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Small technologies, big change: Rethinking infrastructure through STS and geography

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Abstract
Infrastructure tends to be conceived as stabilized and 'black-boxed' with little interaction from users. This fixity is in flux in ways not yet fully considered in either geography or science and technology studies (STS). Driven by environmental and economic concerns, water utilities are increasingly introducing efficiency technologies into infrastructure networks. These, I argue, serve as 'mediating technologies' shifting long-accepted socio-technical and environmental relationships in cities. The essay argues for a new approach to infrastructure that, by integrating insights from STS and geography, highlights its malleability and offers conceptual tools to consider how this malleability might be fostered.

Keywords
efficiency, infrastructure, scale, STS, technology, urban, users, water

I Introduction

Cities and the infrastructures that support them are prominent concerns in geography. Infrastructure and their attendant socio-technical networks have direct implications for environmental quality, social justice, and urban sustainability that are likewise prominent concerns in science and technology studies (STS). Geography and STS, however, approach these matters from different vantage points, both revealing and, at times, overlooking important issues. Both approaches, for example, perceive urban infrastructure as widely static and invulnerable to change.

In this paper, I develop the concept of *mediating technologies* both to challenge widely held perceptions of infrastructure as immutable and to identify specific ways in which approaches to infrastructure in STS and geography can be integrated to redress particular limitations in both disciplines. Practically speaking, mediating technologies refer to small devices that can be added to an infrastructural network with the intention of modifying its performance (eg, efficiency technologies). Whereas the literature tends to assert the stability of infrastructure, mediating technologies clearly challenge these perceptions in that they evince the potential malleability of infrastructure networks through the integration of relatively simple and low-cost devices.

Conceptualizing this overlooked malleability demands the integration of theoretical insights from both STS and geographical studies of

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infrastructure to fill particular gaps in both disciplines. On the one hand, studies in geography tend to be well developed in terms of theorizing political, economic, and social factors but tend to interpret the impact, function, and use of technologies as given (Coutard and Guy, 2007). On the other hand, STS tends to privilege the technical and thus often exhibits less refined approaches to social, political, and economic processes, has little to say on the production of nature, and exhibits 'a rather generic notion of space' and place (Truffer, 2008: 978). Fittingly, then, in Johnson-McGrath's review of major works on technological change, she finds multidisciplinary approaches to be among the most insightful, but unfortunately among the most rare (Johnson-McGrath, 1997).

STS and geographies of technology are not complete strangers. Work on technology in geography draws increasingly on concepts from STS. Still, the tendency in such work has been to neglect STS's theoretical insights (such as the mutual formation of technology and society), focusing rather on its methodological contributions (Dixon and Whitehead, 2008: 604, 608). The neglect of STS insights has also been noted with respect to research on technology in urban studies and research on infrastructure in geography (Coutard and Guy, 2007; Graham, 2010b; Hommels, 2005). The integration of these insights, critics argue, would lead to more nuanced approaches that are less susceptible to the common (but undue) 'alarmism' with respect to infrastructural change in urban geography (Coutard and Guy, 2007), to a fuller understanding of 'obduracy in the city' (Hommels, 2005, 2008), and to a less static view of infrastructure (Graham, 2010b: 6).

Building on these efforts, the concept of mediating technologies introduced here helps to update approaches to urban infrastructure in STS and geography and to offer a means of bringing them together. I choose the term 'mediating' to refer to how the technologies are intended to dampen the environmental, economic, and technological consequences of, in this case, water supply by reworking the relationships between the technical network, the user, the environment, the institutions responsible, and society at large. Moreover, they do this, not by seeking to foreclose and 'black-box' the network but rather by opening it up and rendering it more transparent and responsive to interactions with a variety of actors.

Empirical vignettes, taken from extensive case research on efficiency technologies in Canada's municipal water supply sector, are used to illustrate the above conceptual points. Water efficiency technologies are understudied in research on technology in geography and indeed in STS.[1] By adding such devices to an urban water system, the present and future socio-technical and environmental relationships associated with the system can be altered in both planned and unforeseen ways. Still, neither their deployment nor their performance is given. Understanding their potential impact on urban infrastructure (and how to bring it about) requires an integrated theoretical approach in which the mutually constituting influences of the social and the technical are brought together.

I advance these arguments in three sections. Next, in section II, I examine the focus on the stability of urban infrastructure in both geography and STS and argue that mediating technologies can bring an unforeseen malleability to networked infrastructure. In section III, I examine how theories from STS and geography can be brought together to improve the study of networked infrastructure in both a general sense and with respect to their complementary (but distinct) approaches to scale. In section IV, I provide readers with a picture of how these theoretical relationships might look on the ground through some examples from the Canadian case. I conclude with an outlook to what concerted attention to mediating technologies and theoretical plurality would mean for the study of infrastructure more generally.

II Mediating technologies: Rethinking networked infrastructure

1 Stability and change in the study of infrastructure

Approaches to technology in geography are numerous, perhaps given the interest in technology within several subdisciplines (eg, urban and economic geography and political ecology). Three intellectual approaches into which the work can be categorized have been highlighted in the literature: Marxist, poststructuralist, and actor-network theory (ANT) (Dixon and Whitehead, 2008; Gandy, 2005).[2] These often overlap in practice, with strong foci on political-economic change, power, and social justice in the production of space and nature. In STS, large technical systems (LTS) forms the main conceptual approach applied to the analysis of infrastructure, with a broader range of theories applied to technology in general (eg, the social construction of technology (SCOT), ANT, and multilevel transitions (MLT)).

In both the geography of technology and STS, durability tends to be assumed in the relationship between society and infrastructure and the potential influence of minor technologies is generally overlooked. First, from the STS and LTS perspectives, while there is a strong emphasis on the contingency and dynamism of all technology, the inherent objective of a technological system (including infrastructure) is to achieve 'closure' or 'stability' even if the nature of such closure cannot be predetermined (Law and Bijker, 1992). Moreover, while such closure may only ever be provisional (Summerton, 1994b: 5), once achieved, in terms of LTS, the condition is considered resistant to change (Ewertsson and Ingelstam, 2004; Mayntz and Hughes, 1988). Water supply infrastructure, moreover, is considered to be among the most stabilized 'well-developed and long-lasting infrastructures' (ie, the least malleable) (Coutard et al., 2005a: 1; Graham, 2002).

