We can see that these principles are generic and can be applied at all scales from international to local.

Property rights regimes can be characterised by the rights holders and their rights (see **Table 1**). We can illustrate this with a public impoundment. Government, as the owner, would have a bundle of rights such that it can control access, withdraw rights allocated to others, make and implement management decisions, exclude users, and alienate the resource for particular purposes. By contrast a fishing club that has been granted the rights of fishing would be able to control access to fish, withdraw rights from those who abuse the right to fish, manage the fishery, and exclude those considered to be undesirable. A visitor who is granted access has no authority to withdraw right, make management decisions, or alienate the resource for other purposes.

COLLECTIVE MANAGEMENT

The rights regime brings order and incentive for collective management. When there is no mechanism to regulate who has rights and what those rights are, it opens opportunity for individuals to take advantage, leading to use that is not sustainable, as shown for the Rovuma River. And, when we are unaware of rights that users may have, sometimes established over generations, we make decisions that can have unintentional consequences that are of considerable significance, as illustrated (see **Figure 2**) for the rivers South Africa shares with its neighbours.

Managing the use of common pool resources requires that all resource users understand, agree to and support the apportionment of rights to access and use ecosystem services. In other words, agencies have to implement a property rights regime in which users are granted rights and responsibilities that encourage self-regulation within the parameters set by the government that owns the resource on behalf of the people. It is government's responsibility to establish the formal institutional arrangements for governance, while the various user sectors are responsible for establishing the informal institutional arrangements necessary for self-regulation. The success of formal institutions such as national policy and regulation is strongly dependent on how effective informal institutions are in ensuring compliance.

This understanding encourages us to appreciate that natural resources, especially common pool resources such as water, are situated in complex social–ecological systems. Exposing the feed forward and backward loops and emergent properties enables learning about likely consequences of allocation decisions for system resilience. It also encourages us to seek fundamental solutions while addressing the increasingly urgent symptoms. Importantly, exposing the dynamic connectedness between the subsystems encourages appreciation that resilience can be achieved only when we incorporate robust, informed dialogue in governance, directed at trade-offs in access to and use of our increasingly scarce natural resources[4]. ES

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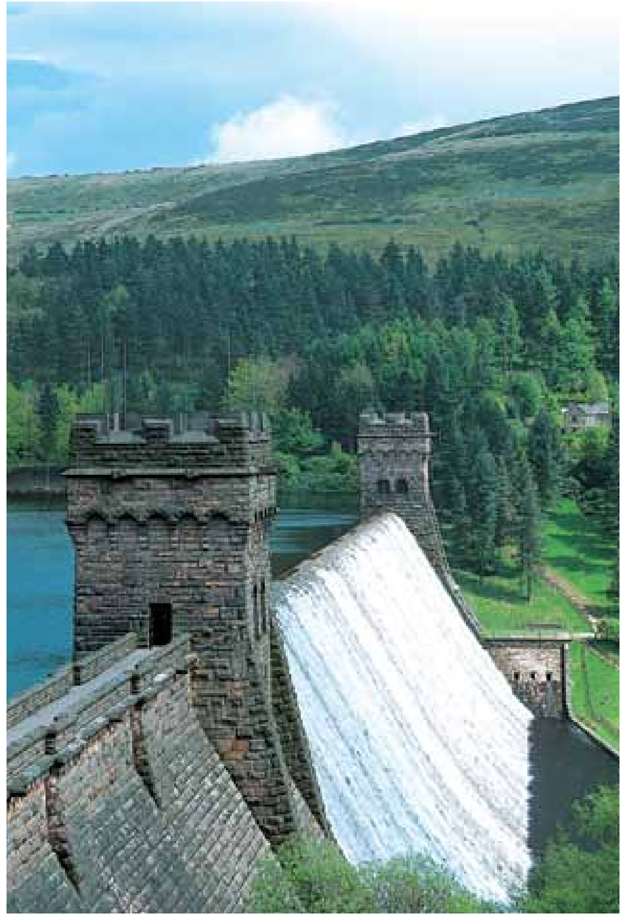
Urban water security as a function of the 'urban hydrosocial transition'

Chad Staddon and **Sean Langberg** introduce the concept of urban hydrosocial transition as a way of thinking about the complex and changing relationship between cities and water services, and present a brief case study of Bristol, UK, to illustrate the concept.



