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Politicising the nexus: Nexus technologies, urban circulation, and the coproduction of water-energy

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About the Nexus Network think piece series

Funded by the ESRC, the Nexus Network is a collaboration between the University of Sussex, the STEPs Centre, the University of East Anglia, and the Cambridge Institute for Sustainability Leadership. The Nexus Network brings together researchers, policy makers, business leaders and civil society to develop collaborative projects and improve decision making on food, energy, water and the environment. In July 2014, the Nexus Network commissioned 13 think pieces with the remit of scoping and defining nexus approaches, and stimulating debate across the linked domains of food, energy, water and the environment.

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Politicising the nexus: Nexus technologies, urban circulation, and the coproduction of water-energy

Introduction

Water and oil, it is often said, do not mix. This paper argues that they do. Indeed, water mixes with just about every form of energy that human society has hitherto harnessed. Water and energy mix to produce cities. Cities like Las Vegas. If the Colorado River were to suddenly run dry, we are sometimes told, the city of Las Vegas, and indeed much of the rest of Nevada, Arizona and Southern California would have two to three years before Lake Mead emptied and the turbines of the Hoover Dam ground to a halt. At which point, faucets and fountains would run dry, lights would go out, the music would stop, and global capital would flee in search of other urban spaces through which to circulate. The Hoover Dam stands as a monument to the binding together of water and energy. The *water-energy nexus* solidified in concrete. Moreover, the fear of going dry is prompting the Colorado River states to reforge the interrelations between water and energy in new and extraordinary ways. Through the application of seawater purification technologies, thirsty cities are now able to effectively turn available energy resources into a fresh supply of water. In a word, to stave off impending water crisis through investment in cutting-edge technology and the application of vast amounts of energy.

Plans are afoot for the construction of two large 'bi-national' desalination facilities in Baja California, Mexico, which would supply both sides of the US-Mexico border with purified seawater. The water authorities of Las Vegas, which lies some 250 miles inland, are considering financing the development of coastal desalination in return for equivalent extraction rights from the Colorado System.[1] This *paper transfer* of nexus-water would function as a pressure relief valve for the political boiler that is the Colorado River Basin. Similarly, in San Diego, desalination is seen as an important strategy to reduce reliance on imported water from external agencies. The mobilisation of the Pacific Ocean represents an attempt to re-scale the governance of urban water. Such examples illustrate the central thesis of this paper: the multifarious and complex interactions between water and energy, or what has come to be known as the *water-energy nexus*, are hotly contested, reflective of struggles between interest groups, and always develop through the exercise of political and economic power. Indeed, by its very conception, 'the nexus' betokens political terrain.

The concept of the nexus has emerged over the past five to ten years as a powerful framework for understanding the relationships between sectors that have traditionally been considered as distinct.[2] The water-energy nexus is part of a broader movement that seeks to illuminate the complex interrelationships between water, energy, agriculture, and climate.[3-5] Even in the last year, the number of academic publications specifically concerned with the nexus framework has burgeoned, a multitude of international conferences have been arranged on the topic, and a number of high profile events have raised public awareness, most notably the UN's *World Water Day* in March 2014. 'Water and energy,' the UN report[6] (p.9) argues, 'are closely interlinked and interdependent.' The message of the day was quite simple: water production requires energy and energy production requires water; demand is increasing but supplies are limited; the poor lack adequate supplies of both; and efficiency measures for one translate as savings for the other. Proponents attempt to identify and eliminate tensions and trade-offs between these sectors, and to highlight synergies and shared goals between them.[6,7] A major aim of this work is to inform new policy and management solutions that integrate water and energy under the same decision-making framework.

The nexus framework is still a fledgling discourse. Interest from the social sciences has developed only very recently. Indeed, the formation of this ESRC-funded Nexus Network represents one of the very first concerted attempts to consolidate a social science approach. Furthermore, critical perspectives on nexus issues are currently virtually non-existent in the literature. As such, the discourse so far has developed along a technocratic and reductionist path. The contested relationships, processes and technologies through which energy and water become enrolled in nexus interactions –what we might call the political production of the nexus– are drastically overlooked in existing scholarship.[8] In particular, there has to date, been a striking absence of theoretically informed spatial and political analysis of the nexus.

Drawing on a diverse range of theoretical and ontological approaches, we argue for an understanding of the nexus framework that goes beyond the technology-focussed interpretations that currently pervade the discourse, to one that is both technical *and* social, material *and* political. With particular reference to urban political ecology,[9,10] the water-energy nexus is presented as being *emergent*, and developing through an historical process of *coproduction*. Building on this political ecology perspective, we mobilise science and technology studies (STS) and *assemblage thinking* as complementary approaches to understanding the emergence of nexus structures as fundamentally processual and socio-technically heterogeneous.

In writing this contribution, our aims are twofold: first, to provide a comprehensive review of existing scholarship on the interrelations between water and energy; and second, to demonstrate the urgent need for, and potential future direction of, more critical, theoretically informed, perspectives on the nexus. The paper begins with a critical analysis of the current state of the discourse. In particular, we challenge an emerging consensus in the literature, which posits that integrated management of water and energy will *necessarily* lead to more sustainable management of both. Fundamentally, this is a call for purely efficiency-based solutions to tensions and trade-offs between energy and water, and one that is entirely consistent with market-based approaches to environmental governance. The concept of 'integration' has become a panacea for the negative aspects of the nexus, an ultimate solution that forestalls more politically informed discussions. This assumed logic ultimately implies that the serious challenges posed by the nexus framework, do not in fact require real political change. Part two of the paper develops a critical approach to understanding the water-energy nexus, and proposes some theoretical and methodological tools for doing so.

Part 1: Dimensions of the nexus

The popularisation of 'nexus thinking' in policy and academic discourses represents a major critique of established categories and practices of environmental governance. Proponents seek to challenge traditional distinctions between sectors, illuminate the linkages between them, and expound the ecological and social benefits of co-management.[11,12] In essence, the literature reviewed here concurs on the following point: the challenges facing our water, energy and food systems, that together provide the basic material flows upon which all human action is predicated, form a set of complex, and above all *inter-related* problems, and must be managed as such. Failure to do so 'can often inadvertently create sub-optimal signals to economic, national security or environment concerns'[3] (p.7896). Hence, transformations or developments in one sector, inevitably create reverberating repercussions, be they adverse or favourable, in other sectors.

Meeting ever-expanding demand with abundant and uninterrupted supplies of water and energy is prerequisite to the functioning of economies and societies. Many regions around the world, however, are experiencing severe challenges in maintaining a secure and sustainable flow of both. Moreover, it is when 'water and energy rely on each other that the most complex challenges are posed'[13] (p.32). These challenges, which arise through the linkages between energy and water, are very often confounded by the development of alternative sources and new technologies, such as seawater desalination, inter-basin water transfer, biofuel energy and hydraulic fracturing. The purpose of these technologies is to mitigate inadequate or unreliable supply, but their effect can be to increase one sector's reliance on the other, and ultimately to increase vulnerability.[14] The confluence of these two trends -the increasing concern over water and energy supply on the one hand, and the deepening of linkages between the two on the other- has prompted the recent surge of academic and policy interest in the water-energy nexus.

