers for Sydney, Australia** (based on Lundie *et al*. 2005)

| | Treatments* | | | | | | |
|---|---|---|---|---|---|---|---|
| Energy-contribution for: | Primary (P) | P + Secondary | P+S + Tertiary | P+S+T + UV | P+S+T + MF | P+S+T + Dist'n | Waste-water Dist'n |
| Electricity for treatment [kWh/m$^3$] (mean value) | 0.35 | 0.58 | 0.72 | 0.79 | 0.84 | 1.47 | 0.07 |
| Primary energy for electricity [MJ/m$^3$] | 4.20 | 6.95 | 8.59 | 9.47 | 10.10 | 17.61 | 0.81 |
| Primary energy for chemicals [MJ/m$^3$] | 0.71 | 2.22 | 2.74 | 2.74 | 2.74 | 2.74 | --- |
| Total [MJ/m$^3$] | 4.92 | 9.17 | 11.33 | 12.21 | 12.84 | 20.35 | 0.81 |
| Relative contribution | 100% | 186% | 230% | 248% | 261% | 414% | 16% |
| **Factor contribution** | **1.0** | **1.9** | **2.3** | **2.5** | **2.6** | **4.1** | **0.2** |

*Treatments: Primary is physical solids reduction; Secondary is biodegradation of organic carbon to carbon dioxide; Tertiary is further treatment for nitrogen and phosphorus reduction; UV is ultraviolet light disinfection; MF is microfiltration removal of particles including most bacteria and parasites; Dist'n is the distribution of drinking water used for sanitary purposes; and wastewater distribution is the energy used for non-potable water domestic distribution. Thermal energy demand has not been included in the above calculations.

## Why the Current Urban Water System?

Despite our centralized water services being engineered to meet public health protection, in hindsight, the direction chosen is now not considered the most sustainable – starting in the mid 1800's when London's senior sanitary engineer Sir Joseph Bazalgette instituted major sewer systems on the basis that bad air (miasma) resulting from human wastes fouling the Thames River, was incorrectly thought to cause cholera and typhoid. The

[1] A kWh/MG is a kiloWatt hour per million US gallons (1kWh/MG = 3.6MJ / MG = 0.000951 MJ/m$^3$ = 0.000264 kWh/m$^3$ as 1 gallon = 0.00379m$^3$)

word Sewer means "seaward" in Old English, and that was the start of the 'solution to pollution was dilution' instituted during Queen Victoria'a era and used by many sanitary engineers to this day. Furthermore, large centralized systems managed by a monopoly where the engineer 'ruled' suited the Victorian era with a large underclass of poorly educated people.

The large-scale introduction of the flushing toilet from the 1890's only exacerbated the need for larger sewers and waterworks, with the latter primarily articulated throughout cities for fire fighting (so to reduced house insurance premiums), with only some 10% required for drinking water purposes. Also lost was the concept of 'night soil' for nutrient recycling to agriculture, partly due to practicalities in not being able to readily cart the wastes resulting from rapidly populated cities of the industrial revolution, and partly due to a mind shift that considered it 'waste' not a resource.

However, public health problems were much more pressing than the environmental or agricultural, so the water closet was almost universally adopted and water-based sanitation became the norm (parts of Japan for example being the exception). Further, in most developed regions, 'big pipe' networks also dominated for drinking water provision. Figure 1 shows the imperatives driving innovation in water services over time. Each phase was guided predominately by the imperatives listed across the top of the diagram. Hence the labeling of the water professional has varied from civil engineer, sanitary engineer to environmental engineer. The social and institutional structures in which these changes were deployed, however, reflect a lag as shown across the bottom (Livingston *et al*. 2004). The outcome from all these developments has been an increase in per capita daily water use from some 30-50 L pre-flushing toilets to over 400 L in North America today ((Black and Fawcett 2008)). As important has been the development of separate specialized bureaucracies with governance of drinking water, stormwater, wastewaters, water reclamation and watershed management; mostly with poor coordination between these specialized agencies.

In essence, the institutions of water management have been built primarily around protecting the health of city residents, often overcoming significant environmental obstacles (such as hilly terrain or scarce source waters) in the commitment to big-pipe-in, big-pipe-out infrastructure. Management structures of water service institutions have reflected the emphasis on technological intervention and systems (also privatization was seen as the answer during the 1990s; yet we just needed better management). Technical knowledge and expertise has been built up in such single purpose institutions, rather than also integrating environmental and social needs. Now there is widespread realization of the mismatch between our technological infrastructure, institutions and the natural water cycle that has been modified to provide for urban development (Livingston *et al.* 2004).

