Capturing Flow: Stormwater governance and water resource development in Chicago and Los Angeles

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Natural Resources and Environment) in the University of Michigan 2016

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Dedication

For my mom.

Acknowledgements

Calling this dissertation the culmination of a long journey is perhaps a bit misleading. My student identity may be shed, but this project is really the first leg of a longer journey. Without the support of many students, faculty, and staff at the University of Michigan, this first portion of the journey would not have happened. I owe a lot to Josh Newell, who decided to bring me in as a student. Without his support and guidance this project would not have proceeded. Thank you for being my advocate and pushing me to aim high. Bilal Butt helped me become a better teacher and critical thinker. He's been there to listen to many of my ups and downs of academic life and offer sage advice. Maria Carmen Lemos inspired me along the way with her tireless energy and enthusiasm. I thank her for all the support and guidance she has given me. Thanks also to Scott Campbell for his sharp insights and introducing me to a broader range of urban theory. I feel incredibly fortunate to be among these talented professors.

I feel equally fortunate to have been among an excellent group of students. From my SNRE cohort to those that followed, I am continuously inspired and motivated by them. They have also made my time in Ann Arbor much more enjoyable. In particular I want to thank my lab mate Sara Meerow for her friendship and organizing all of the wonderful things she does. Eric Seymour has been a good friend and ally through the whole process as well. Thanks also to James Arnott, Arthur Endsley, John Graham, Jennifer Zavaleta, Chad Monfreda, Scott Kalafatis, James Erbaugh and the many others who have read drafts of papers during resilience workshops or provided good will. Finally, I need to thank all of the SNRE staff who helped me navigate all of the loops and hurdles of PhD life. In particular, I want to thank Diana Woodworth, Jennifer Taylor, Li Yong, Helaine Hunscher, and Judith Byington for all the excellent work they do. Apologies if I’ve missed someone. I also need to thank the great people in CSS for providing work space.

I am also incredibly indebted to the countless strangers who consented to interviews, took surveys, told me who to talk to, or talked me through complicated water systems. Without their knowledge and expertise this project would not be possible.

This dissertation was supported by a Doctoral Dissertation Research Improvement Grant (#1536377) from the National Science Foundation, and per NSF I must add that any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The Trent R. Dames Fellowship in the History of Civil Engineering from The Huntington Library was a welcome surprise that allowed me to spend two months exploring the archives. The University of Michigan also provided support for this research through a Rackham Doctoral Candidate Research Grant and the Predoctoral Fellowship that allowed me time to write.

Finally, thank you Anna. Thanks for listening to me talk about water and theory, being loving and supporting, taking me to the ER when water pushes back, and letting me know when I’m being a little ridiculous. The last five years would not have been as great without you.

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List of Abbreviations

AB	Assembly Bill
ACoE	Army Corps of Engineers
AF	Acre Feet
BMP	Best Management Practice
CAMX	California-Mexico
CDWR	California Department of Water Resources
CEC	Clean Energy Coalition
CRA	Colorado River Aqueduct
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DNR	Department of Natural Resources
DWR	Department of Water Resources
eGRID	Emissions and Generation Resource Integrated Database
EPA	Environmental Protection Agency
EUSA	Electric Utility Service Area
EV	Eigenvalue
EWMP	Enhanced Watershed Management Plan
GHG	Green House Gas
GI	Green Infrastructure

GIS	Geographic Information System
GWAM	Groundwater Augmentation Model
IE	Industrial Ecology
IEUA	Inland Empire Utility Agency
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resources Plan
IRWM	Integrated Regional Water Management
IWRM	Integrated Water Resources Management
kWh	Kilowatt-hour
LA	Los Angeles
LAA	Los Angeles Aqueduct
LACDA	Los Angeles County Drainage Area
LACDPW	Los Angeles County Department of Public Works
LACFCD	Los Angeles County Flood Control District
LADWP	Los Angeles Department of Water and Power
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Inventory Assessment
LID	Low Impact Development
LSPC	Loading Simulation Program C++
MFA	Material Flow Analysis
MWD	Metropolitan Water District of Southern California

MWRD	Metropolitan Water Reclamation District of Greater Chicago
NGO	Non-Governmental Organization
NIMBY	Not in my back yard
NPDES	National Pollution Discharge Elimination System
NRDC	Natural Resources Defense Council
PG&E	Pacifica Gas & Electric
PIE	Political-Industrial Ecology
SUDS	Sustainable Urban Drainage System
SWP	State Water Project
TCR	The Climate Registry
TARP	Tunnel and Reservoir Plan
TMDL	Total Maximum Daily Load
UPE	Urban Political Ecology
WEI	Western Energy Innovations
WRRDA	Water Resources Reform and Development Act

Abstract

This dissertation focuses on the factors that shape how water resource managers shape the flow, or metabolism, of water through cities. Through a comparative and mixed-method approach drawing on archival research, key informant interviews, Q-methodology, and spatial analysis, this dissertation presents a framework for understanding the social and material factors that shape urban water flows. Focusing on Chicago and Los Angeles, the study concentrates on the methods and approaches water resource managers use to control volumes of water and achieve political goals. The results reveal the shortcomings of overly technical approaches to solve water resource problems, which are enmeshed within a spatially complex set of socio-political and historical processes. I also reveal the multiple ways water resource managers approach water challenges and come to particular ways of understanding solutions for them. I identify seven perspectives on stormwater governance: Market Skeptic, Hydro-managerial, Hydro-rationalist, Hydro-reformist, Hydro-pragmatist, Market Technocrat, Regulatory and Administrative Technocrat, Institutional Interventionist, Infrastructural Interventionist. It is shown that these viewpoints are shaped through multiple institutional and bureaucratic practices. Some viewpoints are geographically and idiosyncratically defined, while others transcend geographical and institutional specificity. Whether invoking stormwater as a "new" resource to achieve water quality and quantity goals, or negotiating the role of new technologies and financial mechanisms to control the flow of water, this dissertation reveals the commonalities across different ways of understanding water in order to offer more acceptable policies.

Chapter 1: Introduction

Cities across the globe face daunting water resource challenges. The news is full of such stories, whether it is drought in California or Brazil, floods in India or Europe, or the degradation of the very aquatic systems cities rely upon. Climate change will only exacerbate many water quality and quantity dilemmas facing cities and require adaptive approaches (Grimm et al., 2008; Vorosmarty, 2000). Whether improving flood control, developing water supply, or building green infrastructure to capture and retain urban runoff, these strategies rely on manipulating the flows of water. Yet due to water's multiple social and ecological functions, efforts to address water resource challenges are often fraught with competing visions on how to best manage and control urban hydrologic flows (Bakker, 2014).

