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Rethinking urban metabolism: Water, space and the modern city

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'Water is a brutal delineator of social power which has at various times worked to either foster greater urban cohesion or generate new forms of political conflict'. In the paper which follows, Matthew Gandy explores this statement by looking at the expansion of urban water systems since the chaos of the nineteenth-century industrial city. In this early period, the relationship between water and urban space can be understood by the emergence of what he calls the 'bacteriological city', defined by features such as new moral geographies and modes of social discipline based upon ideologies of cleanliness, a move away from laissez-faire policies towards a technocratic and rational model of municipal managerialism, and a connection between urban infrastructures and citizenship rights. Gandy goes on to discuss that while many cities never ultimately conformed to this model, the last thirty years has seen a fundamental move away from the bacteriological city to a more diffuse, fragmentary and polarized urban technological landscape. Characteristics here include declining investment in urban infrastructures, a desire to meet shareholder rather than wider public needs, oligopolistic structures amongst providers, the marketisation of goods such as water, increased health scares and mistrust from consumers, and polarisation of the quality of service provision. For Gandy, these shifts are better understood by more relational, hybridised, rather than functional-linear, notions of urban metabolic systems.

Introduction

> Water is the great connector and coordinator.
> Garrett Eckbo[1]

> Water is indispensable 'stuff' for maintaining the metabolism, not only of our human bodies, but also of the wider social fabric. The very sustainability of cities and the practices of everyday life that constitute 'the urban' are predicated upon and conditioned by the supply, circulation, and elimination of water.
> Erik Swyngedouw[2]

> Infrastructures, which were mutually reinforcing and totalising, are becoming more and more competitive and local; they no longer pretend to create functioning wholes but now spin off functional entities. Instead of network and organism, the new infrastructure creates enclave and impasse: no longer the *grand récit* but the parasitic swerve.
> Rem Koolhaas[3]

Urban infrastructure has often been conceived as a functional lattice of different elements which correspond to the different organs of the human body. The metabolism of the modern city has frequently been presented as an interconnected space of flows dependent on the external input of energy, materials and

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information. Yet irrespective of whether the city is celebrated as a dynamic machine or derided as a voracious monster, the metabolic view of the city raises a series of analytical dilemmas concerning the intersection between social and bio-physical dimensions to urban space. The idea of metabolism, whether used as societal metaphor or in relation to material processes, has emerged from disparate and often contradictory intellectual traditions. We need in the first instance to differentiate between those conceptions of metabolism that derive from nineteenth-century developments within the biological and physical sciences and those that originate within the field of political economy.[4] In a contemporary context, however, the bio-physical emphasis on urban metabolism as a homeostatic and circulatory dynamic predominates within urban and architectural discourse to the relative exclusion of neo-Marxian interpretations of metabolic processes of urban transformation.

The current upsurge of interest in organic architecture, the use of biological analogies in urban planning and design, along with recent neo-organicist explorations of the neurological or "thinking space" of the city, all underlie the importance of clarifying how scientific metaphors continue to play a significant role in contemporary urban discourse.[5] The value of the metabolic metaphor has been its emphasis on the complex interactions between social and bio-physical systems that allow the modern city to function yet the functionalist impetus behind much organicist thinking both now and in the past has consistently failed to grasp the way in which urban space is historically produced. This paper attempts to develop a dialectical rather than a functionalist reading of urban space in which an emphasis on dynamic processes of social and political contestation takes precedence over teleological conceptions of urban form. The term dialectical is used here to denote a mutually constitutive conception of relations between nature and culture in urban space: nature is not conceived as an external blueprint or template but as an integral dimension to the urban process which is itself transformed in the process to produce a hybridized and historically contingent interaction between social and bio-physical systems. In the case of water infrastructure the long-standing emphasis on the role of urban technological networks in the growth and development of urban space is extended to explore the symbolic role of water infrastructure in the modern city and the emergence of new forms of social and cultural hybridity.[6]

One of the difficulties in making sense of these changes has been the persistence of organicist metaphors for the understanding of the flows and networks that underpin the development of cities. If we are to understand the contemporary dynamics of urban infrastructure we need to overhaul the idea of urban metabolism inherited from the nineteenth century in which functionalist conceptions of cities took precedence over the analysis of structural dimensions to urban change. We can, for example, trace a close connection between the development of organicist metaphors in the nineteenth century and new approaches to urban analysis and interpretation associated with the nascent development of the social sciences: the new disciplines of sociology, psychology, political geography and psychoanalysis borrowed freely from the medical sciences in order to combine a series of scientific and moralistic discourses on the urban condition. "The pathology of the city," writes Anthony Vidler (2000: 25), "already fully present in the organicist metaphors of romantic, realist, and naturalist novelists from Balzac through Hugo to Zola, gained new and apparently scientific validation in the last quarter of the nineteenth century." The hygienist city promoted by the nineteenth-century public health movement conceived of urban space as an identifiable assemblage of organs: a functional whole that could be shaped and controlled according to a rationalized conception of human will. Yet the connection between water infrastructure and the ostensible transparency of the hygienist city

was always ambiguous because so much water infrastructure lay hidden either beneath the city streets or relegated to those marginal spaces on the urban periphery where "noxious trades" became concentrated in the wake of successive legislative measures to tackle urban pollution.[7]