▲ **Figure 1. Ladybower Reservoir: early hydromodernity in England's Peak District. (© Severn Trent Water, used with permission)**

The development and extension of water services infrastructure has been a key foundational element of industrialisation and urbanisation since at least the 'Great Sanitary Awakening' of the mid-19th century. As urban areas became both larger and more densely inhabited, the collective need for better water services (drinking water and sanitation in particular) became overwhelming. Cities simply could not grow beyond a certain relatively modest size without the simultaneous articulation of an integrated water services infrastructure to replace the piecemeal local arrangements then in place, a reality amply demonstrated by Dr John Snow's intervention during the 1854 cholera epidemic in London. The mid-20th century completion (in Europe, North America and parts of Australasia) of the resulting project of mass provision of standardised water supply and sanitation services, elsewhere called 'hydromodernism'[1], was then followed by several waves of restructuring in the water-services value chain, based particularly on new ideas about the respective roles of the public and private sectors, new technologies and the water needs of the natural environment.

Of course, in much of the developing world, even hydromodernism is as yet unattained and perhaps unattainable. In addition, rapid urbanisation in many developing nations has gone hand in hand with the growth of what are called peri-urban areas that combine urban and rural characteristics and present new challenges to water (and other) services provision[2,3]. Despite concerted international efforts in recent decades, there are still at least a *billion* people in the developing world without adequate access to basic water services. A typical pattern, exemplified by Kampala, Uganda, involves a very limited extent of piped drinking water and sewerage interconnection to urban households (hydromodernism), with the vast majority depending on expensive private water sellers, local water collection (often undertaken by children), and defecation in pit latrines or in the open. Dr Snow would be horrified by the high level of water services insecurity prevailing in many 21st-century cities.

Fortunately there is a way of easily presenting the historical progression from a low level of water services to a higher level. Cities around the world can be understood from the point of view of their location within the 'urban hydrosocial transition' (UHT), a

FEATURE

historical geographical framework that sees cities as manifestations of successive 'hydrosocial contracts' between agents of economic, political, cultural and technological change. This concept builds on work undertaken by Brown and Morrison[4] on 'water-sensitive cities', Lundquist *et al.*[5] on the 'hydrosocial contract', Swyngedouw[6] (2005) on 'urban metabolism' and Thapa *et al.*[7] on 'water security indices'. A key innovation offered here is the simplified three-part historical geographical schema based on a limited number of readily available key indicators.

Here the UHT is introduced as a way of thinking about the complex and changing relationship between cities and water services. In addition to permitting observers to place any given city on a comparative continuum of hydrosocial development, the concept also suggests likely hydrosocial development futures. The salience of the UHT concept is illustrated through a brief case study of Bristol, a middle-sized city.