To understand how water's multiple social and ecological functions complicates water resource governance, I examine stormwater in this dissertation. Traditionally, stormwater was designated as a hazard or nuisance, polluting waterways and flooding cities and towns. Increasingly, cities are beginning to examine how stormwater can be utilized as resource. This is not only to capture water supplies but also to decrease costs associated with cleansing runoff and managing flood risk. I focus on the ways law, science, and multiple human and non-human stakeholders are enrolled in the process of redefining stormwater, how they interact, and to what consequence (Figure 1). I take a twofold approach to understand how water's multiple social and ecological functions complicate water resource governance. The first explores the relationship between cities and stormwater by examining the social and material dimensions

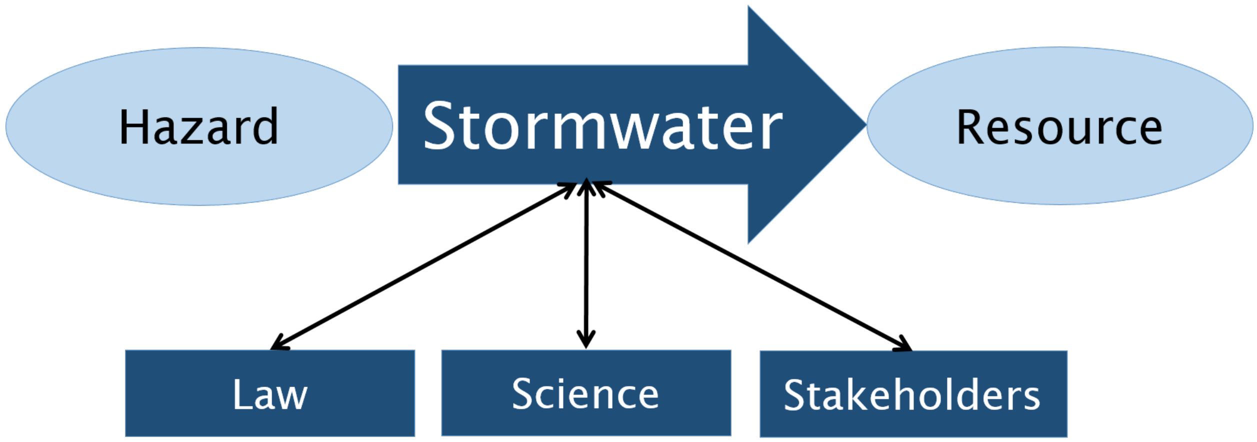

Figure 1. Conceptual outline of transition of stormwater from hazard to resource.

of urban water metabolisms and resource flows. The second empirically examines subjectivity in relation to water governance in Chicago and Los Angeles by focusing on how different viewpoints, preferences, opinions, and methods shape the ways in which urban water systems are understood. I concentrate, on the one hand, how people engaged within diverse networks of institutional and bureaucratic practice come to particular understandings of stormwater governance, while on the other, the various aspects of expertise that influence the relationship between cities and water resource flows. Specifically, I answer the following questions:

1. What are the politics and history of stormwater management and regulation, and in what ways have the flows of stormwater been remade and redefined by politicians, scientific experts, and ordinary citizens?
2. What are the competing technological systems, social perspectives, and institutional arrangements (e.g. legal, scientific, governmental, and non-governmental) that define (storm)water, shape its management, and inscribe its uses and value?
3. How do these competing technologies, perspectives, and institutional arrangements interrelate and influence how stormwater is understood, managed, and controlled?

Addressing these questions leads to a deeper understanding of how scientific and expert preferences shape the relationship between cities and water resource flows. The significance of the questions not only lie in their ability to characterize the social and cultural preferences shaping attitudes towards stormwater management and water resource flows, but also to address multiple dimensions of urban environmental change. In particular, by characterizing the shared and competing viewpoints of how stormwater governance should proceed, I offer some areas of common ground useful for developing more acceptable policies.

In this dissertation, I advance scholarship exploring urban resource flows and how different attitudes, beliefs, and understandings shape urban political ecological processes and outcomes. A key theme is the urban metabolism concept, which has a long history among urban scholars. I use the conceptual metaphor as an analytic to understand nature-society interrelationships and to describe the flows of materials (e.g. water) into, within, and out of cities (Newell and Cousins, 2015; Wachsmuth, 2012). Urban political ecology (UPE) has offered many valuable insights into the processes of metabolic urbanization that unevenly transform social-ecological landscapes (Heynen et al., 2006; Swyngedouw, 2006a), but the extent to which urban metabolisms construct urban subjectivities is not well-developed. By understanding how the viewpoints of those who participate in stormwater management interact, I provide insight into how new stormwater technologies and strategies, such as low-impact development, green infrastructure, and financial rebates and incentives, are negotiated and reshape urban (storm)water metabolisms. These strategies, however, are not apolitical. Instead they are power-laden and come to influence how governance should and does proceed. By excavating the situated politics and power differentials of stormwater governance, this dissertation advances academic fields exploring urban metabolisms, such as urban political ecology and industrial ecology, and those exploring water resource governance, such as geography and environmental studies.

1.1. Literature and Theoretical Overview

Rethinking stormwater management to transform it into an asset for beneficial use, while maintaining and upgrading the infrastructures necessary to mitigate its hazardous properties, showcases how power and influence are negotiated between state actors, federal agencies, local environmental groups, non-governmental organizations, and local communities. These stakeholders encounter stormwater through different experiences, whether through a flooded basement or drafting legislation, but all are implicated in shaping how stormwater flows. To understand the interactions among this complicated assemblage of social perspectives, the theoretical framework informing this study draws from an interdisciplinary set of literatures. As outlined in Figure 2, the primary contribution is a geographical one, but I also draw from political ecology, industrial ecology, environmental governance, science and technology studies among other disciplines. I draw on political ecology explore the relationship between nature and society and to understand how differential power relationships influence social-ecological outcomes. Industrial ecology informs my thinking about resource flows and their effect on environment and society. Environmental governance literature is used to examine the broad set of institutions and rules that direct environmental action and outcomes. Finally, science and technology studies brings attention to the social and cultural aspects of scientific knowledge and technological change.

Along with a range of methodological approaches, I use this set of literature to examine the relationship between cities and natural resources and the role of expertise in shaping social-