In the geographical study of technology, the tendency for stability in infrastructural systems is expressed in two ways: (1) the normalization of infrastructure in society; and (2) the attribution of change (where it is found) to significant societal shifts. With respect to the first, arguments of normalization infer stability in that it is only through stability that an entity can come to be taken for granted.[3] In the words of Callon 'irreversibilisation is synonymous with normalization' (Callon, 1991: 151). In the cyborg approach, derived from poststructuralism, infrastructure is normalized as 'exoskeleton'; it becomes an unconscious part of the user, making urban life possible (Gandy, 2002, 2005). From a Marxist perspective, normalization is expressed as fetishism whereby the infrastructural product (eg, water) is severed from the technical and environmental processes through which it is produced (Kaïka and Swyngedouw, 2000). The goal of infrastructure is 'invisibilization', to become part of the unconscious backdrop of everyday life (Graham, 2010a: 8–9).

With respect to the second point (the association of change with major societal shifts), work has focused on political economy, demography, and environmental degradation. Notable examples include the 'splintering' and 'unbundling' of infrastructure as a result of political-economic and institutional changes with the decline of Fordism (such as liberalization and privatization) (Graham and Marvin, 2001), the production of infrastructure 'cold spots' following major demographic shifts in Berlin (Moss, 2003), and the production of abandoned and new infrastructural spaces stemming from capital mobility (Swyngedouw, 1992) and environmental degradation (Nielsen, 2001).

This leaves little room for mediating technologies to influence infrastructure. In fact, few minor additive technologies have drawn the attention of geographers concerned with infrastructure. The exception includes devices that (installed in keeping with neoliberal goals) are considered to enhance exclusion from LTS based on ability to pay, such as meters and tolls (see Graham and Marvin, 2001). In research on water supply, meters are the key focus and are generally argued to have a negative impact on equity and social justice (eg, Graham, 1997; Loftus, 2006; von Schnitzler, 2008). Coutard identifies this tendency toward universalism and pessimism with the failure to follow STS in accounting for the contingency of all technology (Coutard, 2008). Metering, for example, has demonstrated far more nuanced and variable outcomes (eg, Jaglin, 2008) and can be resisted by utility managers due to its high cost and potential to reduce revenues (Bakker, 2005; Salamah et al., 2009).

In general, this low attention to the potential impact of small changes has been echoed in LTS. Hughes argued, for example, that any changes to the assemblage of artifacts forming LTS (eg, replacement or removal) would lead to a recalibration of other parts of the system to retain consistency and avoid change (Hughes, 1987: 51). Recent work in LTS, however, stresses that large shifts or 'revolutions' are not necessarily required to bring about transitions. Rather, they can be incremental (Summerton, 1994b: 5), come from users (von Meier, 1994), do not depend on radical change via a 'battle of the systems' (Moss, 2000, 2001), and often produce a range of outcomes across space (Usselman, 1994).

With a particular focus on efficiency technologies in the energy system, von Meier develops the concept of 'supple technologies' in contrast to Lovins' 'soft technologies'. Whereas Lovins sees efficiency (soft) technologies as incompatible with current infrastructure (small, decentralized as opposed to centralized systems are needed) (Lovins, 1976), for von Meier they are not only compatible but 'could constitute a radical reconfiguration of existing power systems ... from steps taken to minimize costs and system strain' (von Meier, 1994: 211). The author sees the tools as representing a new way of managing LTS for energy, but stops short of recognizing the full potential for socio-technical change – ie, the new relationships produced with users and the environment.

This study demonstrates that the 'normalization' of infrastructure and its relegation to invisibility is not given and, in many instances, is no longer even the desired technical trajectory on the part of utility managers. Small changes to the peripheral nodes of an infrastructural network (through the addition of mediating technologies) that leave the core of the system intact can bring about important changes in the socio-technical system. As opposed to 'invisibility', the introduction of mediating technologies expresses a new trajectory in which system 'maturation' involves increasing the visibility and user consciousness of LTS. Through mediating technologies, users are purposefully enrolled in the management of LTS for the purposes of improving the economic and environmental performance of the system. Increasing visibility, however, also means reducing the predictability of and control over the system because of the interaction with users (see Oudshoorn and Pinch, 2003).[4] Below, I briefly elucidate these points with an example from the research on water efficiency in Canada. Further evidence is provided in section IV.

2 Mediating technologies: An example

Halifax Water's world-class water loss control program provides an illustration of how the relationships between users, the environment and the utility can be modified through the creative use of efficiency technologies. Water loss control refers to a variety of programs to reduce water losses within the water distribution system (eg, through leaking pipes, water main breaks, water theft). A water loss control program most obviously alters the relationship between the technical network and the local environment by reducing the demand on the local water source and by mitigating the potential technical issues arising from water leakage and pressure loss. In its generic formulation, water loss control would be expected to reinforce the 'invisibility' of the network in that it is likely to reduce (if not prevent) sudden water main breaks of the type that Graham credits with disrupting the 'black-box' nature of infrastructure (Graham, 2010a; Graham and Thrift, 2007). Indeed, such instances have led to led to closed streets, flooded houses, power outages, and transit interruptions in several major Canadian cities (including Toronto, Montreal, and Hamilton).

The Halifax example, by contrast, shows that such programs can be used to deliberately open the 'black-box' to users *while* reducing the negative instances of infrastructure breakdown and disruption. By combining their water loss control program with automated meter notification and consumer engagement, Halifax Water alters the relationship between different groups of users, the utility, and the environment in meaningful ways. For domestic users, the utility monitors household meter readings and notifies homeowners of sudden changes in their consumption. This enables users to locate and repair water leakage on their property (reducing their environmental impact and their water bills) and to avoid burst pipes (and flooded homes) in the winter. For commercial and industrial users, the utility developed a program to educate large consumers on their leakage (and its cost) and then furnished them with the appropriate software enabling them to monitor and repair their own leakage.[5] As such, the utility has engaged users directly in the monitoring and repair of the technical network and the improvement of its environmental and economic performance by consequence.

III Mediating technologies: A call for theoretical integration

1 Opening up new social and environmental considerations

Integrating aspects of STS and geographies of technology in studies of urban infrastructure can help to conceptualize infrastructure differently, including the ways in which it is more malleable than generally conceived and the factors that support (and hinder) the potential of mediating technologies to reorder the associated socio-technical networks. Below, beginning with geography, I discuss key issues in both approaches and the benefits of bringing them together.