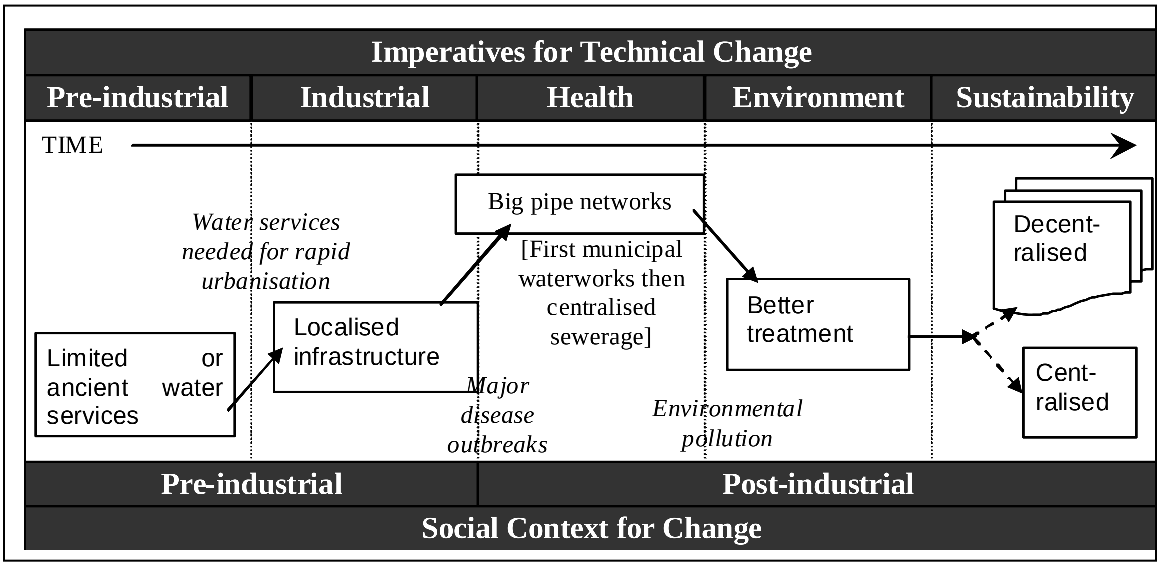


Figure 1 Eras in water services management (from Livingston *et al.* 2004)

## Public Health Links to Urban Water Systems

Our current water infrastructure is vulnerable to intrusions and leakages, both of which still result in disease outbreaks. For example, leaking sewers that discharge raw sewage to sites used for recreation or sources of drinking water, current problems that are likely to worsen due to climate change (Rose *et al.* 2001). Also, intrusions of pathogens into drinking water distribution systems now represent the most common cause of waterborne outbreaks from US drinking water supply systems ((Yoder *et al.* 2008)). Most interesting is that the single largest cause of waterborne illness (legionellosis), is not currently regulated in the US or most parts of the world, partly due to the growth of the pathogen (*Legionella pneumophila*) being largely seen as an in-premise (building) issue rather than the distribution system *per se* (Moore *et al.* 2006; Lau and Ashbolt 2009). Nonetheless, the burden of those waterborne diseases is relatively minor compared to developing regions, or when compared to ill effects in developed regions due to social injustice, obesity, heart disease and mental illnesses (WHO 2008a). Yet taken together, that is urban water systems and potentially peak (health) life expectancies having been reached in the US, it is interesting to speculate on potential pathogen issues that may result from future sustainable water systems (Lundie *et al.* 2008). The next sections explore some potential systems of the future, and conclude with a summary of potential pathogen issues.

*The Urban Water Cycle of the Future*

It is becoming increasingly evident that our current step-wise multiple barrier approach to protecting source water, treating and distributing drinking water, and collecting, treating and discharging of wastewater may not be protecting public and economic well-being as we should want, nor does it support ecological services. Legislatively, technologically, and institutionally we should take a holistic approach to the urban water cycle. Novel water technologies alone, while advancing at an increasing rate (Shannon *et al*. 2008) are only part of our water future. For example, drinking water distribution systems are designed around providing fire fighting flow requirements, not routine customer requirements. Hence, protecting water quality is further compromised by the oversizing and stagnant zones in current distribution systems. Therefore, part of a more sustainable solution is to research alternatives to water-based fire fighting, where water damage from firer fighting is a major economic cost too.

Overall, key changes are necessary in the water industry, as illustrated in Table 2, starting with a fundamental change in the established organizational structure of water management organizations (Beneke 2004). The drinking water treatment industry must look beyond its current technological boundaries and be managed from a sustainability perspective. Technology too can move from the $19^{th}$ century approaches to better embrace novel self-cleaning surface materials and real-time monitoring and control in order to mitigate the risks from emerging contaminants and reduce energy cost, greenhouse gas emissions and residuals generation. It may not be so far fetched to consider localized/household fuel cells or hydrogen cars providing for potable water needs, leaving requirements for non-potable municipal water for distribution infrastructure. To provide for the 'right' mix of novel solutions, however, new holistic assessment tools and integrated governance structures must exist so that future water services have an institutional home and champion (Lundie et al. 2008).