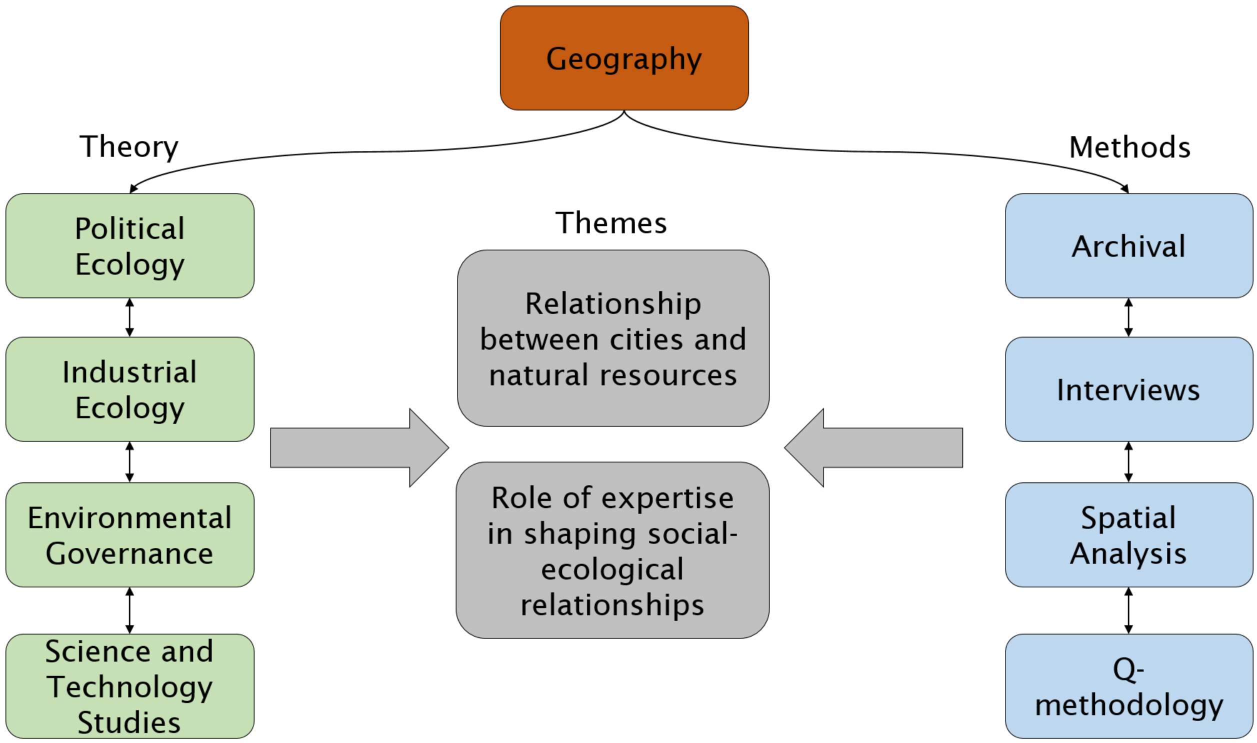

Figure 2. Theoretical and methodological outline used to explore key themes of dissertation.

ecological relationships. Overall, I bring these interests together at the interface of: 1) metabolisms and political ecologies of urbanization and 2) environmental governance and sustainability transitions. The literature is used to explore the relationships between stormwater and how it is perceived, managed, controlled, and valued. The literature on metabolisms and the political ecologies of urbanization provide the theoretical context to understand how social and political power transform and shape the flow of stormwater through cities. The second set of literature is used to provide insight into the governance arrangements that shape stormwater management and how transitions in social and technical systems emerge and evolve. By integrating these literatures, I seek to better understand the nature of expert and non-expert practice emergent in new forms of urban environmental governance and its impact on stormwater management.

1.1.1. Metabolisms and Political Ecologies of Urbanization

I begin this project with the traditional urban political ecological observation that "there is nothing unnatural about the city" (Harvey, 1996), but I look to advance UPE by considering the ways stormwater circulates through the hydro-social cycle as a material flow. Urban political ecologists frequently draw on notions of metabolism to characterize the socio-natural relations that transform and (re)create urban ecosystems through the exchange and circulation of resources, capital, humans, and non-humans into and out of the spaces of global urbanization (Newell and Cousins, 2015; Swyngedouw, 2006b). Similarly, the "complex network of pipes, water law, meters, quality standards, garden hoses, consumers, leaking taps, as well as rain-fall, evaporation, and runoff" (Bakker, 2003a, p. 337) that comprise the hydro-social cycle influences how water circulates as a resource through nature and society. Urban water metabolisms thus reflect a range of social and technical systems as well as the hydrological cycle in a "socio-natural process by which water and society make and remake each other over space and time" (Linton and Budds, 2014, p. 6). Political ecological perspectives on water have shown a strong relationship between hydrological transformations at local, regional, and global scales and social, political, economic, and technocratic power (Bakker, 2005; Budds, 2013; Mitchell, 2002; Swyngedouw, 2013, 2007). Bakker (2003a), for example, shows how water's physical and social properties make it "uncooperative" to certain forms of environmental governance, such as marketization. Swyngedouw's (2004) analysis of water politics in Guayaquil, Ecuador also moves beyond a singular hydrological focus by situating water in a "socio-environmental metabolism" that is imbued with the complexities of social power, control, and capital accumulation.

Despite this rich and influential body of literature there remain a number of perceived shortcomings in urban political ecology, from a privileging of bounded conceptions of the city to a preponderance of qualitative approaches (Angelo and Wachsmuth, 2015; Heynen, 2014; Newell and Cousins, 2015). One way I address these shortcomings is by extending the urban metabolism framework to explore the energy and emissions of Los Angeles's water supply system, and to characterize the historical and political processes that have shaped the flow of water in Los Angeles. The ways urban metabolisms may shape socially held viewpoints, or subjectivities, remains underexplored. Although Kooy and Bakker (2008b) examine the interrelationships between subjectivity and urban water supply infrastructure and Robbins (2007) explores "lawn people" as environmental subjects, the link to urban metabolisms is not made apparent. Grove (2009) has also argued for the field to more thoroughly consider the subjective dimensions of urban ecological change, but little work has taken up this challenge.

I address this shortcoming by focusing on the competing claims and discourses that differentially shape how stormwater is defined, managed, and perceived in Los Angeles and Chicago. It demonstrates how people's encounters with stormwater partially shape their viewpoints and relations with stormwater. The dissertation builds on urban geographic literature examining the role of "nature" in the city (e.g. Gandy, 2013, 2004, 2002; Heynen, 2006; Kaika, 2005; Kooy and Bakker, 2008b; McFarlane and Rutherford, 2008; Wolch, 2007), by extending the urban metabolism framework to include the role of subjectivity and through the integration of political and industrial ecology.

1.1.2. Urban Environmental Governance and Sustainability Transitions

Lemos and Agrawal (2006, 298) define environmental governance as "synonymous with interventions aiming at changes in environment-related incentives, knowledge, institutions, decision making, and behaviors" and is used "to refer to the set of regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes." In global environmental governance, neoliberalism is among the most pervasive ideological and political project to emerge in the post-World War II era (McCarthy and Prudham, 2004). As a governing mechanism, neoliberalism emphasizes a preference for market led initiatives (rather than government led), the decentralization and restructuring of the state, and the privatization of services. Scholars suggest this process has led to a "shrinking state" that is "rolling back" to mobilize market forces (Agrawal and Lemos, 2007; Peck and Tickell, 2002; Peck, 2001).

Neoliberal environmental governance reforms also influence debates on urban water resource management. Some of this scholarship has shown the geographically contingent outcomes of neoliberalism's "thin policies and hard outcomes" in the generation of environmental risks (Peck, 2001; Prudham, 2004); the challenges water poses for commodification and privatization (Bakker, 2010, 2003b); the biopolitics of water development (Bakker, 2013); and discursive framings of hydro-development and drought to facilitate privatization of public water utilities (Bakker, 2003c; Kaika, 2003). Research has also shown how different forms of neoliberal "eco-governmentality" emerge through integrated water resource management (Ward, 2013). Yet other work has shown how the promotion of alternative service delivery (ASD) models through neoliberalism can impede sustainability in the municipal water sector by promoting "devolution without delegation" (Furlong and Bakker, 2010; Furlong, 2012, 2010). Many neoliberal reforms are highly uneven and contested requiring a nuanced understanding of exactly how and where neoliberal policy materializes (Brenner and Theodore 2002; Mansfield 2004b, 2004a; McCarthy 2005; McCarthy and Prudham 2004; Heynen and Robbins 2005).