Nexus technologies: water for energy, energy for water

Expressed in its simplest (and most *simplistic*) form, the *water-energy nexus* considers the embedded energy in water systems and the embedded water in energy systems, or succinctly '*energy for water* and *water for energy*'[15] (p.4229). This physical, quantifiable, metric of the nexus has attracted most attention from scholars.[16] As such, much of the literature is concerned with the technologies through which water and energy are brought together. It is these *nexus technologies*, then, that form the starting point of this discussion. A *nexus technology* simply refers to a technical configuration that draws together water, energy, land, and atmosphere, creating or reconfiguring interactions between them (see *table 1*). Particular attention is often paid to large infrastructures and technologies –this is what Scott et al.,[12] have called the 'pumps and turbines' approach to energy and water coupling.

	Nexus technology	Household	Neighbour-hood	City	National	Supranational
Energy for water	Appliances, baths and showers	▯				
	Rainwater collection	▯	▯			
	Sewerage treatment	▯	▯	▯		
	Water recycling	▯	▯	▯	▯	
	Groundwater pumping	▯	▯	▯	▯	▯
	Desalination (sea and brackish)		▯	▯	▯	▯
	Inter-basin transfer		▯	▯	▯	▯
Water for energy	Appliances, baths and showers*	▯				
	Domestic heating and cooling	▯				
	District heating	▯	▯	▯		
	Thermo-electricity (plant cooling)		▯	▯	▯	
	Biofuels			▯	▯	▯
	Fossil fuels (extraction, processing)			▯	▯	▯
	Hydroelectric		▯	▯	▯	▯

Table 1. 'Nexus technologies' and their multi-scalar interactions

* The example of baths and showers is slightly unusual. Initially, energy is embedded in water through heating and pumping, but when used, that energy is transferred away from the water to the human body. Here, water is both the object of embedded energy, and its intermediary.

A comprehensive understanding of the water-energy nexus, however, necessarily considers coupling at all spatial and political scales, from the technologies and practices of personal hygiene, through geographically and historically specific urban production and consumption infrastructures, to the geopolitics of supranational struggles for control of resources.[12,13] Indeed, because 'water and energy pervade every aspect of ecosystems, human systems and economic activity, the connections between water and energy are everywhere'[11] (p.1984). Moreover, the particular manner in which a nexus technology is deployed might have implications for the (re)configuration of political scale (see for instance, Swyngedouw[17] on the politics of scale). The example mentioned in the introduction, where desalination technologies have become enrolled in the re-scaling of urban water governance, provides a pertinent illustration of this.

Energy is required in every stage of water production, extraction, transportation, treatment, distribution, consumption and disposal. Nexus interactions are implied in every aspect of the water system, from the type of shower head installed in your bathroom and the amount of tea you drink each day, to the specific water mix of a given region (i.e. the various sources of water and their respective energy-intensities), and its distribution and treatment infrastructure. Kenway[18] distinguishes between *direct* and *indirect* water-energy links. *Direct* links describe the energy requirements of water production, distribution and disposal, and *indirect* the energy used in consuming water, say, through domestic heating or cooling, household pumping and laundry. Although the former is generally given priority in the literature, often being assumed to be more important, *end use* is nevertheless highly significant. Indeed, Cohen et al.,[19] have estimated that, even in San Diego –a region that relies on energy-intense inter-basin transfers from Northern California and the Colorado River for the majority of its water– *consumption* accounts for 57% of total embedded energy per unit of water.

In terms of supply and distribution, the literature considers both the embedded energy in new or emerging nexus technologies, and of existing systems. A common concern is the high energy intensity of alternative freshwater sources, that are emerging as traditional sources deplete and competition between users increases.[20] Desalination of sea and brackish water has received particular attention because of the high energy requirements of purification technologies.[21,22] Seawater desalination provides a particularly pertinent example of nexus interdependencies because, given that in practical terms ocean water is inexhaustible, a society with the technology and available energy supply to purify saltwater effectively has access to an unlimited supply of freshwater. Through the development of large-scale reverse osmosis desalination technology, then, concerns over water scarcity are translated into issues of energy availability on the one hand, and the carbon emissions associated with such water sources on the other. Other alternative water sources to come under scrutiny in the nexus literature include inter-basin transfer, where water is transported from regions of abundance to areas of relative scarcity, and deep aquifer pumping.[2,23] Both represent significant attempts to expand water consumption in the face of dwindling traditional sources and growing demand, and both are highly energy intensive, albeit with a degree of regional variation. Others have focussed their attention on the energy intensity of existing water practices and technologies, arguing that increasing efficiency in the water sector will relieve pressure on energy resources. Stillwell et al.,[24] for example, are concerned with reducing the energy consumption of established wastewater treatment infrastructures. The central argument of the *energy for water* literature is that, because of the technological feats water-stressed communities are compelled to achieve, levels of embedded energy in water supply are rising, but, it is also precisely the scarcity of water, and competition for it, that threatens the supply of energy.[25]

Large amounts of water are required in the extraction, processing and conversion of energy, in almost all of its forms.[26] In the USA, for example, the energy sector is the fastest growing water user nationwide, with demand expected to increase 50% between 2005 and 2030, and growth largely concentrated in areas already experiencing high levels of competition amongst water users.[27] Water is consumed in the extraction, production and refining processes of combustible fuels. Demand is set to rise as alternative fuel types, including hydraulic fracturing and oil from tar sands, replace traditional sources.[14] Biofuels, such as corn ethanol and palm oil, which have become a popular option for countries wishing to reduce greenhouse gas emissions and reduce reliance on imported fossil energy, are particularly water intense.[3,28] Although there is of course a degree of regional variation, depending on local climate and agricultural practices, biofuel plantations generally require significant water inputs for irrigation. Here then, an alternative energy option, praised for its ecological credentials, is likely to contribute to water stress over the coming decades.