It is likely that not only will there be an increase in dual distribution systems (Okum 2000), satellite treatment, new network design and operation but also multiple piping and treatment systems providing reused water for irrigation, on-site blackwater treatment or at the decentralized neighborhood scale, multiple stormwater best management practices, and in-line wastewater treatment. Net energy production from food and fecal 'waste' streams may most effectively be achieved by keeping such streams separate from greywater, the largest and easiest fraction for local (non-potable) reuse. Along with rainwater reuse, these open up the possibility of providing various water supplies, in what is know as water fit-for-purpose (Figure 2). Given that greywater represents over 70% of the water in a conventional sewer, largely recycling treated greywater within the producing community/household would dramatically reduce the need for large sewers and drinking water supplies. In so doing, leaving the energy-concentrated food and fecal 'blackwater wastes' for far more efficient energy and nutrient recovery, possibly conveyed in pressure or vacuum sewers to minimize contamination of the local environment (Otterpohl *et al*. 2003). Furthermore, such an approach would reduce demand on 'outside' water resources by up to 70% compared to conventional developed urban water systems.

Table 2 Paradigm shift required in urban water management (adapted from Pinkham 1999)

| **Aspect** | **Old Paradigm** | **New Paradigm** |
|---|---|---|
| Human waste | Nuisance (odorous, pathogens) | Resource (nutrients back to agriculture) |
| Stormwater / used water | Nuisance (flooding, should be removed quickly) | Resource (alternate water source, should be retained, reused or allowed to infiltrate where possible) |
| Demand & Supply | Build supply capacity to meet growing demand | Manage demand in line with resource (supply) limits. |
| Quality | Treat all to drinking quality | Supply water 'fit-for-purpose' |
| Cycle | Once through | Reuse, reclaim, recycle |
| Treatment infrastructure | 'Grey' – i.e., unnatural, engineered systems | Mimic or include use of natural ecosystem services to purify water |
| Scale | Centralised: bigger is better (economies of scale) | Decentralised is an option (diseconomies of scale); avoidance of inter-basin transfers |
| Diversity | Standardise: limit complexity | Allow diverse solutions, determined by local needs and situations |
| Integration (physical) | Water, stormwater, sewage separated physically | Separation of water cycle is reduced because 'waste' water is reused not discharged |
| Integration (institutional) | Water, stormwater and sewage managed by different authorities / departments, under different budgets | All phases of urban water cycle managed in coordination, allowing physical integration and reuse |
| Public & stakeholder participation | Public relations exercise – public and other stakeholders are approached when final choice is made | Active engagement of stakeholders in collaborative search for mutually beneficial solutions (from start until end) |

## CONCLUSIONS

Developed regions with decaying water infrastructure and rapidly developing regions both appear to have unsustainable pathways via traditional water-based sanitation. If not only for broad economic reasons, household water service management needs a new paradigm. Our water management institutions and perceptions about safe water will also need to evolve to facilitate this change. Yet public health protection needs to be a major pillar for a sustainable future, and with any novel engineered system, there will be novel ecological niches for pathogens to develop.

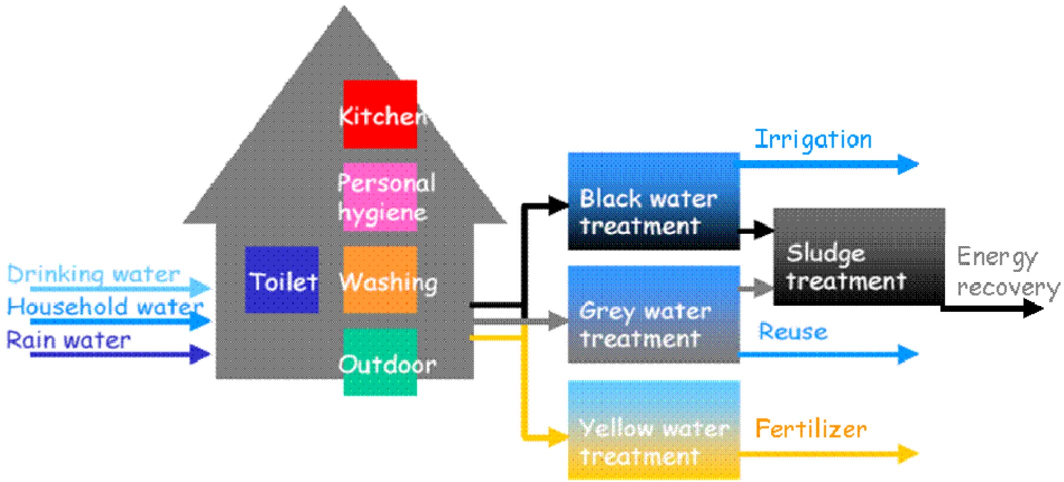


**Figure 2** **Illustration of potential household waters-fit-for-purpose and nutrient/energy recovery streams**


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