One of the ways stormwater management reflects neoliberal governance is through frameworks premised on aligning environmental conservation and protection with economic growth. The goal of such policies is to foster sustainability transitions through rebates and financial incentives (Bulkeley and Castán Broto, 2012; Bulkeley et al., 2013; Hodson and Marvin, 2010). Transitions, however, take many forms. Some transitions to urban sustainability have been formulated through "top-down" visions by state and municipal governments; others take "bottom-up" approaches advocated by NGO's and community groups; while others are fostered through partnerships with private industry. The range of methods and competing views to foster transitions have led municipalities to "experiment" with many of these different approaches in "socio-technical niches" where new types of infrastructure, technology, and management can be tested (Berkhout et al., 2004; Castán Broto and Bulkeley, 2013; Geels and Schot, 2007). For example, new forms of civic planning and civic politics in stormwater management and infrastructural and technological design have fostered innovations in green infrastructure to reshape the relationships between nature, technology, and society (Karvonen, 2011). Many questions remain, however, in how to scale up experiments as public and private interests blur (Castán Broto and Bulkeley, 2013) and new spaces for urban politics and governance are formed (Bulkeley, 2005; Desfor and Keil, 2004; Evans, 2011; Swyngedouw, 2009a). This dissertation integrates and extends this scholarship by examining how diverse perspectives and approaches to handling environmental problems interact and come to influence environmental governance.

1.2. Research Design and Study Sites

The research design is a comparative study of Los Angeles, a city primarily fostering transitions through technologies to capture and recycle stormwater, and Chicago, where stormwater management is focusing on reducing flooding and combined sewage overflows (CSOs) through the use of permeable pavement, green infiltration strips, green roofs, and market incentive programs. Both cities are leaders in adopting and advocating for low-impact developments and the implementation of new technologies and management techniques to alter stormwater flows, but under very different political, technological, and climatic regimes. The goal of the comparison is to understand the diverging and converging perspectives driving transformations in stormwater management in different geographical contexts. The intent of the research design is to provide insight into the potential range of variation that occurs from water stressed sites to water abundant sites (Gerring, 2007). Each case, Los Angeles and Chicago, is considered to be a prototypical case of a city with water resource challenges at different ends of a water availability spectrum. Neither city is an *extreme* case or a *critical* case, but instead reflect contrasting but revealing examples that highlight how different social, political, climatic, and infrastructural contexts influence the relationship between urban hydrological flows and society (Table 1). Each city reflects diverse stormwater challenges that could potentially improve generalizability.

Table 1. Los Angeles and Chicago Characteristics. *Sources:* US Census Bureau, weather.gov

City	Population	Sewer	Precipitation (inches)	Climate
Los Angeles	3,884,307	Municipal Separate Storm Sewer System	14.77	Mediterranean
Chicago	2,718,782	Combined Sewer System	39.47	Humid continental

1.2.1. Study Site One: Los Angeles

Throughout its development, water has featured prominently in Los Angeles politics and the formation of its geographies. Like other cities, as Los Angeles urbanized, impervious surfaces increased and altered urban hydrological flows. Consequences include reductions in the amount of surface water capable of replenishing groundwater aquifers, increased flood risk, and polluted beaches and water bodies. The Los Angeles region is increasingly under pressure to capture more stormwater to augment supplies while reducing flood impacts, but also to meet water quality regulations under the Clean Water Act. In 1987 the Clean Water Act was amended to require the Environmental Protection Agency (EPA) to issue National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater permits for discharges from large Municipal Separate Storm Sewer Systems (MS4s). The NPDES or MS4 permits in Los Angeles are designed to ensure that stormwater discharges into rivers, lakes, or the ocean meet water quality standards. The California State Water Resources Control Board issues NPDES Permits for Los Angeles requiring a decrease in pollutants in stormwater and urban runoff. The MS4 permits are the main regulatory mechanisms used to address water quality and are typically considered the primary factor behind of whether a specific stormwater abatement goal is met or not.

Given the context of current and future water scarcity in the region, successfully integrating stormwater into supply sources will be key for sustaining human and ecological health. The efficient use of stormwater is one strategy advocated to meet the dual water supply-quality challenge in Los Angeles. The demands of the approach on the city to invest in ways to capture, cleanse, and restore water, while mitigating flood risk, generates a range of vested and interested actors in stormwater’s future. One of the key components bringing stakeholders together are funding mechanisms, such as Proposition O, which provides bonds up to $500 million to projects that meet the federal Clean Water Act and protect or rehabilitate local water bodies, promote water conservation, reduce floodwater and pollutants from urban runoff, and capture stormwater. Funds have been used for a variety of "grey-to-green" projects that capture stormwater from neighborhood streets and homes through site design strategies, such as vegetated bioretention ponds and soil filtration systems that can, for example, cleanse runoff before heading into the Los Angeles River. Many of these projects, nonetheless, take on a variety of forms that bring together stakeholders across the city, including non-profits and NGOs, as well as City, State, and Federal agencies. I explore stakeholder perceptions of projects like these that rely on technological innovations in green design and multiple stakeholders to understand where perceptions do and do not align in emerging stormwater governance efforts.

1.2.2. Study Site Two: Chicago

In 2008, Chicago launched its Climate Action Plan, indicating that the city is likely to experience increases in precipitation, more frequent and intense storms, and increased flooding. The report indicates that the frequency of intense storm events that produce more than 2.5 inches of rain in a 24-hour period is likely to increase by as much 50% by 2039 (Dorfman & Mehta, 2011; Hayhoe, et al., 2007). Beyond flooding, the consequences of more frequent and intense rain events include increases in combined sewer overflows (CSOs). Unlike Los Angeles, which has separate stormwater sewers, Chicago has a combined sewer system designed to convey stormwater and avoid flooding. However, storm events producing as little as .67 inches of rain in 24 hours can exacerbate the combined sewer system causing untreated sewage and water to flow into the Chicago River and Lake Michigan, where the city draws much of its drinking water (Dorfman and Mehta, 2011). CSOs are already a considerable problem in Chicago with 2,036 discharge events occurring in 2009 alone (NRDC, 2010). The Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in charge of treating the city's sewage and stormwater runoff at seven treatment facilities, which have to meet the requirement of their NPDES Permit in order to be in compliance with the Clean Water Act. The Tunnel and Reservoir System Plan (TARP), initially adopted in 1972, and not anticipated to be finished until 2029, is a large civil engineering project designed to address CSOs in the Chicago region. With the impacts of climate change looming, however, many stakeholders do not envision this large-scale project as capable of solving flooding and CSO problems in Chicago. Many within the city are looking towards replacing some of the city's impervious surfaces with porous pavement, bioswales, rain gardens, and other forms of green infrastructure to lessen the pressure on the stormwater treatment facilities and reduce the number of CSOs (Dorfman and Mehta 2011). With limited resources and diverging views on the efficacy of green infrastructure, however, there's an inherent conflict about what stormwater is, how resources are to be allocated to manage it, and the best way to achieve this.