In geographical studies of technology, relations of power and political economy (focusing on capitalism and neoliberalism) are the main analytical lenses through which the production of socio-technical relations is conceptualized. Demonstrating the point, recent work under the headings of *technonatures*, *political infrastructures*, *urban metabolism, cyborg urbanism,* and *splintering urbanism* places capitalist 'political economy' or 'expansion and production', 'processes of globalization', and political economy as key arbiters of 'fragmentation, inequality, and crisis', uneven geographical development, and 'economic serfdom' in the production of urban space and nature (Gandy, 2005: 33; Graham and Marvin, 2001; Heynen et al., 2006b; McFarlane and Rutherford, 2008; White and Wilbert, 2009a). Indeed, connections between social and technical change are understood as 'shaped by power relations', making infrastructure a physical articulation of the uneven distribution of power and opportunity in society (Swyngedouw, 2009: 80–81).

These insights are important (and often missing from LTS) but they provide only a limited picture of the potential range of relationships produced between infrastructure and technology in society. At least two reasons stand out. First, the approach can suffer from the coupling of results with politics. Political-economic processes that are considered negative (most recently neoliberalism) are often understood to produce almost universally adverse trends in infrastructure (eg, Graham and Marvin, 1995, 2001). Authors have argued that this predilection stems from a lack of attention to both the contingency of technology (Coutard and Guy,

2007) and to the diversity of experiences and outcomes witnessed across space (Kooy and Bakker, 2008; Rutherford, 2008). Latour, moreover, makes the point that the attribution of expressions of domination (or even efficiency) to technologies overlooks the associated network of social and material relations, the description of which is necessary for any technology to be meaningfully understood (Latour, 1991: 130).

This brings us to the second issue: the focus on political economy confines the scope of phenomena studied. The LTS and green buildings literatures evoke a broader range of key issues and can thus help to provoke new questions. Coutard argues, for example, that despite most arguments being economic it is rather customers' and regulators' attitudes toward networks that 'are essential to explaining current evolutions' in infrastructure (Coutard, 1994: 164). In the green buildings literature, explanatory foci in socio-technical change have included the influence of key actors (eg, government, academia, and industry), the conflicting interests of social groups, and the logic of building science (eg, Guy and Shove, 2000), as well as the relationship between design, financing, construction, and management (Mauruszat, 2001) and the interaction of new technologies with the LTS into which they are introduced (Jensen, 2001). In both STS and work on green buildings, users have also emerged as an important explanatory factor of socio-technical developments (Brand, 1994; Oudshoorn and Pinch, 2003).

Users, however, do not figure prominently in the LTS stream of the STS literature. This is perhaps owing to the assumed trajectories of stability and invisibility (discussed above) or the perceived 'black-boxed' nature and 'cultural embeddedness' of LTS (Graham, 2010a: 8; Summerton, 1994b: 6). Yet, the very purpose of mediating technologies is to enroll everyday users into LTS in individually small but collectively meaningful ways. As demonstrated in STS work, this interaction can be significant in terms of: how users construct different meanings around a technology (and thus its use) (Bijker and Pinch, 1987); how users are 'configured' and produced through product design (van Oost, 2003; Woolgar, 1991); the work of advocacy groups in technological redesign (Parthasarathy, 2003); and the ability of users to undermine the will of producers by reconfiguring technologies (Akrich, 1992).

Though few studies address the impact of users on LTS (as opposed to individual technologies), Usselman's study of railroad signaling in the USA is insightful. There, the influence of railroad operator (user) preference led to the geographical fragmentation of the system (Usselman, 1994). Similarly, on green buildings Guy argues that rather than 'getting closer to something specifiable in advance, we see [the wider development of green buildings] as a matter of solving more [local] problems' – ie, no universal system is likely to emerge (Guy, 2009: 232). While the importance of users (and other actors) in a socio-technical system suggests that outcomes are achieved by design, as Robbins shows in *Lawn People*, the relationships produced and perpetuated between people, organizations and artifacts may not reflect desire but rather the mutually reinforcing characteristics of systems that reproduce often undesired patterns of behaviour (on both individual and collective scales) (Robbins, 2007).

What these issues might mean for the production of space and nature (rather than the performance and uptake of technology) is where work on technology in geography can make an important contribution. In LTS, one finds a lack of attention to the production of space and nature.[6] In contrast to the insistence on the mutual development of technology and society, Hughes declared 'the environment' independent from LTS and recommended that nature be omitted from consideration in LTS analyses (Hughes, 1987: 52).[7] In geography, however, the production of nature is very much bound into the production of technology, society, and the urban, making them all 'natural' (Harvey, 1996; Kaïka, 2005; White and Wilbert, 2009b). Work in geography examining the mutual production of environment and society is often rooted in Marxist perspectives (eg, Harvey, 1996; Swyngedouw, 2007) but geographical usages of ANT are also prominent (eg, Hinchliffe et al., 2005, 2007).

In urban geography, specifically, work on urban metabolism provides a vivid image of how society, infrastructure, nature, and urban space are mutually produced. There, the metabolism of nature in cities enables urban life to function, and produces new forms of nature in and surrounding urban areas as well as new social relations (see Heynen et al., 2006a; Kaïka, 2005). The mobilization of resources is a central element in the production of urban space and the facilitation of urban life. Resources like water are channeled from areas surrounding cities often resulting in deteriorated landscapes in the adjacent countryside; nature, urban, rural, infrastructure, economy, and society form a single circulating system (Cronon, 1991; Gandy, 2002; Swyngedouw, 2004). What STS can add is a less pessimistic view of the relationship given the contingency of the techno-social. Mediating technologies, for example, presage a new dimension to this interaction, in which relatively simple addendums to networked infrastructure can lead to important shifts urban metabolism and who can influence it.

2 A complementary approach to scale

The range of factors involved in producing socio-technical relationships surrounding infrastructure (discussed above) raises the question of how their interactions, linkages, connections and disconnections can be collectively and meaningfully analyzed. Concepts of scale in STS and human geography provide distinct, yet complementary, tools for thinking about the interactions between the range of processes, actors and artifacts at play. Beginning with geographical scale, the two approaches are discussed in turn.