Until recently, the understanding of technological networks and the "hidden city" had been largely left to engineers whilst other "visible" aspects of urban design were widely perceived as the traditional domain of architects and urban planners. This is partly a historical legacy of capitalist urbanization — the critical phase in terms of the politics and planning of urban infrastructure took place in the nineteenth century — but recent developments suggest that we are again entering a transitional phase in the physical constitution of urban space. The pervasive emphasis on the virtual or digital realm associated with the spread of cyber spaces and networks has problematized the role of the city as a tangible locus for physical interaction since the bulk of urban infrastructure remains resolutely fixed in space as a concrete dimension to the lived experience of the city.[8] Water infrastructure plays a pivotal role in the constitution of the "concrete city" not least because its expense and complexity precludes its effective substitution by alternative forms of service provision. For this reason water has become one of the focal points for new attempts to conceptualize the materiality of urban space and the evolving relationship between the human body and urban technological networks.

The paper begins with an exploration of what we might term the "bacteriological city" as a distinctive assemblage of social, political and technical elements which developed out of the chaos of the nineteenth-century industrial city. We explore the co-evolutionary dynamics between social and technological systems extending from the private spaces of the modern home to the largely hidden physical infrastructures which have enabled the modern city to function. We encounter, however, a series of anomalies and contradictions underlying this relatively stable configuration between space, society and technology, which problematizes many of the assumptions associated with conventional accounts of the development of the modern city. The second part of the paper considers how the fracturing of this earlier urban form has contributed towards the emergence of a new kind of urban technological landscape. The integrative impetus behind the development of modern hydrological networks has given way to an emerging dynamic of fragmentation and differentiation with profound implications for the future of the modern city and a viable public realm.

Plumbing the bacteriological city

The gloomy, crowded and disease-ridden nineteenth-century city serves as a critical focal point for many historical accounts of the evolution of urban technological networks and the transformation of modern life. The "bacteriological city" that emerged out of the chaos of the nineteenth-century industrial city was driven by a combination of factors: advances in the science of epidemiology and later microbiology which gradually dispelled miasmic conceptions of disease; the emergence of new forms of technical and managerial expertise in urban governance; the innovative use of financial instruments such as municipal bonds to enable the completion of ambitious engineering projects; the establishment of new policy instruments such as the power of eminent domain and other planning mechanisms which enabled the imposition of a strategic urban vision in the face of multifarious private interests; and the political marginalization of agrarian and landed elites so that an industrial bourgeoisie, public health advocates and other voices could exert greater influence on urban affairs. The bacteriological city was, above all, a new socio-spatial arrangement that could simultaneously ensure a degree of social cohesion at the same time as protecting the political and economic

functions of the modern city. Water played a pivotal role in this reconstruction of urban space to produce what we would recognize as an archetypal modern city with its closely choreographed intersection between technology, space and society.

Yet the hydrological transformation of the nineteenth-century city posed a fundamental dilemma for nascent forms of urban governance: whilst the provision of an improved water supply system could be achieved relatively easily the handling of waste water posed an immense technical, fiscal and political challenge. The introduction of centralized water systems in cities such as Paris in 1802, London in 1808 and Berlin in 1856, set in train a complex sequence of developments which would take many decades to resolve.[9] The accelerating impetus of what Sigfried Giedion (1948) describes as the "water revolution" from the middle decades of the nineteenth century onwards overwhelmed the sanitary arrangements of the pre-industrial city which relied on privies, cesspits and the activities of night soil collectors in combination with limited networks of storm water sewers. The installation of water closets also diluted the nitrogen value of human wastes for agriculture at the same time as the growth of cities rendered the activities of night soil collectors increasingly uneconomic with ever greater distances to potential markets. The economics of human manure was also progressively undermined by the development of synthetic fertilizers which began to play an ever greater role in agriculture (see Corbin, 1986; Laporte, 2000). Despite these developments, however, we find an intense debate in the second half of the nineteenth century over the flushing of human faeces into the new sewer systems of European cities: Baron Haussmann, for instance, strongly opposed any human wastes entering the magnificent new sewers of Second Empire Paris and similar arguments were made on behalf of Berlin by the agricultural chemist Justus von Liebig and for London by the prominent public health advocate Edwin Chadwick.[10] These differing notions of "urban symmetry" belie contrasting conceptualizations of a rational urban order: anxieties over the loss of human manure rested on a cyclical pre-modern understanding of wealth creation whilst the diffusion of new integrated sewer systems reflected a refashioning of relations between nature and society in the modern city to produce a "metropolitan nature" quite different from the organicist conceptions of nature which predominated in the past. The modern city was in other words at the forefront of a new cultural sensibility towards nature as a focus of contemplation rather than material necessity as the last vestiges of any cyclical interaction with a rural hinterland were replaced by a metropolitan emphasis on nature as a source of leisure (see Green, 1990; Gandy, 2002). By the 1890s advances in the science of bacteriology in combination with the persistence of water-borne disease outbreaks had largely supplanted the earlier "organic" conceptions of urban order.[11] The discovery of pathogens and their role in disease epidemiology introduced the role of germs as "biological protagonists" in the on-going debate over urban sanitation and as a result the physical transformation of the city and the introduction of new water purification technologies became a historical inevitability.