1.3. Questions and Methods

Stormwater is a complicated governance problem, with many actors at multiple levels or scales of governance. As Table 2 shows, a wide range of roles and functions exist at every level of governance. Sometimes institutional roles and functions overlap with others while others often do not align. Among the many actors involved in stormwater governance, a wide range of strategies and perspectives exist on the best way to achieve water quality and quantity goals. As Table 3 shows, some strategies rely on market and economic approaches while others look to integrate and coordinate actors across through the management of water, land and related resources to achieve social, economic, and environmental sustainability. As a whole, however, these governance approaches to stormwater tend not to fit simple categories, but instead vary across the regime of actors. Given the diversity of governance approaches and perspective, one of the arching questions focused on how competing perspectives and institutional relationships relate to one another and influence how stormwater is managed and controlled.

Table 2. Institutional actors. This table outlines the roles and functions of different actors at different scales of governance.

Institutional Actors

Governance Level	**Institutions and Entities**	**Roles and Functions**
National	• Environmental agencies • Flood control agencies • Legislative bodies • Non-governmental organizations **Examples:** US Environmental Protection Agency; US Army Corps of Engineers	• Establish national laws, rules, and regulations (Clean Water Act)
State	• Environmental agencies • Water Management Agencies • Legislative bodies **Examples:** State Water Resources Control Board (CA); Illinois Department of Natural Resources	• Regulatory guidelines • Financing (infrastructure) • Permitting (CA) • Flood management/insurance
Region	• Government Councils • Multi-agency working groups **Examples:** Metropolitan Water Reclamation District (Chicago); Los Angeles County Flood Control District; Chicago Metropolitan Agency for Planning	• Permitting (Chicago) • Regional Coordination • Watershed management
City	• Water utilities • City agencies and departments • Non-profits and NGOs **Examples:** Los Angeles Department of Water and Power, Chicago DOT	• Local codes and ordinances • Meet federal and state mandates • Fund infrastructure development
Neighborhood, community, and land parcel	• Homeowner's associations • Businesses and groups • Non-profits and NGOs • Land owners **Examples:** Center for Neighborhood Technology, Water LA	• Taxes • Voluntary actions • Incentives

Table 3. Governance approaches and strategies. This table shows a sample of some of the approaches utilized by water resource managers to control stormwater.

Governance Strategies and Approaches

Governance Options	Goal
Mitigation Banking	Develop private markets to encourage investments in green infrastructure. It will allow property owners and private developers to buy and sell credits to achieve water quality goals.
Centralized	Focus on large structural features (e.g. sewers and catchment basins) that promote conveyance and retention.
Distributed/Decentralized	Distributed features such as bio-retention ponds and other features typically associated with green infrastructure. Includes structural and non-structural BMPs.
Integrated Approaches	Promote the coordination and management of water, land, and related resources to advance economic and social welfare while maintaining the integrity of vital ecosystems.
City Ordinances and Rebates	Incentivize citizen participation and involvement in water governance by encouraging use of rain barrels, rain gardens, cisterns and other residential improvements.

Overall, the questions shaping my study explore how the flows of stormwater have been remade and redefined, and how discursive shifts have transformed the ways stormwater is managed and perceived. The hypothesis at the beginning of the study was that efforts to transform or redefine stormwater from a hazard or a nuisance into a beneficial resource is shaped by the material characteristics of stormwater and that new types of management systems and environmental conditions have shaped perspectives towards stormwater. This stemmed from an observation that traditional bureaucratic institutions, such as state water boards and municipal governments, typically maintained a disproportionate amount of influence over environmental decision-making by shaping water resource governance. Some of these decisions, however, had unintended consequences on human and ecological health, which also created opportunities for local groups outside of formal government and decision-making realms to advocate for their interests and "fill in the gaps."

I saw this as a new form of stormwater management that represented an emerging form of environmental governance, comprised of multiple sets of shared and conflicting subjective stances towards how governance should proceed. The goal was to understand how the differently situated practices of water resource managers inform their opinions of the problem and they are shared with others. In other words, the goal was to take a systematic study of subjectivity in regards to shaping stormwater projects.

1.3.1. Question One and Methods

1. What are the politics and history of stormwater management and regulation and in what ways have the flows of stormwater been remade and redefined by politicians, scientific experts, and ordinary citizens?

Archival data (i.e. government reports, and museum and library collections) was analyzed using content analysis and critical discourse analysis (Chouliaraki and Fairclough, 1999; Fairclough, 1992). This question was addressed by examining the changes between the mid-nineteenth century and early twenty-first century in the way stormwater is perceived and managed in Chicago and Los Angeles. The intent was not to recognize these changes as simply a transformation of natural streams and rivers into more technological systems to manage floods and water supply. Instead, the analysis sought to reveal how the flows of stormwater have been repeatedly remade and redefined by politicians, scientific experts, and ordinary citizens. Transformations take place through formal institutions, informal practices, and hydrological and climatic processes that lurk beyond human control, making any linear projection of development historically and conceptually problematic. Throughout the history of both Chicago and Los Angeles, various groups and institutions have repeatedly vied to control and manage stormwater through the construction and operation of technologies (e.g. sewers, green infrastructure, fees, or incentives) and the creation of legislation designed to fit their shifting and competing goals.

In seeking to find ways to describe and analyze the changes stormwater flows have undergone, this question explored the ways various groups appropriated, enrolled, transformed and redefined stormwater flows to pursue political, economic, or cultural aims. The analysis sought to pay close attention to the lesser-known aspects of these historical interrelationships. The focus centered on how the linkages between technological development and environmental management, on the one hand, and political-economic and cultural identities, on the other, shape urban water governance. The archival materials allowed for clearer insights into the institutions, goals, and power structures behind the technological development of new strategies to address the impacts of stormwater and the evolution of Los Angeles and Chicago as modern cities.

In Los Angeles, The Huntington Library served as primary source for archival material, along with the Los Angeles Public Library. The Huntington Library is an important center for historical studies of the American West and the development of Southern California. In consultation with the subject specialist curator, the research consulted visual materials and photographs, manuscripts, and other archival materials to reconstruct past scientific and popular ideas and narratives about approaches to manage and control stormwater. Specifically the Index of American Design materials and the Solano Reeve Collection held important information related to early planning and surveying of the Los Angeles River. The Los Angeles Regional Planning Commission materials provided invaluable resources to provide political context to the project. However, the Los Angeles County Flood Control Research (1914-1915) papers served as one of the primary sources for the dissertation, which contains research on floods caused by the Los Angeles River and the San Gabriel River from the 1770s to 1913 and contain statements from California residents regarding their experience with floods. Similarly, the John Anson Ford papers contributed important knowledge into early flooding in Los Angeles, as he was a key member of the Los Angeles County Board of Supervisors between 1934 and 1958. Other important collections included the Samuel Brooks Morris papers, which detail his work as a civil engineer specializing in water issues for the Pasadena Water Department and Los Angeles Department of Water and Power. This includes details on the Morris Dam, which was built for supply and flood control, but is now part of the regions stormwater capture plan. While much of this research remains outside of the dissertation, future research will look to the Los Angeles case-study, and California and the American West more broadly, to focus on the evolving interrelationships between society, water, and infrastructure. [1].