Much of the nexus literature is concerned with the water requirements of electricity generation, both hydroelectric and thermoelectric. Hydroelectricity, by combining water and gravity to produce electric energy, is an obvious point of interest in the water-energy nexus. Whilst the turbines do not consume water directly, the process requires large quantities of water to be stored in reservoirs, and considerable quantities are lost through evaporation.[22] Hydroelectric power is perhaps the best understood, and certainly the most visible manifestation of nexus interactions. Of all the nexus technologies, hydroelectric power generation has been the focus of the most sustained attention from scholars, and has a long history of organised opposition.[29]

Thermoelectric power plants, the fuel inputs for which include coal, oil, gas, nuclear, and to a lesser extent biomass, require vast quantities of water for cooling. Recent droughts have put pressure on power plants to use less water.[30] Almost all thermoelectric plants use one of three types of cooling system. *Open-loop* or *once-through* systems withdraw water from a source, hygiene, through geographically and historically specific urban production and consumption circulate it through the power plant and return it to that source. Water is lost primarily through evaporation. These systems require huge amounts of water and account for 91% of *withdrawals* associated with power plants in the USA.[31] Open-loop cooling, however, does not actually *consume* very much water –indeed, less than 5% is actually lost in the process.[30] *Close-loop* or *re-circulating* systems withdraw smaller quantities of water and circulate continuously through the plant. These systems withdraw 30-50 times less water than open-loop, but more than 75% of that is consumed in the process and not returned to the water body.[30] In terms of mitigating the negative effects of the water-energy nexus, this presents something of a catch-22 situation: by switching from open to close-loop cooling systems, power plants can reduce their vulnerability to drought and water scarcity, but in doing so, increase their water consumption overall.[32] Finally, *dry cooling* systems use air flow instead of water to cool. These systems are far more expensive and cause a dramatic drop in plant efficiency, so are not widely used.[33] Overall, thermoelectric plants are responsible for around 40% of freshwater *withdrawals* in the USA –higher even than agriculture- but only 3% of freshwater *consumption.*[34,32] Hence, electrical power generation is severely affected by constraints on water supply, and as a sector, is amongst the most vulnerable to negative implications of the water-energy nexus.

Geographies of the nexus

The coupling of energy and water, as a physical and political phenomenon, is situated firmly in place. In other words, the nexus has a distinct geography, but one that is as-of-yet poorly understood. Moreover, the physical interactions between water and energy are often separated geographically from the social and ecological effects of those interactions. For example, Bartos and Chester[35] have argued that because Arizona is a net exporter of electricity, through the embedded water in that electricity, the state also becomes an exporter of water to less water-stressed regions. Here then, the purchasers of Arizonan electricity, are concurrently purchasers of the state's water. Thus, Scott et al.,[12] have argued that there is not only a 'dissonance between scales of water-energy coupling and levels of institutional decision-making' (p.6628), but also a dislocation between energy and water use and negative impacts of the nexus. A full consideration of the geographies of the nexus, therefore, should form an indispensible part of nexus thinking, both conceptually and practically.

The water-energy nexus is ‘acutely articulated under conditions of resource scarcity’[2] (p.655). That is, as concern over supply intensifies and competition for each grows under conditions of real or perceived scarcity, the centrality of one to the other becomes more stark. Nexus issues are most visible and concerning in resource-poor economies, where demand for both water and energy is greater than supply.[36] The challenges presented by the low value-to-weight ratio of water, and therefore the difficulty of moving it from places of abundance to places of scarcity, are such that this is particularly apparent in arid regions.[37] Further, as has already been demonstrated, the technological adaptations that resource-poor regions adopt, precisely to expand consumption levels under conditions of scarcity, often confound the negative effects of the nexus and deepen interdependencies. So, where water is scarce, the technologies that ensure its availability (desalination, imports, and so on) are highly energy intense. Attention has been given to nexus issues in Spain,[38] Mexico,[39] Australia,[11] China,[16] India,[36] the Middle East and North Africa,[22] and Texas,[40,21] whilst Scott and Pasqualetti[2] are among the few to have considered the importance of the nexus across international boundaries.

It is in the semi-arid American Southwest, and particularly in California, however, that the water-energy nexus has received the most attention from academics and policymakers. Indeed, the discourse has focussed disproportionately on this region, with perhaps 20-30% of the literature on the water-energy nexus pertaining to south-western USA. Apart from the large and vibrant scientific community in the area, which is driving nexus research, there are a number of explanations for this. First, it is a region where the linkages between water and energy are very visible. There is a long history of large-scale hydroelectric power generation, for instance, which is one of the best understood dimensions of the nexus.[23] The reliance of the water supply on abundant energy, too, is most apparent. This is particularly true of Southern California, which has long relied (almost entirely) on imported water, to the degree that the embedded energy in Californian water is twice as high in the South than in the North.[25] Second, the already low and unreliable rainfall is likely to reduce in real terms and become more unreliable as a result of climate change.[5] This is effectively creating a situation where periods of drought, when energy-intense water supplies are most needed, are also when energy production is most precarious. Finally, the literature also cites a growing population, growing economy, and increased competition for dwindling resources, as contributing factors.[26] This is not to imply that nexus issues are unimportant in temperate regions, but that the context-specific milieu of water-energy availability, competition between users, and nexus technologies in arid and resource-stressed regions are such that water-energy interactions are more visible and pressing.

The focus of the nexus literature is often national or regional. Studies have begun to emerge, however, that place cities as the ambit of analysis. Not only are cities key sites of water and energy consumption, of technological development, and of population and economic growth, but the process of urbanisation itself entails increased demand for both. An urban perspective on the water-energy nexus is, therefore, relevant and highly necessary.[11,41] The concept of the *urban metabolism* has been used to articulate the connected flows of energy and water through urban landscapes.[42,18] Such concepts are useful for understanding the flow of water and energy through cities. In the main, however, such work has tended to consider cities in terms of inputs and outputs of water and energy in fairly linear terms, without considering the processes of urbanisation in a more theoretically informed context. There has, then, been very little effort to conceptualise more systematically the role of cities in *producing* or reconfiguring nexus interactions. There is a great need for a more concerted effort to understand how, why, and with what implications, the urbanisation of water and energy is producing the nexus. One of the aims of this paper is to make some contributions in this area. More will be said in part two.

The panacea of integration: (mal)adaptations, tensions and synergies

The *water-energy nexus* is emerging as a powerful discourse on the interconnections, tensions and synergies between two sectors that have traditionally been considered separate and distinct. Above all, it warns of the social and ecological dangers of a compartmentalised management approach. The arguments presented, however, tend to be fairly linear: water and energy are both indispensable resources to modern economies; there are multiple and complex linkages and interdependencies between the two; these linkages are likely to deepen; yet these two vital elements are managed in isolation. Almost all of the literature reviewed here concurs on one point: the need for integration. Policy and practice, it is generally agreed, should be adapted to overcome what Waughray[4] calls 'structural problems' in management. Whilst such a reorientation would present many challenges, and include everything from institutional reform to technological interventions and behavioural change, the potential gains would be significant.[43]

At the heart of the debate is the idea of structural tensions between water and energy sectors, where developments in one put increased pressure on the other, and where stresses and insecurities in one simultaneously become stresses for the other. The examples mentioned earlier, where limited water supply can put pressure on thermoelectric power generation by limiting the availability of water for cooling, provide a good illustration of this. Given the multi-scalar nature of nexus relationships, such tensions are found everywhere. This 'vicious cycle’, in which adaptations to pressures in one sector necessitate adaptations in the other, has led to what Webber[44] has called a *catch-22 situation*:

“We cannot build more power plants without realizing that they impinge on our freshwater supplies. And we cannot build more water delivery and cleaning facilities without driving up energy demand.” (p.34)

Failure to adequately manage these tensions can lead to ‘questionable trade-offs’ between water and energy security.[13] The adoption of close-loop cooling systems for thermoelectricity generation, which use less water but consume more, provides one such example. Seawater desalination provides another. Often touted as a climate-proof, drought-resistant and rainfall-independent source of freshwater, large-scale desalination is considered by many to be a viable adaptation strategy to climate change. Yet, by increasing reliance on industrialised energy inputs, often in the form of fossil fuels, desalination may actually exacerbate the problems it is intended to solve, and as such, represent a form of climate ‘maladaptation.’[45,46] The overwhelming consensus of the nexus literature, then, is that we should understand better the tensions between water and energy, avoid negative trade-offs, and seek out and capitalise on synergies between the two.

As might be expected, synergies are found in both supply-side and demand-side solutions.[7] On the demand-side, emphasis is generally placed on efficiency, with numerous studies espousing the potential for synergies in conservation (see for instance, Bartos and Chester,[35] Scott and Pasqualetti,[2] Stillwell et al.,[40]). Recommendations for conservation are almost exclusively efficiency based, for example the use of ‘green’ household appliances such as efficient household hot water systems.[47] Through the multiple linkages, it is argued, savings in one sector translate as savings in the other, thus counteracting tensions and trade-offs. The aim here is to reduce the interdependencies between energy and water. On the supply-side, a broad range of technological solutions has been proposed. Suggestions include the co-production (here used in a technical, rather than conceptual sense) of electricity, heat and water;[37] the use of low-grade excess heat energy from power stations in District Heating;[48] energy recovery from wastewater treatment;[24] and the use of off-peak wind energy for brackish water desalination.[21] Karaca et al.,[49] have even gone so far as to propose a vision, albeit a barely realistic one, for the *physical* integration of urban water and energy distribution infrastructures. Here again, the overwhelming emphasis of the literature is on the potential for technologies of integration to eliminate the inefficiencies borne out of fragmented management.

The need for policy and institutional reform straddles the demand and supply-side of the nexus debate, and is a recurring theme in the literature. Indeed, the underlying narrative of the scholarship reviewed thus far is almost unanimous: that tensions and negative trade-offs should be avoided, and synergies amplified, through policy and institutional *integration*. Many of these authors, however, are fairly non-specific on what an integrated water-energy policy framework would actually look like. More detailed visions have been proposed by the likes of Goldstein et al.,[50] who have argued that institutional boundaries should be softened through data sharing and free movement of information between the two sectors; Scott et al.,[12] who call for greater recognition of the multi-scalar politics of the nexus; and Sovacool[31] who has suggested the designation of 'electricity-water crisis areas' as a potential policy tool. Nevertheless, generally the idea of integration has become a catholicon for the negative aspects of nexus interaction, unquestioned and never problematized, but one that is consistently ill-defined. Fundamentally, the call for integration through policy change and technological development is a call for the eradication of inefficiencies. The message that permeates the nexus discourse, that integration will necessarily lead to greater sustainability – the implication being that inefficiency is the root of our water and energy problems– is no more than an assumption. It is moreover, an assumption that should be challenged. The city of Los Angeles, for instance, has maintained integrated management of its water and energy supply for over a century, under the umbrella company, the Los Angeles Department of Water and Power (LADWP). Not only can it not be said that Los Angeles has, in this time, fostered a more responsible or 'sustainable' approach to water and energy resources, but MacKillop and Boudreau[51] have even suggested that this institutional structure actually facilitated the unique (and hardly efficient) sprawling development of the city.

This really brings us onto the key point of this paper. The assumed logic resonating through the nexus literature, that the primary response to tensions and trade-offs should be to integrate, overlooks the deeper challenges and contradictions of water and energy consumption, and ultimately deflects some of the more difficult questions posed by the concept of the nexus. Rees[8] has pointed out that nothing about the current discourse in any way implies radical change. Perhaps this point lies at the heart of the recent success of the nexus framework. The argument is, after all, compelling: water and energy are essential ingredients to the functioning of economies and societies; there are indeed multiple linkages between them, despite being managed separately; and these linkages do embody many tensions and trade-offs. The solution, 'integration, integration, integration' is, at first glance, an obvious one, and indeed difficult to disagree with. We are, then, presented with a set of severe problems that seem to jeopardise our very security and quality of life, and *at the same time* a ready-made solution to those problems, which tells us that real change is not in fact needed. The important question is thus forestalled: what type of politics and imaginaries are being reproduced, if inadvertently, by the current nexus discourse? And how might the debate look if we were to challenge some of those prevalent assumptions and conclusions?

Part 2: Towards a critical perspective on the nexus

Integration and the neoliberalisation of the nexus

Recent burgeoning interest in nexus issues has gone hand in hand with an emerging and overwhelming political consensus on how nexus interactions should be managed. This is expressed, as we argued in part one, in the assumed logic of the panacea of integration. Bazilian *et al*'s[3] assertion, for instance, that integrated policymaking 'would lead to a more optimal allocation of resources,' and through accompanying improvements in efficiency, an 'overall optimisation of welfare' (p.7903), and Stillwell *et al*'s[40] contention that 'Improving water efficiency will reduce power demand, and improving energy efficiency will reduce water demand' (p.18), exemplify a pervasive concurrence in the literature. The consensus holds that efficiency is the key to sustainable management of the nexus. Integration has become a buzzword of the discourse, ostensibly uncontroversial, yet politically loaded nonetheless. Indeed, despite a veneer of scientific impartiality, the suggested mechanisms through which this should be achieved are saturated with political meaning. Yet, this distinct *nexus politic* is rarely acknowledged explicitly. It is important that contributions to the nexus debate from the social sciences highlight and problematize the deeper social relations at play.

The call for integration centres around two primary recommendations. One, the potential for greater efficiency through technological development; and two, need for institutional and policy reform. It will not have escaped the reader's attention that these 'solutions' would come top of the list in a Hayek/Friedman guide on 'how to do neoliberalism'. In the first instance, the call for efficiency-driven technological 'fixes' represents a strongly market-based approach to managing the contradiction between, on the one hand the need to mitigate tensions between water and energy, and on the other the economic imperatives for sustained growth in both sectors.[52] Proponents argue that innovations such as water-saving shower heads, the co-location of water desalination facilities with power plants, the use of renewable energy in water transportation, or the development of dry-cooling systems for thermoelectric generation, reduce the interdependencies between water and energy, and therefore mitigate the negative implications of the nexus. The technological solution, however, does not resolve these contradictions, but rather diminishes them as an obstacle to continued growth. In other words, the application of technology becomes a method of governing the water-energy nexus based on the logics of the market. Further, such application of technology aims to create a fragmentation of uses across space, and a multiplication of contracts and 'service providers,' which again, are key hallmarks of the neoliberal process and a further source of contradiction and instability.