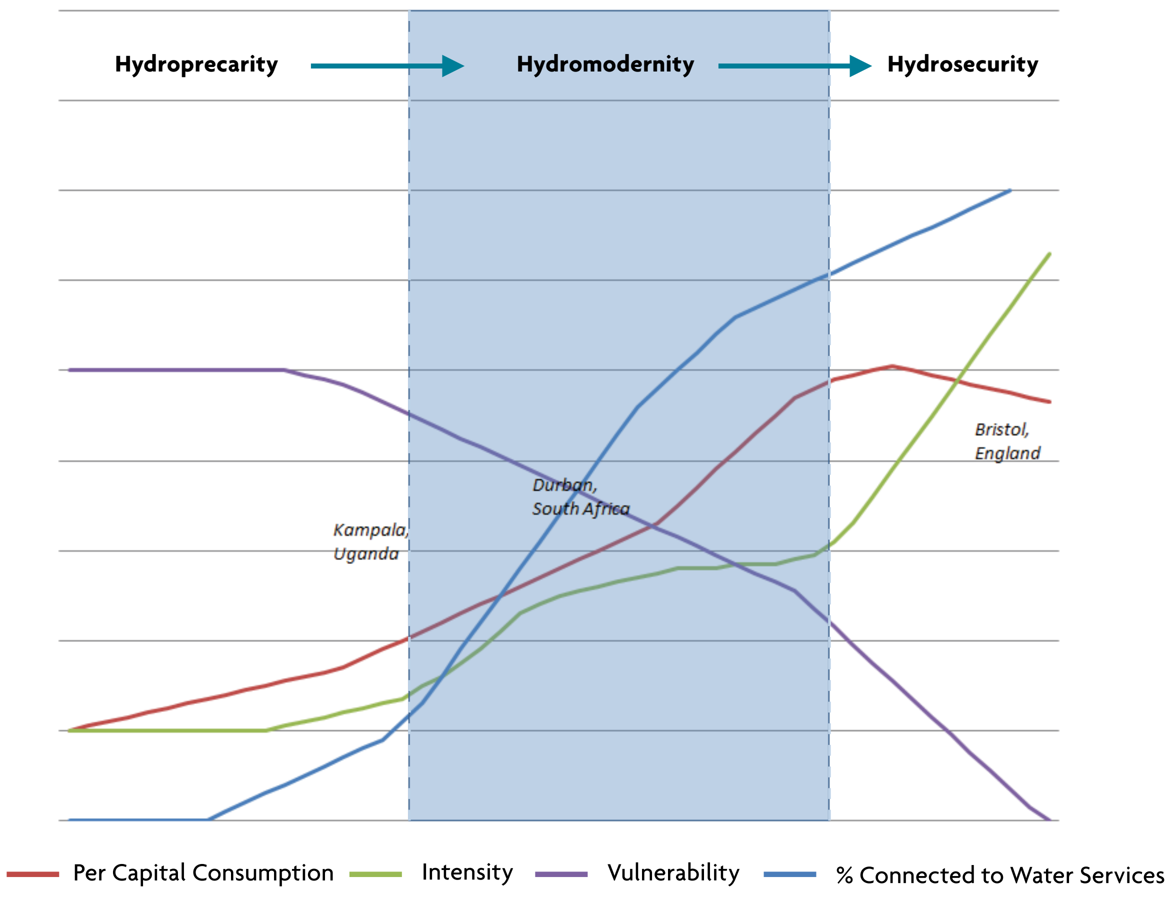
THE URBAN HYDROSOCIAL TRANSITION

We are used to the basic idea that different sorts of services or conditions go through stages and this is essentially what the UHT model proposes. It postulates that all cities can be located within a three-stage broadly historical transition from an early phase, called 'hydroprecarity', through a middle phase – hydromodernity, towards a contemporary phase, called 'hydrosecurity'. This is not to say that cities must move through these phases at the same rate, or even that they cannot evoke characteristics of multiple stages – indeed a certain hydrosocial hybridity definitely characterises many developing world cities.

Without sufficient space here to explore underlying drivers of hydrosocial transition (something we are currently working on), we must restrict our attention to empirical description of the model. There is a useful synergy here with Thapa *et al.*'s[7] contribution to this issue on water security indices, inasmuch as they may offer one concrete way of characterising numerically the different phases of the UHT. They focus on four key performance indicators: percentage served by piped water supply, percentage served by wastewater systems, annual damage due to flooding (an indicator of poor drainage) and measure of urban environmental quality. To these we propose adding the following indicators:

- daily per-capita water consumption; and
- a measure of capital intensity in water services provision.

The first of these measures relates to the fact that the transition from Phase 1 to Phase 2, hydromodernism, meant that householders could start to develop new uses for piped water, such as more fixtures and fittings, dish and clothes washers, and a taste for more water-intensive landscaping. **Figure 1** shows the sorts of large-scale infrastructure associated with hydromodernism. Such uses go well beyond merely providing personal hygiene and hydration, accounting for perhaps 40–50 per cent of current per-capita per-day domestic consumption.



▲ **Figure 2. The urban hydrosocial transition.**

By Phase 3 per-capita daily consumption starts to reduce as a function of growing conservationist views, both on the part of householders (who change water behaviours) and their governments (who bring in new rules to regulate for water efficiency in the built environment), and a shift towards water efficiency, particularly with respect to pressurised and hot water use (as these both require additional energy which is disproportionately expensive). Capital intensity in water services has been growing since we stopped just collecting water from open water sources and looks set to continue to grow, with the recent implementation in the UK of expensive UV treatment, ozonation, and granular activated carbon treatment to provide for only modest increases in water quality security. In Phase 3, water intensity in both the productive and domestic spheres also rises, partly as a function of an emergent biocentric conservation ethic, but also because regulation of abstractions and discharges (see this issue) becomes progressively tighter and the energy needed to move, pressurise, treat and heat water is rising disproportionately.

On our reading, Thapa *et al.*'s variable 'damage due to flooding' could usefully be recast as an indicator relating to overall resilience of the water services network to all sorts of challenge, including drought as well as flooding.

Figure 2 brings several of these variables together into a pictorial representation of the three phases of the UHT. It shows that Phase 1, hydroprecarity, is characterised by a low, but rising, proportion of the population covered by piped water supply and sewerage and the concomitant rise in both absolute as well as per-capita consumption. As urbanisation increases, a point is reached where absolute consumption begins to accelerate faster than per-capita consumption, largely due to the ways in which we conceive, build and maintain urban environments during the second, hydromodernist, phase. Moreover, there is an inevitable lag between the technical and administrative possibility of greater domestic water use and its reality, linked to the slow progress of replacing pre-existing urban fabric.

Put another way, in the UK, replacing crowded urban dwellings of the late 19th and early 20th centuries with the larger, more suburban dwellings of the mid and late 20th centuries takes considerable time. By contrast, in the USA and Canada, where many cities were urbanising 'from scratch', and space was less constrained, this process was much quicker. In all cases, however, a point is eventually reached where both per-capita and absolute water consumption actually start to decrease and water intensity, at home and in the economy, continues to rise. Simultaneously the capital intensity in water services undergoes a rapid acceleration, largely as a function of the need to guarantee the continued operation of the system in any context or weather. This heralds the arrival of Phase 3, hydrosecurity.