The Chicago Public Library also served as a source for archival materials. Of particular interest was the Chicago Sewers Collection, 1855-2004. This collection holds important documentation regarding the establishment of the Board of Sewerage Commissioners in February 1855 and the design of the first comprehensive system of underground sewers in the United States. The sewers were built to address cholera and dysentery epidemics, but due to Chicago's wet prairie and low lying topography, stormwater was a particularly hazardous vector carrying manure and debris from barns and dead livestock (Cronon, 1991). The Harold Washington Archives and Collections at the Chicago Public Library provided mayoral records and infrastructure records. The collections contain information on streets, sanitation, and water infrastructure projects. These sources helped provide important context into the Chicago case-study.

[1] This is expanded on in the conclusion, under future research. See section 7.3.

1.3.2. Question Two and Methods

2. What are the competing technological systems, social perspectives, and institutional arrangements (e.g. legal, scientific, governmental, and non-governmental) that currently define stormwater, shape its management, and inscribe its uses and value?

To answer this question, I relied on 57 semi-structured interviews with decision-makers and water managers from local non-profits to federal officials. The sampling method was purposive in order to target a knowledgeable and influential population with a vested interest in the future of stormwater management. This meant seeking out the widest possible range of stakeholder groups implicated in shaping stormwater management, including federal, state, county, and city water managers, environmentalists, urban planners, developers, academics, private sector consultants, lawyers, and utility engineers among others. The intent of the purposive sampling approach was to select respondents with clearly different perspectives and opinions regarding stormwater management and water resource planning. The initial set of actors were identified through literature and online searches but expanded through a "snowball" technique by asking previous respondents if they could recommend someone else for the study, usually someone with potentially contrasting viewpoints.

The interview questions contained a set of structured and open ended questions to explore how stakeholder groups define stormwater, perceive how it should be managed and valued, and barriers and drivers to successful management. Interviews began by asking respondents to explain their role in stormwater management and then moved to ask questions about how they think it should be managed, perceptions of current approaches, the legal, political and economic context of how new technologies or strategies are implemented, and the need for new institutions to manage stormwater in the future.

The interviews were conducted in-person and either digitally recorded and transcribed or recorded in a notebook. The interviews were supplemented with direct observation of formal meetings and conferences to discuss the future of stormwater management, such as the Southern California Stormwater Conference (n=5). These meetings were also purposively chosen to elicit a range of institutional viewpoints on how to address regulatory orders and regional water challenges, how to establish new rules, how to design financial mechanisms to manage stormwater, and how financial and technological innovation can create more sustainable strategies to manage stormwater. Notes were taken during these meetings and if the meetings were posted online, key portions were transcribed.

1.3.3. Question Three Methods

3. How do these competing technologies, perspectives, and institutional arrangements relate to one another and influence how stormwater is understood, managed, and controlled in order to address issues of risk and vulnerability (e.g. droughts, floods, water supply)?

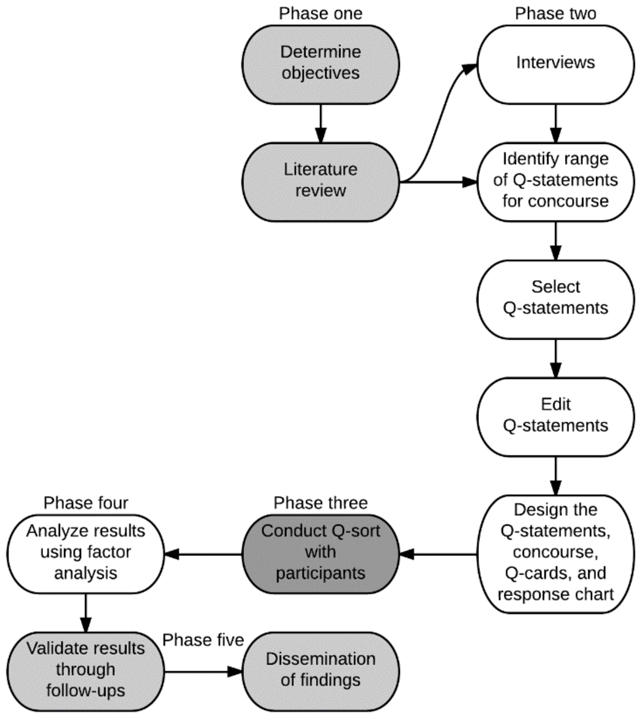

Figure 3. Q-methodology process and phases. Adapted from Nijnik et al. (2013)

In order to identify different points of view and relate them to the points of view of others, I use Q-methodology. Q-methodology, as outlined in Figure 3, is a rigorous method for examining the areas of consensus and conflict between stakeholders, and for specifying, selecting and evaluating policy options (Watts & Stenner, 2012). The approach is used as a tool to reveal ones subjectivity, or their social perspectives, attitudes, or understandings about a particular issue or topic, in a structured and statistically interpretable form (Robbins and Krueger, 2000). The outcome, or result, captures the key "discourse coalitions" (Hajer, 1995) that drive policy transformations, while also providing the necessary data to potentially deliver policy resolutions. By exploring what water managers believe are the optimal stormwater governance strategies, Q-methodology provides a means to quantify and measure the range of stakeholder values, opinions, motivations, or perspectives to foster more desirable management outcomes.

Q-methodology originated in the field of psychology, but has been adopted in a range fields (Barry and Proops, 1999; Robbins and Krueger, 2000; Stephenson, 1935). It is a hybrid approach that is both quantitative and qualitative. The approach differs from traditional survey approaches in a number of ways. First, the approach does not provide generalizability about the representativeness of the opinions distributed across the population (Watts and Stenner, 2012). Instead, the method is geared towards identifying the range of opinions that exist among a population. In other words, Q-methodology looks to identify the *range* or *diversity* of opinions about a topic, and how they differ or are shared among a population, not the level of support or number of individuals in the population that share the perspective. A second key point to make about Q-methodology is that it holds that subjectivity is "operant" and self-referent (Barry and Proops, 1999; Robbins and Krueger, 2000). This means that respondents actively define and give meaning to the categories of the study themselves, rather than working from a predefined category established by the researcher (Robbins and Krueger, 2000; Watts and Stenner, 2012).

Once a topic of study is chosen, Q-methodology proceeds through a number of steps. First, it works by constructing a set of statements (Q-set) from interviews, literature, and other sources. Participants are then purposively chosen to be representative of the breadth of opinion about the topic. This comprises the P-set. Participants then rank statements in a quasi-normal distribution chart along an axis of more strongly agree or disagree with the statement (the Q-sort). The results of the Q-sort are subject to a factor analysis that identifies patterns in each individuals' Q-sort and places them into bundles, or categories of social perspectives. The result of this process allows the researcher to understand and explore the key viewpoints or attitudes of each dominant social perspective that shapes stormwater management. Q-method is described here in five extended phases:

During *phase one*, the study objectives and research objectives are identified and a literature review is performed. The goal is to establish a "domain of subjectivity" that will be used to explore respondent perceptions (Robbins and Krueger, 2000).