The concept of geographical scale focuses on delineations of territorial organization (eg, the home, local, national, global). These are not taken as static or universal; rather they are understood as constructed and thus transitory (Smith, 1992). As such, theorists argue that analyses should focus on the production of scales (and how their apparent fixity is retained or undermined) rather than scales *per se* (Delaney and Hilda, 1997; Smith, 1992). Of particular concern for urban geographers is the realignment and reformation of scale with the decline of Fordism (eg, Kohl and Warner, 2004; MacLeod and Goodwin, 1999). It is key to remember, however, that such productions of scale, despite their contingency, are real and have material effects (Delaney and Hilda, 1997).

Despite many points of agreement, scale remains a matter of significant debate in geography (Chapura, 2009). Some of the issues raised in these debates are relevant for the study of infrastructure where mediating technologies are of concern. Marston has highlighted an overemphasis on capitalist production while 'ignoring social reproduction and consumption' in geographical applications of scale (Marston, 2000). In part, this is an argument for broadening the consideration of scale to (more regularly) include the individual, the home and the community where everyday decisions are made. Truffer, furthermore, highlights a focus on territorialized processes, arguing for greater attention to non-localized networks (Truffer, 2008: 979). This critique relates to arguments that networked processes have been sidelined in geography in favor of scalar accounts that tend to focus on the hierarchical (or at least vertical) processes involved (Marston et al., 2005).[8]

In STS, scale is approached through the theory of Multi Level Transitions (MLT), which arranges scales around the development, deployment, uptake, and function of technology. MLT proposes three scales of interest: the 'technical niche' (where innovation occurs), the 'technical regime' (where techniques are configured and stabilized in society), and the 'technical landscape' (consisting of cultural norms, macroeconomic conditions, and broad-based political patterns – Geels and Schot, 2007). The niche acts an 'incubation room' where emerging techniques are protected from regime pressures (eg, market selection) (Geels and Schot, 2007; Kemp et al., 1998). The regime comprises combinations of techniques, actors, institutions, supporting infrastructure, types of knowledge, and cultural codes that together act to stabilize or undermine technologies (Geels, 2002; Geels and Schot, 2007; Kemp, 1994). Finally, the landscape is understood as 'the [exogenous] backdrop against which specific technical changes are played out' (Rip and Kemp, 1998: 388) and one which is very slow to evolve (Geels, 2002: 1262).

Like the geographical approach, MLT has its shortcomings. The theory has been criticized within STS for: (1) a disproportionate focus on the niche (and innovation) as the locus of technological change;[9] (2) given that focus, a lack of attention to (and theorization of) processes at the regime and landscape scales; and (3) a lack of definition of the boundaries between the three scales (Berkhout et al., 2004; Genus and Coles, 2008; Shove and Walker, 2007). Moreover, given the landscape's conceptualization as exogenous, that scale is rendered virtually devoid of explanatory potential.

As such, employing the MLT approach alone would mean losing sight of several key issues. First, for large 'embedded' systems like infrastructure, it is clear that shifts at macro scales are important in techno-social change and should not be ignored (in fact, most work in geography has focused at this level).[10] Second, in terms of efficiency (or mediating) technologies, it is not innovation that is at issue (the technologies have long existed) it is rather their implementation, use, and performance that will dictate the manner of socio-technical change. As such, a focus on the regime scale is key.

For the analysis of infrastructure, an approach that takes the technological and geographically oriented scales as integrated and overlapping is needed. The approach I propose (and demonstrate in section IV(2)) follows work in political ecology that highlights analyses which combine ecological scale and political scale (Neumann, 2009: 400). Whereas political (geographic) scale describes the organization of governance, politics, and power, ecologists have argued that ecological processes produce and are observable at their own '"natural" scale' (Sayre, 2005: 280). That is, like the STS approach to technology, which builds scale from the perspective of the technology, the natural scale describes the networks and boundaries (not necessarily territorialized) associated with an ecological process or artifact.

The technologically centered scales cannot be understood in absence of the geographical scales with which they are connected (or even embedded). Geography highlights the constructed nature and fluidity of scales (Jonas, 2006), draws attention to the importance of the landscape and regime scales, and provides the means to theorize politics and governance at those scales. STS researchers acknowledge that politics is generally not well developed in the MLT literature, where managers for example may be taken as outside of politics (Genus and Coles, 2008: 1443; Shove and Walker, 2007) and, neoliberalism, although seen as important, has not been systematically addressed (Geels, 2004; Smith, 2003). While STS can enhance the role of users, geography can politicize it and embed it within relations of power and exclusion.

STS, for its part, encourages a focus beyond capitalist production (including on small changes) and requires the integration of a networked approach with geography's (generally) vertical one. The MLT approach – focused on the networks associated with given technology – draws attention to a variety of processes affecting the development, deployment, performance and reformation of technology, including new types of actors (eg, developers, managers and users), objects (technological artifacts), networks of association, and configurations of scale that do not necessarily reflect political delineations. As such, the lack of definition of the boundaries between the three MLT scales (Shove and Walker, 2007) may mark an opportunity to examine scale in a way that recognizes the fluidity of interactions across scales (as highlighted in geography) while combining a networked and vertical approach.

This paper is not the first to advocate an integration of geographical and MLT scales. For Truffer, they should be understood as 'two independent dimensions of analysis' where research describes the three MLT scales at each scale of geographical analysis (local, national, global, etc) (Truffer, 2008: 979). Instead, I have argued for an approach where the networks associated with a technology may overlap and crossover geographical scales, linking them together in unforeseen ways. These arguments are elaborated through examples from research on efficient fixture programs in Canada in section IV(2).

IV Water conservation in Canada: Mediated infrastructures

The data below are taken from a two-part project on water governance and efficiency in Canada. The first phase (2005–07) examined the effect of neoliberal restructuring on water efficiency programming in Ontario. The second phase (2007–08) reversed the arrow of inquiry, instead concentrating on municipal leaders in conservation across Canada to determine what governance issues inhibited and fostered their progress. The complete data set includes two large-N expert questionnaires, 18 municipal case studies (including interviews and archival research), and two expert workshops. Greater detail is available on the project website.[11] The cross-Canada case studies are shown in Figure 1. The vignettes taken from data to illustrate this paper's conceptual contributions are summarized in Table 1. The table is not exhaustive but highlights certain relevant experiences. These are categorized according to the theoretical issue(s) they exemplify. In the following two subsections, I use the empirical material to demonstrate the benefits of integrating theories from STS and geography for the study of infrastructure. First, in section IV(1), I demonstrate the range of concerns and actors at play in the development and change of techno-social relationships (eg, technical design, the production of space, the role of users), some of which would be neglected if either theoretical approach were absent. Next, in section IV(2), I demonstrate the relevance of an approach to scale that pays attention to both the networks associated with the technologies (STS) and the geographical scales with which they interact.