In the second instance, the argument for integration through institutional and political restructuring does not *necessarily* denote neoliberal proclivity, but it does leave the policy door wide open to market-based reform. The process, or rather *processes* of neoliberalisation are understood to be a 'politically guided intensification of market rule and commodification'[53] (p.184). The capacity of the neoliberal movement to restructure various social and natural relations, to subject them to the play of the markets, has been highly dynamic and adaptive.[54,55] The restructuring and re-scaling of the institutions and practices of environmental governance has been an important frontier of this process.[56,57] Indeed, the reconfiguration of human-environment relations lies at the heart of the neoliberal project.[58] The emphasis on efficiency-based restructuring that characterises the emerging nexus consensus, therefore, indicates a clear preference for the use of market proxies in the co-management of water and energy.[52]

Our intention here is not to explore what insights on the water-energy nexus can tell us about the nature of neoliberalism –although this would be a pertinent contribution– but simply to make two points. The first of which is that, as a new and exciting area of interest across many disciplines, and one that will undoubtedly affect policymaking in the coming years, the nexus concept offers potentially fertile ground for market-based reform. The fact that the current literature presents its arguments in the very particular, and politically loaded language of efficiency-through-integration, suggests that the discourse is rapidly becoming assimilated into a market-environmentalist ideology. Secondly, the result of this may be essentially to forestall broader, more meaningful political discussions on nexus issues. If a consensus is allowed to form, which tells us that inefficiencies are the root problem and integration is the primary solution, then more critical interpretations are precluded, or easily ignored. The social sciences, which have only recently begun to acknowledge the importance of this emerging framework, have important contributions to offer. Crucially, we must consciously avoid reproducing the assumptions and inferred politics of the technocratic aspects of the discourse.

The coproduction of water-energy

The current nexus literature lacks historical perspective. Consequently, much of the research so far purports to offer solutions to the trade-offs and tensions outlined in the previous section, without first understanding how and why these negative interrelations develop. This paper argues, however, that a comprehensive and conceptually rigorous understanding of the interactions between water and energy must consider how this nexus is *produced*.[10] Moreover, we contend that the complex relationships between energy and water, expressed in the term 'nexus,' are most fruitfully understood in dialectical terms. That is to say, that the water-energy nexus does not exist *de facto*, but rather emerges historically through a set of contingent, and above all *contradictory* socio-natural relationships.[59-61] A nexus approach should consider, then, how elements are *coproduced* through particular 'techno-political processes.'[62] There are, of course, rich traditions of critical scholarship on the historical emergence of water and energy systems, as distinct phenomena. With particular reference to urban ecology on the one hand, and science and technology studies on the other, we draw together these frameworks to provide an integrated account of the *urbanisation* and *coproduction* of water-energy.

The period of rapid modernisation and industrialisation that swept through Europe, North America, and later the colonies, in the 18[th] and 19[th] centuries was one in which abundant and reliable flows of water and energy became indispensible to the functioning of urban space and productive economic activity. The Promethean urge to control water, to direct its flow for the betterment of industrial society,[59,61,63,64] was complemented by the fantastical drive for electrification, and the making of the urban 'electrical sublime.'[65-67] Together, water and energy cleanse urban space and 'facilitate lucidity.'[68] The colossal works of engineering that achieved this represent huge capital investments, the primary function of which was to enhance and facilitate the productive circulation of capital. The technologies that reticulate water and energy through urban space, although different in their development trajectories, were both central to the establishment, and are now indispensable to the reproduction of the 'modern' city.

Goubert[69] argues that during this period, water underwent a 'double-edged conquest.' The first movement of this was human's conquest over water. Central to the project of modernity was the subjection of nature -in this case, water- to increased technical and scientific knowledge, the manipulation of water to fulfil the ambitions of industrial society, and its assimilation into the logics of economic growth. The second movement of conquest was that of water over humans, and our increasing dependence on its abundant and reliable flow. 'Finally,' Goubert (p.115) writes, 'fresh water was carving out a kingdom for itself, a kingdom both visible and invisible, subterranean and manifest, public and private, intimate and social. A water-devouring economy was gradually set in place.' With regard to the development of the nexus, this concept of dual conquest may be extended to consider the multiple conquests of water-energy. For increased reliance on water, concomitantly increases reliance on energy, which in turn feeds back into a dependence on water, and so on. The conquest of one is at the same time, the conquest of the other, the two locked into a *concatenation of growth*, where seemingly the only logical option is to expand supplies of both. Thus, the nexus develops.

Very often, these trajectories have been articulated and driven forward through crisis, be it real or perceived. Indeed, the catalysis of crisis is writ large in the historical development of urban water systems in particular. The making of what Gandy[70] calls the 'bacterialogical city' and Melosi[63] the 'sanitary city' was driven by the chaos of nineteenth century urbanisation. Most sizeable urban settlements experiencing unprecedented growth, faced water crises. Water quality was poor, its quantity inadequate, its supply expensive and unreliable, and waste removal systems were archaic. A series of devastating disease epidemics, culminating in the cholera outbreaks of the 1830s and the establishment of causal links with contaminated water, provided the impetus for a water revolution. The same is manifestly so today, as the fear of drought, and the spectre of water scarcity, compels cities to seek out ever more extraordinary water source options, to achieve ever greater technical heights, to stave off impending water crisis. Although development of urban energy systems, as described in the Large Technical Systems (LTS) literature (as charted by the likes of Hughes,[67] Nye[66] and Coutard[71]), was not driven forward by disease epidemics in the same way, crisis in many cases still played a catalytic role. Baldwin[72] for instance, has argued that the fear of blackouts and the spectre of social unrest associated with darkness, played a major role in prompting the shift from unreliable gas street lighting to electric alternatives in mid-1800s North American cities. Baldwin writes that 'In an era when differences in lighting were a marker of status, blackouts threatened to level a fragile social hierarchy.' (p.750)

Since Marx wrote the *Grundrisse*, critical political economists have been fascinated by the role of crisis in the development of capital. David Harvey[73,74] has contributed particularly in this area. Capital, Harvey argues, evolves through crisis, but it never solves these crises. Instead, it moves them around geographically or temporarily. Thus, the resolution of each successive crisis contains the kernel of the next. The historic emergence of the water-energy nexus might be understood accordingly, as emblematic of the crisis-ridden development capital and its circulatory processes. Again, the burgeoning phenomenon of seawater desalination, as a strategy to combat water-stress, provides a pertinent example of this. In Southern California, desalination is poised to become a significant urban water source, and will account for at least 7% of San Diego County's supply by 2016, with larger operations planned in the next 5-10 years. Yet, at approximately 4 kWh per cubic meter of water produced, reverse osmosis desalination is significantly more energy intense than any other water source option available to the region.[46] Moreover, with electricity accounting for 25% of the overall cost of water to be produced from the new Carlsbad desalination plant in San Diego, the county's water supply will become more vulnerable to energy price fluctuations and market variability. The corollary of this is that the crisis of water scarcity, which is here understood to be a crisis of accumulation is not resolved *per se*, but rather, through a deepening of nexus interaction, transferred to the energy sector.