At the same time as the "hidden city" of pipes and sewers was being extended beneath the city streets a parallel transformation in the private sphere was also taking place. When reflecting on the relationship between water and cities it is easy to underestimate the significance of transformations in the design, use and meaning of private space in contributing towards the reshaping of urban space as a whole. Indeed, one might argue that the growing use of water within the home, exemplified by the diffusion of the modern bathroom, drove the hydrological reconstruction of the modern city. The spread of the private bathroom marked a new bashfulness towards the body as emerging fashions for washing, hygiene and bodily privacy fostered increasing aversion to human excrement. The modern home

became subject to a new moral geography of social behaviour that enabled the development of modern technologies to be incorporated into an "invented tradition" of domesticity.[12] The plumbing of the metropolis was thus a process of both physical reconstruction and social engineering so that the use of water in the modern city was marked from the outset by a tension between punitive and progressive hygienist discourses. The evolution of modern plumbing systems can be conceived in Foucauldian terms as part of a "bio-political" dynamic wherein social relations and codes of bodily conduct were increasingly subjected to indirect modes of social discipline (see Osborne, 1996; Otter, 2002). By invoking a Foucauldian reading of power we can extend our conception of the regulation of urban space to include those aspects of social order and behavioural conduct which lie outside of the formal arenas of legal sanction and administrative control yet are nonetheless crucial to our understanding of how modern societies function (see Agamben, 1998). The symbiotic relationship between water supply systems and the development of the modern city has not only involved a hybridized interaction between nature and culture but also a co-evolutionary dynamic between technology and the human body. Although the spread of these new technological and architectural interactions with the human body remained highly uneven in different national and cultural contexts (and was largely restricted to middle-class homes until the wider diffusion of prosperity in the second half of the twentieth century) we might argue that the ideological force of emerging ideologies of cleanliness and bodily conduct extended beyond the private bathroom to include the development of municipal baths, public health campaigns and other aspects of everyday life in the modern city (see, for example, Glassberg, 1979; Trupat, 1996).

The diffusion of water technologies is closely linked with the development of the public realm as an identifiable facet of the modern city but it is at the same time a fragile dimension to urban space that reveals a number of tensions underlying the political and economic impetus behind capitalist urbanization as a geographically uneven and historically episodic process of social and cultural transformation. The emerging "bacteriological city" involved a medley of different social, political, economic and environmental goals set within the context of a movement away from fragmentary and laissez-faire approaches to urban governance.[13] With its dense networks of water infrastructure and its eventual integration into modern discourses of pollution control, the bacteriological city forms an integral element in the development of the public realm as both a physical artefact and a political idea. The close relationship between urban water infrastructure and the development of municipal governance emerges as one of the critical dynamics behind the development of the modern city. Yet we should be careful not to exaggerate the significance of public health concerns within this process since the core dynamic of urban reconstruction rested on the facilitation of a more rationalized urban structure for the political control of space and the enhanced role of modern cities as arenas for capital accumulation. The "heroic" school of urban history has tended to provide a highly romanticized and individualized account of the role of architects, engineers and physicians in this urban transformation that ignores the wider political and economic exigencies underpinning the development of the modern city and new modes of urban governance.

By the early decades of the twentieth century the bacteriological city was widely perceived as the logical end point to the processes of spatial rationalization under way since the middle decades of the nineteenth century.[14] A distinctive arrangement of space emerged which reached its zenith in the fully networked industrial city of the Fordist era. The hygienist emphasis on the purification and ordering of space had radically altered the relationship between the body and the city to produce a new socio-technological

nexus extending from the interior space of the modern home to territorially bounded managerial modes of urban governance. In historical terms the bacteriological city — and the associated "modern infrastructural ideal" to use Graham and Marvin's (2001) term — represents a remarkably stable structure or constellation of different elements since its inception in the middle decades of the nineteenth century. An emerging interface between water, space and society gradually extended from the urban milieu of the bacteriological city to encompass regional and national dimensions to water resources planning and wider strategic goals such as rural development, power generation and fiscal policy (Bakker, 2002; Moral and Saurí, 2000; Swyngedouw, 1999). The development of water infrastructure was thus integrally connected not only with the emergence of new forms of municipal governance but also with a wider transformation in the scope and rationale of state activity. Giant water infrastructures such as dams and aqueducts became part of a distinctive technological landscape founded on the Promethean impulse to transform nature in the service of a new society at the forefront of science, modernity and progress (see, for example, Banham, 1988). The local, regional and national state took on a variety of water-related tasks that the private sector was either unable or unwilling to perform leaving managerial and technical expertise concentrated in the public sector. Yet these new regional structures were increasingly remote from the original political dynamic between municipal reform and potable water supply in which water infrastructures had played an active role in fostering the development of a viable albeit partial public realm.