1 Challenges to change: Users, governance, and technology

The important insights to be gained from STS in the study of infrastructure are the wide variety of potential factors and actors involved in the production of techno-social relations and the susceptibility of technologies themselves to such processes. The research indicates that, while political-economic trends like neoliberalism are salient, some of the most important factors affecting the design, deployment, and performance of water efficiency technologies explored below include: existing governance relationships, inter-municipal ideas of autonomy, local culture and demographics, and the interaction of users and technical design. As such, STS can help researchers to respond to the call of Gibson-Graham and other researchers to refuse to reify capitalist political economy and neoliberalism (Barnett, 2005; Gibson-Graham, 2006; Larner, 2003).

Issues of political economy and most recently neoliberalization have proven to be important in

Figure 1. Municipal case studies

a variety of ways. Authors have identified a number of issues with respect to social justice and infrastructure access (section III(1)). In terms of mediating technologies, neoliberalization was shown in this study to influence the range of technologies deployed and their social construction (and thus performance). Under neoliberalization, for example, utilities tend to favor the implementation of economic instruments for water conservation and efficiency (eg, pricing and metering, water markets) as opposed to socio-political or techno-physical measures (eg, low-flow devices, education) (Renzetti, 2005). Interviews following up on the survey results from this study (Figure 2) showed that the demand to operate on business principles using cost benefit analysis led to low implementation of education programs for efficiency in Ontario despite the assertion of both the need for and the relative ease of implementing them (see also Furlong and Bakker, 2007). Similarly, the promotion of processes like alternative service delivery through neoliberalization has been shown to limit the breadth of efficiency devices

Table 1. Examples from the research on water conservation and efficiency in Canada

Issue/program	Sample of programs and challenges	Municipality
Mediating technologies/ water loss control	Their world class water loss control program is used to improve local infrastructure, prevent water main breaks, improve the utility's economy, and to help customers reduce their own water use and to protect their property by alerting them to leakage beyond the property line. The infrastructural age in Halifax makes this a much better investment in water savings than user conservation programs.	Halifax, NS
Scale/efficient fixture replacement	Toronto, in conjunction with other municipalities in Ontario, Alberta, and the USA, formed a group to create standards and tests for water efficient toilets. They then used their purchasing power to compel companies to produce and sell better products. This oversteps their jurisdictional capacity, as standards are a federal jurisdiction.	Toronto, ON
	The CRD's insistence on requirements for efficient devices within its region compelled the province to design new rules for the province as a whole.	Capital Regional District (CRD), BC
	Several municipalities in AB have set local efficient fixture bylaws despite it being a provincial jurisdiction. In Edmonton, the city had difficulty in the sale of water efficient fixtures due to the rapid turnover of staff at retail outlets.	Calgary and Edmonton, AB
	Local residents were resistant to the implementation of low flow devices because they believed that water conservation was intended to enable further population growth in the community.	Region of Waterloo, ON

(continued)

Table 1 (continued)

Issue/program	Sample of programs and challenges	Municipality
Existing governance relationships	The CRD sells bulk water to 13 local municipalities, but due to its regional structure it has no control over local pricing or metering, which can vary widely.	CRD
	Sherbrooke removed its meters upon amalgamation in 2002, as many of the formerly independent municipalities did not have meters. Meters were considered to be of little benefit in water management as the biggest local users are provincial institutions (universities and hospitals) that are exempt by provincial law from water charges in Quebec.	Sherbrooke, QB
Municipal ideas of autonomy	Following amalgamation in 1998, the utility could not harmonize prices across the former municipalities due to political resistance. Prices can vary widely depending on the infrastructure work needed.	Kingston, ON
	It has been relatively easy to raise prices in Toronto, but difficult to harmonize prices across the city after amalgamation in 1998. In 2006, prices still were not harmonized.	Toronto, ON
Local culture	The CRD is a leader in water conservation in Canada, but given the local gardening culture it can do little on outdoor water use.	CRD
	The utility has been unable to impose outdoor water use restrictions due to local political resistance, although they have been able to implement seemingly more controversial programs like price increases.	Toronto
Technical design	Outdoor consumption was overly high for a number of reasons, including developer landscaping practices, poor homeowner knowledge of how to regulate timed sprinkler systems, and poor soil and plant choices for the local climate.	Kelowna, BC
	The provincial regulator (NSUARB) compelled CBRM to reduce demand following action from a well-user group. Old infrastructure means that water loss control is the most cost-effective way to reduce demand.	Cape Breton Regional Municipality (CBRM), NS