The UHT model is intended first and foremost as a descriptive model, allowing urban water services managers, planners and scholars to see where, on the general historical geographical development path, a given city or urban region may be located. This knowledge can then be used to predict future development paths and challenges, subject to two conditions.

First, it is likely that, as with other forms of urban infrastructure, urban hydrosocial systems not yet in Phase 3 could accelerate their arrival through state policy and massive infrastructural investment. There is even the possibility of stage jumping, again if there is the right combination of state policy and capital investment. Several cities in the Persian Gulf region have done exactly this, moving from Phase 1 to Phase 3 in little more than a generation.

Second, we do not suggest that the UHT model describes all possible variables of interest to the story of urban water services provision. Rather, we have designed the model with a view to incorporating quantitative variables that should be relatively easy to acquire in most jurisdictions. The following case study should highlight empirically the key features and insights offered by the UHT model.

THE URBAN HYDROSOCIAL TRANSITION IN BRISTOL

▲ **Figure 3. St. Mary Redcliffe church (© Lukas Blazek)**

Prior to the attempt to create a mass water services system from the mid-19th century onwards, the only water supply for which Bristol civic leaders took responsibility was the pipe from Knowle to St Mary Redcliffe church, (see **Figure 3**) which had been originally installed by Robert de Berkeley in the 12th century.

Some neighbourhoods had developed their own very local systems, but as late as the early 19th century there was neither a public commitment nor the necessary technical infrastructure to create a comprehensive water supply and sewerage system. This systematic water services infrastructure was initiated in 1846 when the Bristol Waterworks Company (now Bristol Water) was created to develop and manage a uniform public drinking water supply network for the burgeoning city.

Currently Bristol Water supplies customers with approximately 300 megalitres (ML) of drinking water per day, drawn largely from two sources: the Sharpness Canal, and the Chew Valley and Cheddar Reservoirs to the north and south of the city respectively. The main Bristol sewage treatment plant, located at Avonmouth and operated by Wessex Water (see **Figure 4**), treats most of the sewage generated by the city of Bristol, approximately 210 ML of it each day. Plant upgrades and sustainability-orientated changes to the treatment process mean that it now transforms that sewage into its own power (through biogas recovery), agricultural fertiliser (which is given away virtually free of charge) and clean water for release back into the natural environment according to the terms of its licences with the Environment Agency.

From the point of view of the UHT the key things to notice are as follows. The shift from Phase 1 to Phase 2 was largely completed by 1900, when virtually 100 per cent of the urban population had some form of reliable water supply, sanitation was considerably improved and water services companies had become vertically integrated entities. Both direct measures (percentage population served) and indirect measures (health outcomes and disabilty-adjusted life years) bear this out. The transition from Phase 2 to Phase 3 was manifest in the 1990s when the emphasis began to clearly shift from 'more water from further' (to use Barraqué's[8] felicitous phrase) and 'more hard engineering' to more attention to behaviour change, efficiency and the environment.

The key drivers of business strategy for both water services companies are now firmly linked to environmental sustainability, horizontal integration with other synergistic services sectors, and water demand management. Strikingly both companies are now far more interested in encouraging consumers to use less of their services than they are in simply building more capacity to accommodate increasing demand. We are a long way from the 'more water from further' approach characterising the first phase of the UHT. Wessex Water, which provides sewerage services to Bristol and both water supply and sewerage to much of Bristol's hinterland, has trialled various smart metering and differential water tariff programmes with customers in its service area to see if they can realise cost-effective demand reductions. Both companies have invested heavily in improving infrastructure resilience to handle extremes of both flood and drought, which seem to be occurring with greater frequency than in the past.

CONCLUDING COMMENTS

In retrospect it is perhaps unsurprising that urban water services manifest common and predictable historical geographical development trends. It would perhaps be stranger if it were not the case. After all, technological innovations in, for example, wastewater treatment are transmitted through professional networks with ever-increasing speed, and, as we have seen, the hydrosocial contract has evolved slowly from an initial inkling that there was a role for the public sector in addressing water-related illnesses such as cholera in the 19th century through a period of industrial massification of water services towards the current phase of both greater democratic localism and environmental sensitivity.

The UHT is, however, not temporally lock-step or completely uniform; different places have experienced their own versions of each of these three phases at somewhat different times. The extent to which any particular local expression of one of its phases marks an improvement in water security depends upon, as Breen *et al.*[9] put it in their contribution to this issue, "how secure people feel with prospects for access to and equitable distribution of the benefits of aquatic systems". Further, as Breen *et al.* show us within this issue, such systems may provide more than drinking water and sanitation services; food, irrigation, transport, recreation and even spiritual reward may also be possible. ES

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▼ **Figure 3. Avonmouth Wastewater Treatment Works: beyond the 'engineering paradigm'. (© Chad Staddon)**

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