The development of the bacteriological city — with its integrated technological networks — rested on a widely held misconception that all cities would ultimately conform to this model. When viewed in a global context, however, the anomalies inherent in the bacteriological city become immediately apparent. The "water revolution" which emanated from the nineteenth-century cities of Europe and North America did not in fact extend very far with even the better-connected towns and cities elsewhere often dependent on intermittent or sporadic access to piped water. In most colonial cities, for example, the reconstruction of the underground city was only ever partially completed with disastrous consequences for public health. During the early decades of the twentieth century, at a time of rapid public health improvements across Europe and North America, cities under colonial control such as Baghdad, Bombay and Lagos, all experienced devastating outbreaks of disease on account of their chaotic and inadequate urban infrastructure (see Klein, 1986). Until recently, the uneven levels of connectivity in developing countries had been widely perceived as a temporary phenomenon to be overcome through ambitious efforts at urban planning and reconstruction. In the late 1970s, for example, urban planners in Lagos, Nigeria, anticipated that within 20 years the entire city would be connected to a modern water supply system yet the actual figures for West Africa's premier metropolis by the early twenty first century were under five per cent for direct household water connections leaving most of the city's fifteen million people dependent on wells, boreholes, standpipes, tankers, street vendors and other sources (Coker, 2003; UN, 1980). The infrastructure crisis now facing fast growing cities such as Lagos, Mumbai or Nairobi, is a testament not simply to the technical and fiscal challenge inherent in the production of the bacteriological city but the legacy of an incomplete modernity which rested on a brutal distinction between "citizens" who could lay claim to potable water and mere "subjects" who were left to make do as best they could (see Mamdani, 1996). The period since the 1970s and 1980s has, despite a series of international declarations, witnessed a general deterioration in urban living conditions. The teleological discourses of technical and managerial progress associated with the bacteriological city — fostered by the positivist impulses of the engineering

sciences — served to obscure the contradictory dynamics behind capitalist urbanization. Processes of industrial restructuring, mass rural-urban migration in the developing world, and the gathering impetus of economic globalization since the early 1970s, shattered the assumptions and relationships which underpinned the integrated urban ideal that had developed during the first half of the twentieth century. The "megacities" of the global South now reveal some of the sharpest dilemmas and contradictions posed by the urban infrastructure crisis with widening disparities emerging in access to sanitation and potable water. The emerging "brown agenda", focused on the need for global improvements in water and sanitation with its implicit linkage to a rights-based conception of access to water and sanitation, sits uneasily alongside the shift away from the bacteriological city with its focus on centralized, universal and state-directed patterns of service delivery. Yet the current sanitation crisis is most acute in precisely those cities that never enjoyed the same kind of technological transformation as that experienced in the cities of Europe, North America or more recently in parts of south Asia.

Fractured spaces

Though we can delineate the characteristic features of the bacteriological city it is much more difficult to discern any clearly defined infrastructural successor. The contemporary city is being shaped by a different combination of fiscal and political pressures which have generated new kinds of relationships between the physical structure of space and changing patterns of urban governance. The era of "municipal managerialism" which persisted under a range of different political systems has been displaced by a more diffuse, disconnected and differentiated urban form in which the idea of the "public" as a clearly defined political and ideological entity has been thrown into doubt and in which those activities formerly undertaken by the state have become redistributed among a panoply of different private or non-governmental agencies ranging from corporate giants in the field of municipal service provision to new types of grassroots organizations. It would be wrong, however, to suggest that the bacteriological city has disappeared since most cities remain dependent on these immense technological networks yet the context in which these urban hydrological systems now operate has been radically transformed. What is now emerging is a complex palimpsest of different forms and structures that leaves existing conceptions of the city in a state of flux and uncertainty.

The drift towards an increased "marketization" of water can be interpreted as an intensification of incipient trends contained within the history of capitalist urbanization; the most recent chapter in an oscillating dynamic between "public" and "private" in the provision of water and sanitation which both predates and extends beyond the specific arena of European and North American urbanization. Water has always been closely intertwined with the flow of capital; municipal bonds for water infrastructure, for example, represent a core element in the development of modern capital markets. The issue hinges on the changing relationship between capital, space and power: namely the intersection between patterns of capital investment and the evolution of municipal governance. This process involves a series of different elements or possible configurations between tiers of governance, capital markets, corporate entities and other players, but the core issue is that a relatively stable, centralized and state-dominated structure is being replaced by a very different set of political and economic dynamics to those that prevailed under the bacteriological city.