Source: Cross-Canada Survey 2007

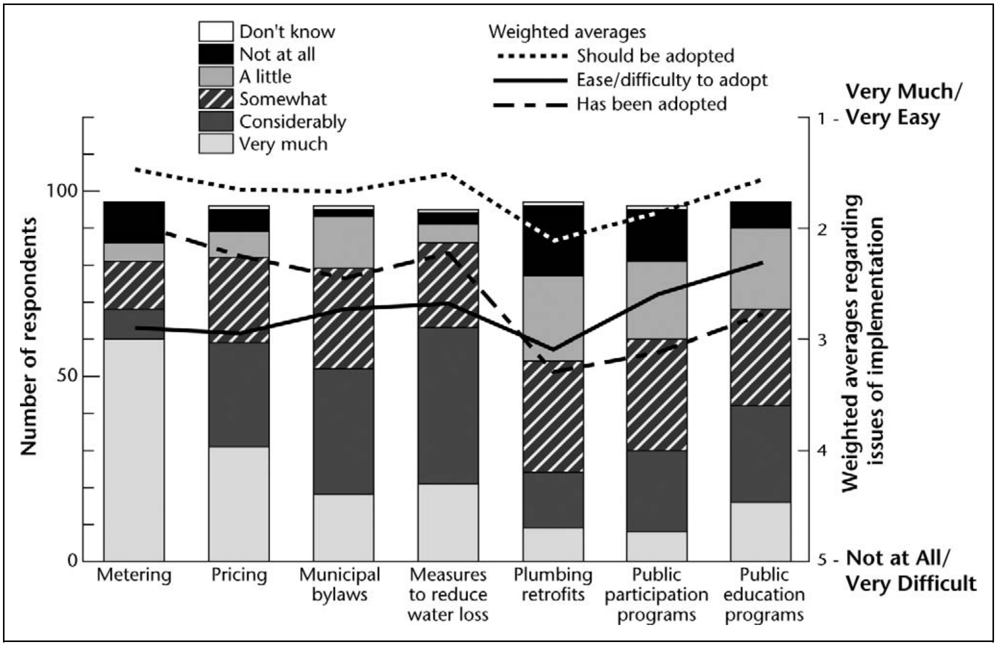

Figure 2. Level of implementation of various efficiency tools including the relative ease/difficulty of implementing them
Source: Cross-Canada Survey 2007

and programs in the Canadian context by promoting devolution without delegation (Furlong and Bakker, 2010).

In terms of the social construction of technology under neoliberalization, meters offer a good example. Under neoliberalization, the principle of full cost recovery gained prominence through theories of market environmentalism as a necessary tool for sustainable and efficient water supply (Bakker, 2004). In this framework, meters represent devices for revenue collection based on the user pay principle. This narrow view leads, in some cases, to low levels of metering because the cost of implementing meters is high compared to the revenues that might be collected (eg, Peterborough, Vancouver)[12] and, in others, to resistance to metering as a tool of social injustice that penalizes low-income users.[13] This masks the range of goals for which meters are important. In this research, utility managers highlighted system knowledge and planning issues ('How can you know if you can't measure?') over any other issue for meter installation.[14] Others highlighted communication with water consumers (Kelowna, Cape Breton), the unfairness of flat rate pricing for pensioners (Ontario), and the ability to address leakage (Halifax, Cape Breton Regional Municipality).[15]

Going beyond issues related to recent trends in political economy, several other factors have proven significant. First, continuing with well-developed concerns in geography, long-established governance relationships present a key example in the Canadian context. Canada's high degree of federalism has proven a persistent problem in environmental regulation because it discourages different levels of government from taking action on issues that may lead to charges of jurisdictional interference (Parson, 2001). With respect to mediating technologies, this issue manifests in the reticence of federal and provincial governments to create standards and regulations for water efficiency technologies. Seventeen-liter toilets, banned in most OECD countries, are still available for retail sale across Canada with only three provinces prohibiting their installation in new development and renovations (but not their sale) (Furlong and Bakker, 2008).

Second, ideas of local autonomy in regional and amalgamated governance have likewise proven important for mediating technologies. In the Capital Regional District (BC) and Waterloo (ON), a regional wholesaler treats and sells water to several local municipalities. Jurisdictional issues mean that, in both cases, the regional provider faces difficulties in setting uniform policies across the region for efficiency, pricing, and even lawn sprinkling.[16] Amalgamated municipalities have faced similar challenges in terms of developing uniform efficiency measures across former municipalities and in maintaining pre-existing efficiency standards. Following amalgamation in Toronto, suspicion of the larger municipality meant that pre-existing efficiency programs were cut (as opposed to extended) and programming restarted in order to appear as a collective rather than a 'Toronto' initiative. Respondents considered this to have set programming back by approximately 20 years.[17]

Such problems can have several antecedents. They are connected to neoliberal restructuring, as amalgamation was a neoliberal policy to reduce the costs of municipalities by reducing their number (and their numbers of representatives) (Bish, 2001; Kushner and Siegel, 2005). However, they also reflect spatial and historical conditions. In Sherbrooke (Quebec) meters were removed following amalgamation because the newly added municipalities did not have them. In this case, the historical arrangement in Quebec whereby provincial institutions are not charged for municipal water combined with the unusually high density of institutions in the Sherbrooke area meant that the potential value of metering in terms of influencing consumption or recovering costs was low.[18]

Turning more obviously to the concerns of STS, the diversity of issues (local culture, demographics and technical design) and thus arrangements across space for the implementation and function of mediating technologies is highlighted. The Capital Regional District, BC, for example, has a large demographic of retirees who have settled there for the climate and the opportunities it provides for gardening. Thus, any outdoor water efficiency programs can be difficult to implement, leading the utility to focus on indoor programs.[19] Utilities may also focus on different types of efficiency technology programs because of the history of the local infrastructure. In eastern Canada, where the infrastructure is much older, water loss control programs are favored because they yield the greatest savings. In Alberta, where the infrastructure is relatively new, programs tend to focus on increasing user efficiency, thus impacting users and the link between the home and the water network more directly.

The design of the water efficient technology can also affect the development of the sociotechnical relationship, given user interaction with the technology. One example is that of automated, underground lawn sprinklers in Kelowna (BC). There, efficient, timer operated underground sprinkler systems were required in all new development. Efficiency gains were thwarted, however, as the devices proved too complicated and time consuming for most homeowners to use as indicated. Instead of programming them according to season etc, they tended to leave them on the same setting year-round. Moreover, while having the sprinklers underground was meant to reduce water demand by reducing evaporation, because users could not see the water many neglected to turn them off, resulting in continuous watering.[20]

Finally, efficiency programs also have direct implications for the production of urban space and nature. In Ontario, most large municipalities that have pursued water efficiency have done so to avoid the costly expansion of infrastructural

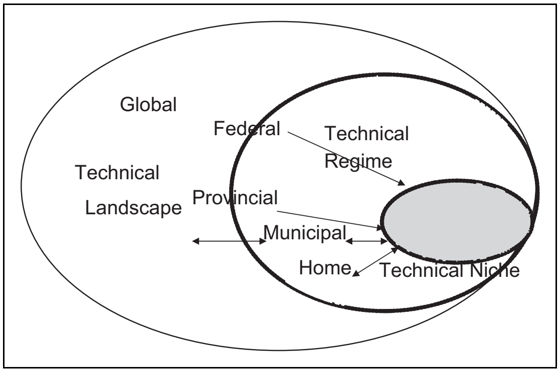

Figure 3. Interactions between STS and geographical concepts of scale in the case of water efficient fixtures

capacity as their populations grow (eg, Toronto, Durham, Peel, York). These programs are designed to accommodate population growth and new development within the confines of existing infrastructure demands. This has led to conflicts over the production of urban space in Waterloo, for example, where some residents resist efficiency programs in order to thwart urban expansion and densification.[21] In other cases, where water supplies are shared, cities may be compelled to improve efficiency and density and to reduce their 'metabolism' of the water source. Toronto, for example, which sells water to York region, entered into the agreement stipulating that both cities would improve their efficiency and work toward a region-wide infrastructure strategy (Thorne, 1998). Calgary, on the other hand, is one of many users in its watershed and is thus compelled to control its demand on the resource through efficiency programs concentrating mainly on technology to reduce user demand (City of Calgary, 2007).