In *phase two*, a concourse of statements containing the *range* and *intensity* of perspectives on the topic is created. Statements for the Q-sort are typically taken verbatim from people's natural dialogue, but may also come from newspaper articles, NGO publications, web-sites, and other sources that can capture the *range* of discourses or perspectives on a topic (Brannstrom, et al., 2011; Eden, et al., 2005; Jepson, et al., 2012; O'Neill, et al., 2013; Robbins & Krueger, 2000). This study developed a concourse out of interviews or publications written by the respondents, so that the Q-statements reflect the exact phrasing of the people being studied, but also publications and news articles that captured perspectives of how stormwater should be managed (Robbins & Krueger, 2000; Webler, et al., 2009). The collection of statements continues until a "saturation point" of statements is reached and inclusion of additional statements to the concourse does not offer new perspectives among the range of statements (Eden et al., 2005). Statements are then parsed down to manageable number of statements capable of reflecting the full diversity of viewpoints. While no specific rules exist for choosing the final number of statements for the Q-set, numbers range from 20-60 statements.

During the *third phase* respondents are recruited and asked to conduct the Q-sort. Identifying the P-set, or the study participants, is based on their relevance to the study. Purposive sampling is the standard in Q-methodology and was used in this study to recruit the original interviewees identified earlier in the study, as well as key stakeholders recruited through the snowball sample. This was done to ensure the widest range of experiences and perspectives possible (Brannstrom, 2011; Brannstrom et al., 2011; Fisher and Brown, 2009; Robbins, 2006).

Once the participants are identified they conduct the Q-sort through a rank ordering exercise. The Q-sort also provides an interview script to solicit and record respondent reactions to the statements as they ranked them or for follow-up interviews. This approach allows for more meaningful narratives to be constructed around the results and ensure more accurate interpretation after statistical analysis (O'Neill et al., 2013; Ward, 2013; Webler et al., 2009).

The *fourth phase* involves Q factor analysis, which clusters the sorts, enabling the researcher to identify common orderings of statements and indicate shared points of view and subject positions. Data software packages such as, PQMethod software, exist specifically for the analysis of Q-data. The factor analysis works by mathematically creating new variables, or factors, that explain variation among many variables (the Q-sorts). In this way it structures the subject positions of each participant and allows for empirical measurement of how different knowledge groups interact and how their viewpoints converge or diverge. The factors work as a way to *explore* patterns in how people bundle their world views (rather than explain them).

The interview data then helps contextualize the results of the factor analysis. Furthermore, the comparative aspect of this study offers the advantage of analyzing the social perspectives from each city in their own right, and together as a comparison. This common approach utilizes the data in multiple settings to offer a more rigorous understanding of the relevant similarities and differences between both sites or research groups (Kline, 1994; Watts and Stenner, 2012).

During the *fifth phase*, factors are interpreted and validated through follow-up interviews with the participants most strongly aligned with a factor that emerged from the analysis. Validation and interpretation also came from online post-sort questionnaires that asked respondents why they ranked the statements the way they did, the statements they most agreed and disagreed with, and why.

1.4. Dissertation Structure

A number of themes cut across each of the chapters. The first is that urban metabolisms and resource flows. Chapters 2, 3, and 6, in particular, engage with the concept of urban metabolism to examine the political, material, and subjective dimensions or urban resource flows. The second is that of expertise and subjectivity. Chapters 4, 5, and 6 present the Q-methodology results, which empirically examine how different perspectives and forms of action converge and diverge across the range of actors vested in stormwater governance. However, taken as a whole I provide a number of ways different forms of knowing shape how environmental governance is achieved and shape the flow of water. Chapter 7 concludes by providing an overview of the dissertation and its broader themes and future research directions.

Chapter 2**,** published in *Geoforum*, introduces the concept of political-industrial ecology. The chapter engages with the metaphor of urban metabolism to explore the social, political, and material dimensions of Los Angeles's urban water metabolism. Specifically, the chapter incorporates theory and method from urban political ecology and industrial ecology to more fully capture the social and political processes shaping the water supply metabolism of Los Angeles. To explore how spatial form influences the material metabolism of water, the chapter incorporates spatiality into the traditional life cycle assessment (LCA) approach by coupling it with GIS. The result reveals that the water sourcing and conveying life cycle phases have the largest carbon footprint. The outcome of this intervention advances the LCA enterprise by being more geographically nuanced, but also reveals the need for downscaled, or utility-scale, modeling to provide more accurate carbon footprints. Then to explore the social and political dimensions of Los Angeles' water supply metabolism the chapter utilizes interviews and historical analysis to provide a critical exploration of how Los Angeles' various water supply infrastructures came to be and illustrate how a sustainable transition based only on a narrow carbon calculus is problematized by historical circumstances and strategic new paradigms to secure water resources.

In Chapter 3, I expand upon political–industrial ecology to understand the politics surrounding how the volume, composition, and material throughput of stormwater in Los Angeles is calculated and applied by experts. Stormwater remains a fragmentary object of governance, however, just like the bureaucratic institutions assembled to control and manipulate its flows. For some, stormwater is a nuisance, flooding homes and polluting waterways, while for others it is a beneficial resource yet to be harnessed. The intent of this Chapter is to understand the technopolitical efforts designed to transform stormwater from a hazard or flood control problem into a resource. Specifically, it seeks to understand how the active processes of calculating the metabolic inflows and outflows of stormwater in Los Angeles serve as a way for the city to direct governance approaches and capture water. The intent is to draw attention to the ways urban metabolisms are calculated in practice, what they do and do not include, and the role this plays in establishing new forms of governance. This process, I argue relies on understanding stormwater as an assemblage that reflects how various forms of technical expertise, environmental conditions, cultural and political discourses, and social groups are enrolled in its management. While the categories for liability and responsibility remain contested over time and space, it is shown that stormwater in Los Angeles needs to be understood in relation to the ecological systems and scientific, political, and cultural practices designed to make it into a resource and align with existing patterns of growth and development.

Chapter 4 explores how stakeholders involved in stormwater management in different contexts (policy makers, scientists, planners, engineers, community leaders, etc.), understand stormwater problems, their perspectives and preferences towards solutions, and how these perceptions relate to one another. This is the first Chapter of the dissertation to utilized Q-methodology to reveal the shared and competing social perspectives on the changing role of stormwater in environmental governance. The results present four knowledge groups, or factors, that define the variability in stakeholder perspectives: 1) The Market Skeptic, 2) The Hydro-managerial, 3) the Market Technocrat, and 4) The Regulatory and Administrative Technocrat. Among these perspectives, they all desire for more integrated approaches across all of the institutions and sectors concerned with the management of water. They also prefer science and data driven approaches to more community-driven approaches. Perspectives begin to diverge, however, in terms of infrastructural preferences, the role of market and economic incentives, and the role of new institutions and rules to govern stormwater. The chapter reveals how water's multiple categories within society differentially frame the preferred solutions for dealing with stormwater and how that may impede the development of more collaborative approaches and institutions capable of ensuring long-term sustainability.