A key development since the mid-1970s has been the emergence of a fiscal crisis facing the maintenance of urban infrastructure with declining levels of investment leading to widespread dilapidation and neglect. By the late 1980s, for example, over 25 per cent of London's water mains were over 100

years old and over 30 per cent of its water was being lost through leaks. Rusted and corroded water supply systems in London and elsewhere had become part of an emerging post-industrial landscape marked by new patterns of social segregation, rising poverty and a pervasive politics of municipal crisis. By the 1990s, and the widespread reorientation of municipal governance towards the needs of capital, the large-scale divestment of public assets such as municipal water supply systems had become an integral component in ambitious privatization programmes. Although these vast sales raised money in the short-term as a means to bolster state finances the underlying pretext has been an attempt to avoid fiscal and political responsibilities in the future: a prospect underpinned by new technical and regulatory complexities facing the management of urban infrastructure in comparison with the relatively simple systems of the past. Recent changes in the water and sanitation sector have been marked by a transition from a municipal ethos dominated by civil engineering to a commercially driven need to assuage the demands of shareholders which has generated intense conflicts of interest between the users of water systems and the profit maximization strategies of privatized utilities. In the UK, for example, cost-cutting measures by water utilities after privatization in 1989 led to spiralling water charges, a surge in disconnections and outbreaks of dysentery. The ensuing political outcry eventually led to new legislation in 1999 encompassing a "windfall tax" on the vast profits enjoyed by privatized utilities and lower price caps to protect low income households from escalating water and sewerage charges (though utilities have partially circumvented this with the introduction of more expensive token based "pay as you use" systems for poorer households). As a response to these changes share prices for UK water utilities dropped by as much as 50 per cent to levels below their regulatory asset value and two of the ten privatized utilities adopted a "mutualization" structure whereby long-term capital costs would be passed back to the state (see Bakker, 2001, 2004; Castro *et al*., 2000).

Other changes experienced in the UK and elsewhere include the diversification of water companies into other services and an internationalization of activities into lucrative overseas contracts. Examples of this process include Thames Water — London's former public water utility — which after privatization in 1989 developed overseas interests in a number of countries including China, Egypt, Indonesia and Thailand, and was itself acquired by the German multi-utility RWE in 2000. At an international level there is now a drift towards an increasingly oligopolistic structure for global water provision dominated by a small number of mainly European companies. There is also the prospect in the wake of the disastrous water privatizations in Buenos Aires and Manila of a further widening of disparities in supply with the strategic withdrawal of these corporate entities from problematic cities or regions to focus only on those urban citadels from which higher water charges and profits can be extracted so that the poor must continue to rely on degraded and inadequate public supply systems (see Chinai, 2002; Swyngedouw *et al*., 2002). The material assets of capital infrastructure have also been increasingly used as leverage for other financial activities. In this instance capital assets such as water and sewerage systems — usually developed over many decades from public sources of investment — have become closely entwined with the development of new forms of economic activity rooted in speculative rather than productive forms of profit generation (notable examples include the ill-fated Enron corporation which collapsed in 2001). Taken together these changes mark a further shift away from the municipal model though some cities such as New York have, after a protracted political debate, opted to retain public control over their water systems (see Gandy, 2002). A range of research has indicated that many of the most efficient water utilities remain under public control (Stockholm being an axiomatic example), that

public utilities are better able to respond to new political challenges such as improved equity in water access (as in South Africa) and that public utilities in developing countries can raise their own sources of capital (as indicated by the successful bond issue in Ahmedabad, India). The implications are that the alternative to the bacteriological city is not necessarily outright privatization as promoted by the World Bank and other Western financial institutions but extends to a range of possibilities in part dependent on the ability of different interest groups, including the local state itself, to articulate different patterns of service delivery and mobilize alternative sources of investment such as municipal bonds rather than bilateral loans vulnerable to currency fluctuations (see Hall, 2004; Lobina and Hall, 1999). Pivotal to the efforts of the World Bank to extend privatization is the dependence of inadequate and dilapidated municipal systems on external sources of capital that cannot be generated locally (hence the crucial significance of local bond issues and other strategies being pioneered in India and elsewhere). In some instances state divestiture has been a precondition for obtaining bilateral loans in a dramatic contrast with the nineteenth-century cities of Europe or North America which could utilize colonial sources of capital to finance the expansion and modernization of urban infrastructure.

The conversion of water from a "public good" into a "marketable commodity" also holds wider implications so that water is no longer perceived as an integral component of modern citizenship rights (though this distinction was in any case very unstable in the bifurcated context of colonial and post-colonial cities). The decline of the bacteriological city has been accompanied by an erosion of the political connections between water supply and the public realm that developed under the aegis of technological modernism and scientific modes of municipal governance. Since the notion of modern citizenship as articulated by David Harvey, Richard Sennett and other urban scholars is pivotal to the development of a thriving public sphere it follows that a weakening in the ostensible connection between urban infrastructure and the public realm has profound political implications (see Harvey, 1996; Sennett, 1974). The connection between water and citizenship rights is now left in an anomalous position since there is no longer any clear connection between the socio-spatial structure of the city and the articulation of a cogent public interest. The contemporary city can be characterized by a form of "antibiotic urbanism" in which the historic associations between urban governance, political reform and public health, pioneered by figures such as Edwin Chadwick, James Hobrecht and Robert Koch no longer apply. The public health crises of the past — exemplified by cholera and typhoid — affected not only the poor but also the middle classes and threatened the social and political cohesion of the entire city. Contemporary public health threats, by contrast, are largely restricted to zones or enclaves of deprivation in the absence of organized urban social movements to rival those of the industrial city.