2 Integrating the two approaches to scale: An empirical example

The experiences described in the previous section allude to the multiple interactions of geographical and STS scales at work in the creation of new (and varied) socio-technical relationships through the introduction of mediating technologies. Below, I draw on the example of the implementation and function of water efficiency devices and appliances in buildings and homes to illustrate the interaction of technical and geographical scales. An overlapping interaction of these scales, as elaborated in the text, is depicted in Figure 3.

The assortment of efficient fixture programs across Canada attests to the complex interaction not only between different geographical scales but also between them and the technical scales and networks identified in MLT. In the first vignette below, the control of the provincial and federal scales over the standardization and regulation of technical devices means that they influence both the technical niche and regime in ways external to the control (and often the interests) of municipalities. As such, municipalities must seek new means to influence both higher scales of government and actors in the technical regime to engender desired results in both the technical niche and their own municipalities.

In Canada, the federal scale is responsible for setting technological standards and performance testing. Yet, it has thus far refrained from taking any initiative regarding water efficient fixtures and devices (eg, low-flush toilets, clothes washers). When municipalities in Ontario began implementing efficient fixture replacement programs in the late 1990s, they found that many of the toilets they purchased and installed did not perform to specification. Instead of reducing the water consumed, in many cases water consumption increased because of the need for multiple flushes, the flushes were at higher flows than specified, or users frustrated by their performance replaced the 'efficient' toilets for higher volume toilets or modified them to flush at higher flows.[22]

The inaction on the part of the federal scale to create and monitor product standards in addition to the reticence of the federal and provincial scales to ban high-flow devices (as in the USA and Europe) engendered low demand for the devices in the technical regime and low interest in producing a functioning low-flush toilet (or labeling them properly) within the technical niche. The impact was to setback utility efforts at reducing household water use in many Canadian cities as consumers in the technical regime became increasingly resistant to low-flow toilets (due to their perceived low functionality) and many of the new toilets had to be replaced because they did not meet their stated specifications.[23]

In 2003, this dysfunctional interaction between the technical niche and the federal scale provoked 17 municipalities across Ontario, Alberta, and the USA to band together to resolve the toilet issue. They sought both to assume the standardization function of the federal scale and then to impose the standards onto the technical niche through their collective purchasing power. The coalition of utilities hired an engineering consultancy to develop toilet-testing procedures, to test the toilets from the leading North American manufacturers, and to develop a list of acceptable toilets for homeowners and developers to purchase through utility rebate programs (Veritec Consulting and Koeller and Company, 2007). By 2006, 15 other such inter-utility coalitions had developed through the Canadian and American Water and Wastewater Associations (CWWA and AWWA) to redress similar limitations to their programming goals.[24]

In the above case, one sees how utilities can form networks across the municipal scale (irrespective of provincial and national boundaries) to project influence beyond their normal sphere (to higher scales of governance and into the technical niche) in order to produce the desired local techno-social and environmental relationships. Urban water utilities are seeking to redress their lack of authority over efficient fixture standards and regulations in other ways. In Canada, plumbing codes are a provincial jurisdiction and no province has strict requirements for water efficient fixtures. Despite this, several municipalities in Alberta have sought to change the technical regime (at least locally) by setting their own efficient fixture bylaws. These bylaws require a certain standard of fixture to be installed in all new development and renovations. In British Colombia, the province implemented efficiency regulations following a bylaw developed in the Capital Regional District (CRD – Victoria) (for details, see Furlong and Bakker, 2008: 16).

Yet, despite their innovation and success, the ability of utilities and municipalities to produce the desired technical regime remains limited and precarious. For example, in Alberta local water efficiency bylaws, while so far having met with compliance, could be challenged on jurisdictional grounds by local developers or the provincial government.[25] In British Colombia, the province's efficiency regulations simply support regulations adopted by individual municipalities but do not seek unified standards across the province, thereby dampening the potential influence on the technical regime (eg, in terms of retailing of efficient devices). The retail element of the technical regime is an important one. The continued ability of local consumers to purchase inefficient fixtures at any retail outlet poses an important limitation to local efficiency bylaws and programs. Developers also exact important influence in the technical regime. In Calgary, for example, the municipality was compelled to omit restrictions on multiple-shower heads from its efficiency bylaw in order to secure their cooperation.[26]

Retailing further exemplifies the links between the national and international scales and the technical regime. For example, even where a local retailer in Alberta might like to stock the efficient devices to meet local bylaw requirements, they may be subject to the purchasing policies of their main branch in central Canada where the same efficiency standards are not in place. As such, without national regulation, local retailing is difficult to reform. Retailing is also influenced by international trends in employment toward less stable work. Efficiency managers in Edmonton noted the challenges to sales of efficient devices due to the high turnover of retail staff in major appliance outlets. This limited the ability to maintain staff trained to explain and promote the alternative devices to consumers.

As such, while the municipal scale exists in direct interaction with the technical regime with which it must negotiate, develop, and deploy its efficiency programs, its ability to do so is affected by the influence of higher scales of governance on both the technical regime and the technical niche. While municipalities may have the greatest interest in quality efficiency devices, they have little individual influence over their development in the technical niche. The creation of horizontal networks across municipalities through, in this case, international professional associations serves to increase their potential influence over the technical niche both directly and through the ability to pressure higher scales of government for policy reform.