Now, then, we are moving towards an understanding of the water-energy nexus, not as a challenging set of externalities, but as a cyclical and deeply contradictory process of *coproduction*. An understanding of the historical development of these interrelationships points to a nexus that cannot simply be managed by mitigating tensions and trade-offs through the amplification of synergies and efficiency-based restructuring.

Nexus assemblages

In Southern California, virtually all water agencies are looking to diversify their supply portfolios in order to reduce exposure to shocks. Ocean desalination, which is the most expensive and energy-intense strategy available, has become a (questionably) viable technological option, in large part because of its capacity to 'piggy-back' on existing infrastructures. These facilities are frequently co-located with coastal thermoelectric power stations, in order to share intake and output systems, and to use the heated wastewater to improve efficiency. Desalination plants can quite simply be plugged into existing systems, significantly reducing costs. This was the business model on which San Diego's Carlsbad development was based. Recent changes to Californian environmental law, however, which require the phasing out of once-through cooling systems, dramatically undermine this model. This is forcing the Carlsbad developers to establish alternative intake/output techniques, prompting widespread concern over the economic and environmental viability of large-scale desalination in California. Here, changes to the cooling processes of power stations are reconfiguring the capacity of desalting technologies to become enrolled in state-wide efforts towards water supply diversification.

In contrast, just a few miles south of the border in Mexico, which has no plans for similar laws, developers of the 'binational' Rosarito desalination plant are encountering no such obstacles. The development of desalination is, therefore, contingent upon a milieu of technical, political, economic and environmental relations. These examples illustrate the complex material and social hybrid relationality and contingency that characterises the contested development of the water-energy nexus. Furthermore, they demonstrate the geographical embeddedness of these socio-technical configurations, and point to the importance of institutional and political difference in shaping the deployment of technology. Current nexus thinking is ill-equipped to understand such heterogeneity.

In recent years *assemblage thinking* has emerged as a powerful conceptual, ontological and methodological approach for researching and understanding the social and the material.[75,76] Scholars currently working on assemblages draw on a variety of intellectual traditions, notably Marxism, science and technology studies and actor-network theory, but its recent popularity has largely been inspired by the work of Giles Deleuze and Félix Guattari.[77] Although intellectually disparate, in essence current scholarship on assemblages seeks to understand how social-material amalgamations, such as cities, are 'enacted into being in networks of bodies, materialities, technologies, objects, natures and humans'[78] (p.13). But opportunities exist for applying the conceptual and methodological insights of assemblage thinking to advance research on nexus issues. The focus of the nexus literature so far has been on the technologies of water-energy interaction. The concept of a *nexus assemblage*, which refers to a sociotechnical configuration that, because of its extraordinary qualities, highlights, exemplifies or reconfigures the interactions between areas of environmental governance, advances this definition by emphasising the social and political embeddedness of these technologies. This approach provides a framework that calls for the methodological and theoretical prioritisation of the technologies and materialities of the water-energy nexus, *and* the socio-political relationships through which the nexus emerges.

Assemblages consist of human, material, technical, social and natural parts, all of which fall somewhere along a continuum from purely *expressive* to purely *material*, and through close interaction co-develop into networks of (greater or lesser) coherence.[79] The capacity of components of the assemblage to influence the whole, be they human or not, Jane Bennett has called the *vibrancy* or *vitality* of materiality. Indeed, in any movement or effect there are 'always a swarm of vitalities at play'[80] (p.31). Following on from this position, Colin McFarlane has argued that the contributions of the assemblage literature, be they conceptual, descriptive or methodological, imply a normative commitment to explore how these social-material networks are produced, to whose potential benefit, and to how they might be imagined differently.[81,75] This is the 'history-potential relation' that describes both the 'depth' of assemblages, how the historically and geographically contingent processes of assemblage formation produce particular trajectories, *and* the potentialities of new configurations to emerge from the old.[82] Although assemblage thinking has been accused by some of being apolitical and lacking the conceptual tools to engage with issues of inequality (for example, see Brenner et al.,[83]), we seek to mobilise *assemblage* in a way that, in conversation with the political economy and ecology perspectives outlined above, emphasises the complex, contradictory and contested development of nexus interactions. Applied to the nexus framework, this understanding goes beyond the quantitative view of technologies as 'using this much water' or 'this much energy', and highlights heterogeneous nature of nexus technologies, or rather the infrastructures through which the interactions between water and energy are reconfigured.

Conclusion

The remarkable recent success of 'nexus thinking' to disseminate through academia, policymaking and mainstream environmental circles is, in many ways encouraging. Although there is nothing particularly new, and certainly not radical, in these ideas of relationality and interconnectivity, a conscious critique of compartmentalised approaches to environmental governance is nevertheless propitious. Some of this success is due simply to the fact that the arguments put forward by proponents are, in many cases compelling. As concerns over resource scarcity grow, and ideas of natural limits to growth resurface in the popular imaginary, understanding the tensions and contingencies *between* sectors, and not just within them, becomes ever more pertinent. In part, however, the popularisation of the nexus framework is enabled by, on the one hand the universal appeal of its underlying message, and on the other the uncontroversial nature of its recommendations. The principle of integration is presented as a panacea, but its effect has been, we have argued, to draw attention away from the more fundamental tensions at play. There are, undoubtedly many benefits to be achieved through more holistic management of water, energy, land and climate, but the drive for efficiency should not be an *end in itself*. The corollary also holds, that integrated management does not *necessarily* precipitate more 'sustainable' practices. In contrast, we have argued that the historic development of the nexus, what we term the *coproduction* of water-energy, emerged through contradictory relationships that are deeply connected to, and part of, processes of modernisation, industrialisation and the historic development of capital. The tensions identified in the nexus literature are not merely techno-managerial challenges, but rather arise through a much deeper set of contradictions.

Much of the current nexus literature is concerned with quantifying and cataloguing the relationships between constituent elements. As such, it adopts an air of political impartiality, but of course, political inference lurks in every letter. Whether conscious or inadvertent, the calls for efficiency through technological development and political restructuring, which pervade the discourse, represent a strongly market-oriented approach to managing the nexus. In its current state, the discourse expresses an emerging consensus, which is rapidly assimilating itself with neoliberal ideology. This in itself, is an important observation. Building on this critique, we have proposed some alternative ways of conceptualising and researching nexus issues. Drawing on traditions from across the critical social sciences, we have argued that there already exists a great wealth of conceptual tools available that might be adapted to add theoretical rigour to a discourse that has so far been dominated by technocratic approaches.