In addition to this fracturing of the public health dynamics of urban space we can also identify a series of changes in the relationship between water and urban society. Trust in public water supplies in developed economies has declined since the 1980s as a result of tangible health scares from pathogens such as *Cryptosporidium* and *E. coli*, as well as the generalized spread of political and environmental mistrust.[15] Public supplies both in developed and developing economies must also contend with the emergence of more differentiated markets for potable water exemplified by the proliferation of bottled waters in an apparent reversion to nineteenth-century patterns of elite water consumption. The Coca Cola soft drinks manufacturer, for example, has recently and somewhat controversially been selling repackaged municipal tap water to consumers in London after minimal and from a public health standpoint quite unnecessary

treatment procedures. And in India the same corporation has been aggressively promoting table water to urban elites whilst at the same time promoting soft drinks in water deficient rural India in preference to the development of more equitable potable water sources (a strategy underlined by the rapacious water extraction activities of bottled water companies in India and elsewhere).[16] The rural water crisis affecting much of India and many other parts of south Asia and sub-Saharan Africa is also a crucial dimension to the subsistence crisis which is forcing millions to seek a better life in cities so that the urban infrastructure crisis is integrally related to intensifying patterns of rural poverty.

A key dilemma behind the shift to an increasingly market-driven conception of urban infrastructure is that those elements of fixed capital with the greatest "sunk costs" generate significantly lower rates of return than other infrastructure networks such as telecommunications. There is not so much an emerging "digital divide", as has been mooted in some of the literature, but rather a glaring "concrete divide" in the corporeal experience of space marked by persistent and widening disparities in access to basic services. The continuing global prevalence of water-borne disease is a clear indication of this regional and global disparity in urban living standards. The urban slum is now the focal point for contemporary debate over the future of urban infrastructure. In sub-Saharan Africa, for example, over 70 per cent of the urban population live in slums and global numbers of slum dwellers are set to double within the next thirty years (Davis, 2004; UN, 2003). Widening inequalities in the distribution and quality of urban services such as water supply form part of a process of urban polarization over which the state appears to now play only a minimal role in the face of pressures towards further liberalization, deregulation and fragmentation. This is not to argue, however, that the state itself — especially the nation state — is becoming irrelevant to this process since it continues to play a pivotal role in facilitating processes of globalization (see Sassen, 1995; 1998) so that control over the apparatus of state power must remain a focal point for political discourse despite the burgeoning significance of different forms of grassroots democracy (see Appadurai, 2002). Democratic control over municipal water supply has become a contested arena that links with the anti-globalization movement's attempts to defend public services. The issue of the local state, therefore, whether as service provider or regulatory agency, remains pivotal to the resolution of the urban sanitation crisis not least because NGOs and other grassroots organizations cannot act as credible substitutes for democratic forms of urban governance. The "cyber slums" of the South — with the latest wireless technologies but inadequate water and sanitation — lie caught between the discourses of grassroots activism and neo-liberalism; the question as to who will coordinate, build and finance the necessary water and sanitation infrastructures that can offer the prospect of a better quality of urban life for the majority of the global urban population remains unanswered.[17]

As for the affluent cities of the future, these are likely to contend with the extension of water metering and other devices to promote greater water efficiency within individual homes as part of an integrated network of technological control extending to all areas of everyday life (see Mitchell, 2003). And beyond the spaces of the home a new hydrological landscape may evolve bringing the latest developments in water efficient design to even the most arid urban locales (see Suzenet *et al*., 2002). At a regional scale, however, there is likely to be escalating conflict over access to diminishing and increasingly expensive water resources so that socially created forms of water scarcity begin to intersect with conflicts generated by the hydrological frontier of fast growing cities. The kind of complex political dynamics experienced over many decades in parts of the Middle East or southern California, for example, and other semi-arid urbanized landscapes,

will become a much more widespread phenomenon. In more extreme cases rates of urbanization may even be curtailed by water stress, particularly where fast growing cities are dependant on vulnerable ground water reserves, having wider implications for economic growth within the economy. The cost of water is certain to increase further under intensifying pressure for prices to reflect the full marginal costs of production (however these might be defined) as part of the on-going challenge to "welfarist" patterns of water provision associated with the bacteriological city. The further liberalization of water services will intensify social and economic contradictions within the urban arena leading to complex regulatory and political dilemmas. And as increasing numbers of cities become integrated into a highly competitive global urban system the scale and intensity of water conflict is likely to become more pervasive.