V Conclusion

This paper introduces the concept of mediating technologies as relatively simple additive technologies that, when appended to the peripheral nodes of an infrastructural network, can alter established socio-technical relationships in significant ways. The relevance of the concept is demonstrated through a critique of the outdated perception of urban infrastructure as essentially static, 'normalized' and 'black-boxed' (widely common in both STS and the study of technology in geography). Rather, through an increasing interest and deployment of efficiency devices and programs, the socio-technical and environmental relationships around urban water infrastructure are subject to important transition and variation. Such technologies bring infrastructure networks into direct interaction with users, both opening up the 'black-box' and rendering the performance of the system as a whole less predictable.

This reduced predictability, stability, and fencing of the infrastructure network makes the analysis of the factors involved in influencing socio-technical change all the more important. As such, in the second portion of the paper, I examined the main approaches to infrastructure in geography and STS to highlight complementary insights that can be brought together for fuller analyses of urban infrastructure. More specifically, I argued for the integration of: (1) geography's better-developed approaches to social, political, and economic factors as well as its critical insights regarding the production of space and nature; (2) STS's concern with a wider range of actors, artifacts, and institutions engaged in the design, deployment and performance of technology (eg, users, interacting technologies, and networks of managers, retailers, financiers, etc); and (3) the distinct approaches to scale in each discipline – ie, geography's political scales and those of the multilevel transitions theory in STS.

This work challenges and advances the literature in several ways. First, whereas the literature posits that the inherent trajectory of infrastructure is toward stability and invisibility as it 'matures', through the integration of mediating technologies this long-accepted trajectory is undermined. By bringing users into direct engagement with infrastructure, not only is its stable state subject to change, but the trajectory is shifted from one of 'invisibility' to one of active consciousness whereby users are purposefully engaged in the performance of the network. Concomitantly, whereas the literature sees the invisibility of infrastructure to be disrupted strictly via malfunction and exclusion, mediating technologies reflect a situation where visibility (rather than an aberration) is, for many infrastructure managers, the norm to which they aspire.

Such a transition, however, cannot be entirely predetermined. Mediating technologies (because of their size, proximity to users, and relatively low degree of complexity) engender an entirely new set of questions about who can influence the meaning and performance of infrastructure. Persons and groups who have little access to either political processes or to large-scale (especially underground) infrastructure can place their mark on mediating technologies in a variety of ways. Such direct user involvement in the infrastructure network serves to make it more malleable as well as less stable and predictable. This can be positive in that it signals the potential for mediating technologies to improve opportunities for municipalities to work within their communities (and across scales) to develop systems that are more fitting with the needs of their locality and are yet flexible enough to evolve as needs change.

Finally, this research speaks to issues in other types of infrastructure. Most obviously for energy systems, mediating technologies in the form of efficiency devices would have similar possibilities to shift socio-technical relationships and engage users in the management and performance of the infrastructure. For other infrastructures (eg, road networks or telecommunications), the associations are less obvious. What can be said, however, is that where small technologies have been added to these systems for the purpose of, for example, exclusion by enabling user based pricing, the performance and impact of these technologies is not guaranteed. The contingency of all technology and its potential for multiple goals is a key issue raised in this paper.

This paper signals the need to look beyond infrastructure as a single unit, static in its physical state and social and environmental effects. Breaking infrastructure down into assemblages of small technologies that matter enables one to see the possibility to employ small change to mediate large problems. This is what makes mediating technologies a significant concept for rethinking urban infrastructure and therefore the production of urban space and nature: they signal a relatively simple route to malleability in networks and systems that are widely understood to be inert. This paper not only alerts us to this malleability, it brings together theoretical tools to understand and manage it.

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Notes

1. Water efficiency devices have been widely studied in other areas of research concerned with improving water efficiency and environmental concern (eg, Gleick, 2003; Lovins, 1976) and energy efficiency has been an object of concern in human geography with respect to energy poverty (Boardman, 1998; Buzar, 2007).
2. Latham and colleagues, more specifically, identify the approaches as splintering urbanism, cyborg urbanisms, and fetishism (Latham et al., 2009). Here, however, a more general framing is useful given that splintering urbanism derives itself from Marxist, ANT, and cyborg approaches, fetishism is derived directly from Marxist ideas, and cyborg urbanism marks an offshoot of poststructuralism (Graham and Marvin, 2001; Kaïka and Swyngedouw, 2000).
3. According to the literature, public awareness of infrastructure arises either through exclusion or disruption (break-down) (eg, Gandy, 2005; Graham, 2010b; Kaïka and Swyngedouw, 2000; McFarlane and Rutherford, 2008).
4. The users' literature in STS is important in theorizing this point and is taken up in section III(1).
5. Interview 13B with utility management in Halifax; see also Yates (2005).

6. Several edited volumes attest to this statement (Coutard, 1999b; Coutard et al., 2005b; Summerton, 1994a).
7. Studies continue to be conducted in this way (eg, Elzen et al., 2004).
8. This work has been heavily criticized for advocating 'geography without scale'; this position is not adopted here (eg, Jonas, 2006; Leitner and Miller, 2007).
9. Examples of such approaches are common (eg, Jacobsson and Bergek, 2004; Jaffe et al., 2002; Norberg-Bohm, 1999; van de Poel, 2003).
10. This is perhaps why so little LTS work has availed of the MLT insights, a notable exception being Coutard's scalar approach in the Governance of Large Technical Systems, which very much resembles MLT (Coutard, 1999a).
11. The details and results of the surveys, case studies, and workshops are posted on the project website (http://www.watergovernance.ca/projects/water-in-canada/municipal-water-supply).
12. Interviews 11B and 29 with utility staff.
13. This issue was highlighted at the second workshop (see Gardner, 2008).
14. This is based on the culmination of interview material.
15. Interviews 23B, 15B, 13B with municipal and utility staff.
16. Interviews 9B and 46 with utility staff.
17. Interviews 38 and 42 with utility and municipal staff.
18. Interview 27B with utility management.
19. Interview 9B with utility staff.
20. Interview 23B with efficiency staff.
21. Interview 46 with utility staff.
22. Interviews 40, 41, 46, 28, 14, and 15 with efficiency staff and consultants in Toronto, Waterloo, Peel, and Durham.
23. Interview 38 with utility staff.
24. For more information, see the Alliance for Water Efficiency (http://www.allianceforwaterefficiency.org).
25. At the second workshop, utility members from Ontario stated that they would be unable to pursue such a bylaw because of these concerns.
26. Interview 6B with utility staff.

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