In particular, we have sought to draw attention to the intrinsic heterogeneity expressed in the term 'nexus.' The examples used throughout, which have centred around, but are by no means restricted to, the contested politics of large-scale seawater desalination in southwest USA and northwest Mexico, demonstrate the need for a broader, less technocratic discussion on nexus issues. The social sciences, which are currently undergoing a renewed interest in materiality and interdisciplinarity, are very well placed to answer such a call. Our efforts would be better spent in fostering *dissensus* in this fledgling discourse, rather than in building *consensus*. Therein lies the potential for alternative imaginaries. The implications intimated in nexus concepts like 'tensions,' 'trade-offs,' and 'maladaptations,' should provide the basis for a radical critique of current paradigms of environmental governance, yet the trend so far has been one of assimilation and consensus-building. The task of the critical social sciences is to insist on dissensus. In a word, to *politicise* the nexus.

Bibliography

1. Shrestha E, Ahmad S, Johnson W, Shrestha P, Batista JR. Carbon footprint of water conveyance versus desalination as alternatives to expand water supply. Desalination. 2011;280(1):33–43.
2. Scott CA, Pasqualetti MJ. Energy and water resources scarcity: Critical infrastructure for growth and economic development in Arizona and Sonora. Natural Resources Journal. 2010;50:645.
3. Bazilian M, Rogner H, Howells M, Hermann S, Arent D, Gielen D, Steduto P, Muella A. Komor P, Tol RSJ. Considering the energy, water and food nexus: towards an integrated modelling approach. Energy Policy. 2011;39(12):7896–906.
4. Waughray D. Water security: the water-food-energy-climate nexus. Washington: Island Press, 2011.
5. Kenney DS, Wilkinson R, editors. The Water-Energy Nexus in the American West. Cheltenham: Edward Elgar Publishing, 2011.

6. UNESCO. The United Nations World Water Development Report: Water and Energy, Volume 1. Paris; 2014.
7. Pittock J. National Climate Change Policies and Sustainable Water Management: Conflicts and Synergies. Ecology & Society. 2011;16(2).
8. Rees J. Geography and the nexus: Presidential Address and record of the Royal Geographical Society (with IBG) AGM 2013. The Geographical Journal. 2013;179(3):279–82.
9. Swyngedouw E, Heynen NC. Urban political ecology, justice and the politics of scale. Antipode. 2003;35(5):898–918.
10. Heynen N, Kaika M, Swyngedouw E, editors. In the Nature of Cities: Urban Poltical Ecology and the Politics of Urban Metabolism. London: Routledge; 2006.
11. Kenway SJ, Lant PA, Priestley A, Daniels P. The connection between water and energy in cities: a review. Water Science & Technology. 2011;63(9):1983–90.
12. Scott CA, Pierce SA, Pasqualetti MJ, Jones AL, Montz BE, Hoover JH. Policy and institutional dimensions of the water–energy nexus. Energy Policy. 2011;39(10):6622–30.
13. Hussey K, Pittock J. The energy–water nexus: managing the links between energy and water for a sustainable future. Ecology and Society. 2012;17(1):31.
14. King CW, Holman AS, Webber ME. Thirst for energy. Nature Geoscience. 2008;1(5):283–6.
15. Perrone D, Murphy J, Hornberger GM. Gaining perspective on the water− energy nexus at the community scale. Environmental science & technology. 2011;45(10):4228–34.
16. Kahrl F, Roland-Holst D. China's water-energy nexus. Water Policy. 2008;10(1):51–65.
17. Swyngedouw E. Authoritarian governance, power, and the politics of rescaling. Environment and Planning D-Society and Space. 2000;18(1):63–76.
18. Kenway S. The Water-energy Nexus and Urban Metabolism-Connections in Cities. Urban Water Security Research Alliance Technical Report. 2013;(100).
19. Cohen R, Wolff G, Nelson B. Energy down the drain: the hidden costs of California's water supply. Energy down the drain: the hidden costs of California's water supply. Oakland: NRDC/Pacific Institute; 2004.
20. Schnoor JL. Water–energy nexus. Environmental science & technology. 2011;45(12):5065–5065.

21. Clayton ME, Stillwell AS, Webber ME. Implementation of Brackish Groundwater Desalination Using Wind-Generated Electricity: A Case Study of the Energy-Water Nexus in Texas. Sustainability. 2014;6(2):758–78.
22. Siddiqi A, Anadon LD. The water–energy nexus in Middle East and North Africa. Energy Policy. 2011;39(8):4529–40.
23. Lofman D, Petersen M, Bower A. Water, energy and environment nexus: The California experience. International Journal of Water Resources Development. 2002;18(1):73–85.
24. Stillwell AS, Hoppock DC, Webber ME. Energy recovery from wastewater treatment plants in the United States: a case study of the energy-water nexus. Sustainability. 2010;2(4):945–62.
25. Klein G, Krebs M, Hall V, O'Brien T, Blevins BB. California's Water-Energy Relationship. California Energy Commission; 2005.
26. Larson D, Lee C, Tellinghuisen S, Keller A. California's energy-water nexus: Water use in electricity generation. Southwest Hydrology. 2007;6(5):20–1.
27. Carter NT. Energy's water demand: trends, vulnerabilities, and management. Washington DC: CRS Report for Congress; 2011. Report No.: 1437944361.
28. Gheewala SH, Berndes G, Jewitt G. The bioenergy and water nexus. Biofuels, Bioproducts and Biorefining. 2011;5(4):353–60.
29. Froschauer K. White Gold: Hydroelectric Power in Canada. Vancouver: UBC Press; 1999.
30. Feeley TJ, Skone TJ, Stiegel Jr GJ, McNemar A, Nemeth M, Schimmoller B, et al. Water: a critical resource in the thermoelectric power industry. Energy. 2008;33(1):1–11.
31. Sovacool BK. Running on Empty: The Electricity-Water Nexus and the US Electric Utility Sector. Energy Law Journal. 2009;30(1):11–51.
32. Koch H, Vögele S. Dynamic modelling of water demand, water availability and adaptation strategies for power plants to global change. Ecological Economics. 2009;68(7):2031–9.
33. Wolfe JR, Goldstein RA, Maulbetsch JS, McGowin CR. An electric power industry perspective on water use efficiency. Journal of Contemporary Water Research & Education. 2009;143(1):30–4.
34. Fthenakis V, Kim HC. Life-cycle uses of water in US electricity generation. Renewable and Sustainable Energy Reviews. 2010;14(7):2039–48.