Conclusions

Water is not simply a material element in the production of cities but is also a critical dimension to the social production of space. Water implies a series of connectivities between the body and the city, between social and bio-physical systems, between the evolution of water networks and capital flows, and between the visible and invisible dimensions to urban space. But water is at the same time a brutal delineator of social power which has at various times worked to either foster greater urban cohesion or generate new forms of political conflict. When we think of what a city is we cannot avoid contemplating the complex mass of structures that bind different elements of urban space into a coherent functional entity. Yet this integrated urban form is by no means the prevalent model when we consider the phenomenon of modern urbanism in a wider geographical or historical context: the diversity of different institutional structures and arrangements for water provision illustrates the complexity of urban infrastructure and its evolving relationship with different modes of social and economic organization.

The urban ideal of the fully connected metropolis emerged as a powerful symbol for modernity in the wake of the chaotic and disconnected nineteenth-century city. Under the bacteriological city a relationship evolved between more democratic forms of urban governance and the development of modern citizenship rights. The ostensible technical and managerial simplicity associated with this phase of urban governance afforded the possibility for an unproblematic conception of urban metabolism as an assemblage of material flows; a web of movements enabling what we would recognize as an archetypal modern city to function effectively. In practice, however, the interweaving of social and technological systems within the bacteriological city was far more complex than most architects, engineers and planners were ever willing to admit. The messy and indeterminate spaces of the urban unknown persisted within this intellectual context as a margin or boundary beyond which these technical discourses fell silent. With the fading of the bacteriological city and its characteristic modes of urban governance the bio-physical conceptions of urban metabolism have become further problematized through an inability to explicate the changing nature of the contemporary city within an increasingly globalized urban system. The use of biological analogies may serve some heuristic or imaginative value in the context of architectural design for individual buildings but when applied to an entire city or region these essentially arbitrary combinations of scientific metaphors quickly become untenable and lose any analytical utility. If the idea of urban metabolism can be disentangled from its organicist and functionalist antecedents, however, it can serve as a useful point of entry for a critical reformulation of the relationship between social and bio-physical processes. A dialectical or hybridized conception of urban metabolism can illuminate the circulatory processes that underpin the transformation of

nature into essential commodities such as food, energy and potable water: the idea of metabolism in this sense derives not from any anatomical or functional analogy but from an emphasis on the interweaving of social and biophysical processes that produce new forms of urban or "metropolitan" nature in distinction to the rarefied realm of nature which remains dominant within much urban and environmentalist discourse. A scientistic model is replaced by a historically driven conception of urban nature which is rooted in the political dynamics of capitalist urbanization as a contested and multi-dimensional process of urban change. We can discern a coalescence here between neo-Marxian conceptions of the transformation of "first nature" and more recent emphasis on the role of networks in the production of urban space. In developing a more "bio-dynamic" conception of urban space we can also draw on significant contributions from within the history of modernist architecture and design such as Alvar Aalto, Hans Scharoun or Bruno Zevi.[18] Relational or hybridized conceptions of urban metabolism — with emphasis on phenomena such as commodity chains, the particularities of local context and the fluidity of urban form — are quite different from non-dialectical models of urban metabolism rooted in a homeostatic conception of the city as a self-regulatory system. The newly emerging conceptions of urban hybridity developed by Bruno Latour, Erik Swyngedouw and others, recognize that water networks are also active agents in the production of space not only through reflexive interactions with processes of socio-technical evolution but also through their constitutive role in the production of urban culture.[19] These relational perspectives differ fundamentally from the linear flow-based models of urban space associated with concepts such as "industrial metabolism", "ecological footprints" and other functionalist conceptions of urban space.[20] Though the ecologically orientated ideas of Peter Baccini, Herbert Girardet and others seek to make a clear differentiation between their conception of urban space and the technocratic urban models derived from the classic genres of scientific urban management — exemplified by the intervention of Abel Wolman — there is nonetheless a convergence between these different perspectives around the conception of the city as a metabolic system which can be examined in isolation from wider processes of historical change.

Under the twentieth-century discourses of scientific urbanism and technological modernism we find that the hydraulic conceptions of the modern city were extended and consolidated to produce a highly sophisticated model of urban space as an efficient machine. In reality, however, the evolving dynamics of urban space from the middle decades of the twentieth century onwards became increasingly difficult to subsume within the technocratic assumptions of the bacteriological city. A combination of political, economic and social developments, which gathered accelerated momentum in the wake of global economic turbulence of the 1970s, contributed towards the emergence of a set of new configurations between space, society and technology. The role of water within this process of urban restructuring reveals a series of tensions between the abstract commodification of space and the continuing centrality of material interactions between human societies and technological networks. By focusing on the flow of water through urban space we can begin to disentangle the nexus of social and technological structures that constitute everyday life in the modern city and the creation of a viable public realm. What is clear, however, is that the relationship between the development of urban infrastructure and a functional public realm is a fragile and historically specific phenomenon. The need to connect policy deliberation over water infrastructure with the establishment of effective and legitimate forms of urban governance remains as important now as it was in the past but such arguments can no longer rely on either the bacteriological logic of public health advocacy or the rationalist conceptions of urban

space promoted by political and economic elites.

Notes

1 Eckbo, (1990, p. 3).
2 Swyngedouw (2004a, p. 1).
3 Koolhaas (1994, p. 1264).
4 Swyngedouw (2004b). The development of the concept of metabolism in the nineteenth century also involved significant intellectual exchanges between developments in, for example, agricultural science and new approaches to political economy exemplified by the influence of Justus von Liebig's critique of capitalist agriculture on the writings of Karl Marx. See, for example, Foster (2000).
5 Recent examples of "organic architecture" and metabolic conceptions of urban form are to be found in, for example, Gans and Kuz (2003), Gauzin-Müller (2002), Pearson (2001), Senosiain (2003) and Slessor (1997).
6 The cultural and symbolic dimensions to water are explored in, for example, Böhme (1988; 2000), Ipsen (1998) and Sennett (1994).
7 On the history of attempts to control urban pollution see, for example, Barles (1999), Bernhardt and Massard-Guilbaud (2002), Luckin (2000) and Tarr (1996).
8 The "corporeality" of the water-technology-body interface sits uneasily alongside those urban discourses which emphasize the putative dominance of the digital realm. The increasing emphasis on various manifestations of cyber space has brought into sharp relief the somewhat anomalous characteristics of water infrastructure in comparison with other urban technological networks. It is difficult, for example, to relegate the crumbling water infrastructure of the modern city to Marc Augé's (1995) notion of "non-place" because it continues to play such a significant role in the way we perceive space as a cultural as well as a tangible dimension to the urban experience (see, for example, Baeten, 2002; Garver, 1998; Kaika and Swyngedouw, 2000; Keil and Graham, 1998; Skeates, 1997).
9 On the history of water supply see, for example, Barles (1999), Barraqué, (1995), Goubert (1989), Guillerme (1988), Jacobson and Tarr (1994), Melosi (2000), von Simson (1983) and Tepasse (2001).
10 On nineteenth-century debates over the continuing use of human manure in agricultiure see, for example, Büschenfeld (1997), Gandy (1999), Tepasse (2001) and von Simson (1983).
11 We should note, however, that disputes over the epidemiology of urban disease persisted long after advances in bacteriology as evidenced by the public disagreements between the "experimental hygiene" of Max von Pettenkofer and the new science of bacteriology advanced by Robert Koch. See Koppitz (2004) and Vögele (2001).
12 On ideologies of domesticity and the modern home see, for example, Frank (2003), Kaïka (2004), Lupton and Miller (1992) and Wright (1975; 1980).
13 On public health campaigns, water supply and the reform of urban governance see, for example, Evans (1987) and Penzo (1994).
14 By the early decades of the twentieth century rates of water connection neared 100 per cent across much of urban Europe and North America (see, for example, Barraqué, 1995; Goubert, 1986; Guillerme, 1988; Melosi, 2000). Despite the significance of this technical transformation of space we still know comparatively little about the evolving relationship between the technical and political transformation of cities with most attention devoted to the development of other technological networks such as electricity, telecommunications and transport infrastructures. France, for example, completed its water distribution network significantly later than Britain and Germany and in much of the developing world the extent of network coverage has steadily declined in relation to rapid urban growth. The development of more sophisticated and interdisciplinary approaches to the study of urban technological networks can be traced in particular to the work of Thomas Hughes (1983). Other key sources include Bijker *et al.* (1989), Coutard (1999), Gökalp (1992), Graham and Marvin (1995; 2001), Guy *et al.* (2001), Jacobson and Tarr (1994), Lahiji and Friedman (1997) and Troy (1995).
15 On recent public health scares affecting water supplies in developed economies see, for example, Gostin *et al.* (2000), LeChevallier *et al.* (1991) and MacKenzie (1994).
16 See, for example, McDougall (2004).
17 The United Nations, the World Bank and other multinational institutions estimate that vast investments of at least $60 billion a year are needed to avoid a further deterioration in urban living conditions (see, for example, Camdessus and Winpenny, 2003).
18 See, for example, Frampton (2003), Pelkonen (2003) and Porteous (2002).
19 A focus on the production of "metabolized" water encompasses not just its physical and chemical properties but also an associated assemblage of symbolic and cultural meanings as it becomes incorporated into the political ecology of the modern city. See, for example, Swyngedouw (2004), Latour (2004) and Latour and Hermant (1998).

20 Some similarities can also be discerned here with recent post-structuralist theorizations of urban space which seek to counter the "nodal" emphasis of much of the world-city literature (see, for example, Crang, 2000; de Landa, 1998) but these ideas have thus far been mainly applied to virtual rather than concrete spaces in the city. For overviews of recent flow-based conceptions of urban and industrial metabolism see, for example, Baccini (1997), Fischer-Kowalski and Hütter (1999) and Schramm (2000). Different variants on the urban metabolism theme also include, for example, the Japanese based Metabolist movement which emerged in the late 1950s and played on the "cybernetic" impetus within planning and architectural discourse. Founder members such as the Japanese architect Kisho Kurokawa used elaborate capsules and other structures to capture aspects of urban growth and effectively invert the tendency for urban infrastructure to be hidden within architectural structures (see Kurokawa, 1992).

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