35. Bartos MD, Chester MV. The Conservation Nexus: Valuing Interdependent Water and Energy Savings in Arizona. Environment, Science and Technology. 2014;48(4):2139–49.
36. Malik R. Water-energy nexus in resource-poor economies: the Indian experience. International Journal of Water Resources Development. 2002;18(1):47–58.
37. Santhosh A, Farid AM, Youcef-Toumi K. Real-time economic dispatch for the supply side of the energy-water nexus. Applied Energy. 2014;122:42–52.
38. Hardy L, Garrido A, Juana L. Evaluation of Spain's Water-Energy Nexus. International Journal of Water Resources Development. 2012;28(1):151–70.
39. Sanders KT, King CW, Stillwell AS, Webber ME. Clean energy and water: assessment of Mexico for improved water services and renewable energy. Environment, Development and Sustainability. 2013;15(5):1303–21.
40. Stillwell AS, King CW, Webber ME, Duncan IJ, Hardberger A. The Energy-Water Nexus in Texas. Ecology & Society. 2011;16(1).
41. Mo W, Wang R, Zimmerman JB. Energy–Water Nexus Analysis of Enhanced Water Supply Scenarios: A Regional Comparison of Tampa Bay, Florida, and San Diego, California. Environment, Science and Technology. 2014;48(10):5883–91.
42. Villarroel Walker R, Beck MB, Hall JW, Dawson RJ, Heidrich O. The energy-water-food nexus: Strategic analysis of technologies for transforming the urban metabolism. Journal of Environmental Management. 2014;141:104–15.
43. King CW, Stillwell AS, Twomey KM, Webber ME. Coherence between water and energy policies. Natural Resources Journal. 2013;53(1):117–215.
44. Webber ME. Catch-22: water vs. energy. Scientific American. 2008;18(4):34–41.
45. Barnett J, O'Neill S. Maladaptation. Global Environmental Change. 2010;20(2):211–3.
46. Cooley H, Heberger M. Key Issues for Seawater Desalination in California: Energy and Greenhouse Gas Emissions. Pacific Institute; 2013.
47. Brazeau RH, Edwards MA. Water and Energy Savings from on-Demand and Hot Water Recirculating Systems. Journal of Green Building. 2013;8(1):75–89.
48. Morandin M, Hackl R, Harvey S. Economic feasibility of district heating delivery from industrial excess heat: A case study of a Swedish petrochemical cluster. Energy. 2014;65:209–20.
49. Karaca F, Camci F, Raven PG. City blood: A visionary infrastructure solution for household energy provision through water distribution networks. Energy. 2013;61:98–107.

50. Goldstein NC, Newmark RL, Whitehead CD, Burton E, McMahon J, Ghatikar G, May D. The Energy-Water Nexus and information exchange: challenges and opportunities. International Journal of Water. 2008;4(1):5–24.
51. MacKillop F, Boudreau J. Water and power networks and urban fragmentation in Los Angeles: Rethinking assumed mechanisms. Geoforum. 2008;39(6):1833–42.
52. Castree N. Neoliberalising nature: the logics of deregulation and reregulation. Environment and Planning A. 2008;40(1):131–52.
53. Brenner N, Peck J, Theodore N. Variegated neoliberalization: geographies, modalities, pathways. Global networks. 2010;10(2):182–222.
54. Peck J, Tickell A. Neoliberalizing space. Antipode. 2002;34(3):380–404.
55. Harvey D. A Brief History of Neoliberalism. Oxford University Press; 2005.
56. Heynen N, Robbins P. The neoliberalization of nature: Governance, privatization, enclosure and valuation. Capitalism Nature Socialism. 2005;16(1):5–8.
57. Himley M. Geographies of Environmental Governance: The Nexus of Nature and Neoliberalism. Geography Compass. 2008;2(2):433–51.
58. McCarthy J, Prudham S. Neoliberal nature and the nature of neoliberalism. Geoforum. 2004;35(3):275–83.
59. Gandy M. Concrete and Clay: Reworking Nature in New York City. Cambridge: MIT Press; 2002.
60. Swyngedouw E. Social Power and the Urbanization of Water: Flows of Power. Oxford: Oxford University Press; 2004.
61. Kaika M. City of Flows: Modernity, Nature, and the City. New York: Routledge; 2005.
62. Bridge G. Resource geographies II The resource-state nexus. Progress in Human Geography. 2013;38(1):118–30.
63. Melosi MV. The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present. Baltimore: Johns Hopkins University Press; 2000.
64. Laporte D. History of Shit. Cambridge: MIT Press; 2000.
65. Nye DE. American Technological Sublime. Cambridge: MIT Press; 1994.
66. Nye DE. Electrifying America: Social Meanings of a New Technology, 1880-1940. Cambridge: MIT Press; 1990.
67. Hughes TP. Networks of Power: Electrification in Western Society, 1880-1930. Baltimore: Johns Hopkins University Press; 1983.
68. Otter C. Cleansing and Clarifying: Technology and Perception in Nineteenth-Century London. Journal of British Studies. 2004;43(1):40–64.
69. Goubert J-P. The Conquest of Water: The Advent of Health in the Industrial Age. Cambridge: Polity Press; 1986.

70. Gandy M. Rethinking urban metabolism: water, space and the modern city. City. 2004;8(3):363–79.
71. Coutard O, Guy S. STS and the City: Politics and Practices of Hope. Science, Technology & Human Values. 2007;32(6):713–34.
72. Baldwin PC. In the Heart of Darkness: Blackouts and the Social Geography of Lighting in the Gaslight Era. Journal of Urban History. 2004;30(5):749–68.
73. Harvey D. The Enigma of Capital and the Crises of Capitalism. Oxford: Oxford University Press; 2010.
74. Harvey D. Seventeen Contradictions and the End of Capitalism. London: Profile Books; 2014.
75. Anderson B, McFarlane C. Assemblage and geography. Area. 2011;43(2):124–7.
76. Featherstone D. On assemblage and articulation. Area. 2011;43(2):139–42.
77. Marcus GE, Saka E. Assemblage. Theory, culture & society. 2006;23(2-3):101–6.
78. Farias I. Introduction: decentering the object of urban studies. In: Farias I, Bender T, editors. Urban Assemblages: How Actor-Network Theory Changes Urban Studies. Oxford: Routledge; 2010.
79. DeLanda M. A New Philosophy of Society: Assemblage Theory and Social Complexity. London: Continuum; 2006.
80. Bennett J. Vibrant Matter: A Political Ecology of Things. Durham: Duke University Press; 2010.
81. McFarlane C. The city as assemblage: dwelling and urban space. Environment and Planning-Part D. 2011;29(4):649.
82. McFarlane C. Assemblage and critical urbanism. City. 2011;15(2):204–24.
83. Brenner N, Madden DJ, Wachsmuth D. Assemblage urbanism and the challenges of critical urban theory. City. 2011;15(2):225–40.

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