Chapter 5, is the second chapter of the dissertation drawing on Q-methodology and is used to examine the ways stakeholder preferences and perspectives of stormwater management converge and diverge in Chicago. In Chicago, as with other cities, decision-makers must choose how resources are to be allocated to manage stormwater and decide among the multiple and sometimes conflicting options available to reduce the impact of stormwater at different sites across the city and region. Using Q-methodology, this paper seeks to understand the disparate understandings of how to best manage stormwater in the city. The results reveal two dominant perspectives towards stormwater management approaches in Chicago: the Infrastructural Interventionist and the Institutional Interventionist. The Infrastructural Interventionist prefers stricter laws and regulations, developed in tandem with science and data-driven approaches, as the best way to improve stormwater management through infrastructural interventions. In contrast, the Institutional Interventionist, prefers new rules and institutions to foster integrated management approaches, as well as more robust economic instruments capable of assigning a monetary value to stormwater, as critical to resolving stormwater problems. Difference between the two groups' viewpoints center on the type of infrastructure to be developed, either centralized or distributed, as a means to control stormwater. Agreement stems from desires to place a monetary value on stormwater as means of driving their preferred type of intervention. Understanding how these two social perspectives interact and conflict is important in considering the actions that will ultimately be undertaken to direct landscape changes capable of resolving the multiple challenges Chicago faces in managing stormwater.

Chapter 6 is a comparative study of Chicago and Los Angeles. Drawing on the Q-methodology results in Chapters 4 and 5, this chapter produces a set of "super factors" through a second-order factor analysis that captures the common and dissociated viewpoints of both the stakeholders in Los Angeles and Chicago. The chapter also uses the comparative study to expand more broadly on the relationship between urban metabolisms and the formation of particular subject positions. By relationally examining how expert attitudes toward stormwater in cities with different political, technological, and climatic regimes this research accounts for geographical and institutional variations in environmental knowledge and the ways people come to different subjective framings of stormwater governance. The results indicate four contrasting domains of knowledge: 1) Hydro-reformist, 2) Hydro-managerial, 3) Hydro-rationalist, and 4) Hydro-pragmatist. While I cannot claim that these perspectives provide a universal typology of stormwater perspectives, they reveal geographically specific and extended viewpoints that may be shared across many sites. Subject positions align around shared framings of integrated water resource management and the utilization of the best available science and technology to drive decision-making. These framings nonetheless exist along a spectrum among those involved in stormwater management but formulate a set of cohesive stances towards how stormwater should be managed to improve water quality and quantity problems. Divergence centers on differences in the perceived effectiveness of different types of infrastructural interventions, of market and economic incentives, and how new institutions and rules to govern stormwater should be crafted.

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Chapter 2: A Political-industrial Ecology of Water Supply Infrastructure for Los Angeles[2]

Abstract

This paper develops a political–industrial ecology approach to explore the urban water metabolism of Los Angeles, which sprawls for thousands of miles across the American West. Conventional approaches to quantify urban carbon footprints rely on global, national, or regional averages and focus narrowly on improving the efficiency of flows of resources moving into and out of the city. These approaches tend to ‘‘black box’’ the methodologies that guide the carbon emissions calculus and the social, political, ecological, and economic processes that perpetually reshape nature–society metabolisms. To more fully delineate the water supply metabolism of Los Angeles, this paper combines theory and method from urban political ecology and industrial ecology. Specifically, we infuse spatiality into the traditional life-cycle assessment (LCA) approach by coupling it with GIS. By illustrating how decisions about system boundaries, emissions factors, and other building blocks fundamentally shape the end result, this intervention at once destabilizes and advances the LCA enterprise. Then, using interviews and historical analysis, we provide a critical analysis of how LA's various water supply infrastructures came to be and illustrate how a sustainable transition based on a narrow carbon calculus is problematized

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[2] This chapter has been published as: Cousins, J.J., Newell, J.P., 2015. A political-industrial ecology of water supply infrastructure for Los Angeles. *Geoforum* 58, 38–50. doi:10.1016/j.geoforum.2014.10.011

by historical circumstances and strategic (and often conflicting) new paradigms to secure water resources. The political–industrial ecology approach offers valuable insights into the spatiality of material metabolisms and the socio-political processes (re)shaping the relations between nature and society.

2.1. Introduction

> ‘‘*Owens Lake, the terminus of the [Owens R]iver, sat at an elevation of about four thousand feet. Los Angeles was a few feet above sea level. The water, carried in pressure aqueducts and siphons, could arrive under its own power. Not one watt of pumping energy would be required. The only drawback was that the city might have to take the water by theft*’’. [Reisner, 1986, 61]

While theft may no longer be an option in Los Angeles's quest to secure and increase its water supply, Reisner draws attention to two important aspects that this paper seeks to address. The first aspect is the embodied energy and emissions of Los Angeles's water supply metabolism. Los Angeles, like other global cities, has established programs for reducing GHG emissions while making overt references to reduce their reliance on distant and uncertain resource flows and infrastructures (Bulkeley and Betsill, 2013; Bulkeley, 2010; Rice, 2010). These concerns over ‘‘urban ecological security’’ reflect exposure to regulatory, climatic, and political drivers that influence how the City of Los Angeles is managing its water supply through the development of local and decentralized systems to build greater self-sufficiency and reliance while simultaneously reducing GHG emissions (Hodson and Marvin, 2009; Hughes et al., 2013; LADWP, 2010a). Indeed, climate models indicate that snowpack in the Sierras may decrease from its mid-20th century average by 25–40% by 2050 reducing the water available via the Los Angeles Aqueduct (CDWR, 2008). This, coupled with ongoing drought conditions, is driving policy makers and planners to rework the socio-technical systems delivering water to the region.

Faced with simultaneous pressure to reduce GHG emissions while securing a stable supply, cities like Los Angeles have begun to assess the nexus between water and energy consumption by measuring the carbon footprint of their water systems. The methodology guiding these analyses is life-cycle assessment (LCA), an important tool in industrial ecology that quantifies environmental impacts of products and processes during each phase of its ‘‘life’’—from material extraction to disposal (Freidberg, 2013; Graedel and Allenby, 2003; Newell and Vos, 2011). In theory, once the carbon emissions burden—or the relative impact or footprint of the respective life phases, process, or product—is known, strategies to facilitate low-carbon and sustainability transitions can be made (Bulkeley, 2010; Bulkeley et al., 2013; Hodson and Marvin, 2010; Smith et al., 2005). This calculative process of urban environmental governance centered on ‘‘carbon control’’ often drives interventions to re-work urban socio-technical systems (Bulkeley and Castán Broto, 2012; Jonas et al., 2011; While et al., 2010). To increase local supplies, LADWP is focusing on projects that increase recycled water, expand water conservation, enhance stormwater capture, and establish green building initiatives (LADWP, 2010a, 2010b; Solorio, 2012; Villaraigosa, 2008). The objective is to make water demands more efficient while developing supply sources that are less vulnerable to climate change (LADWP, 2010a; Villaraigosa, 2008). But this (re)development of socio-technical systems to re-work Los Angeles's water metabolism may not always align with the desired emissions targets or foster a social and environmentally just system.

The second aspect this paper addresses is the historical and political processes shaping the water supply metabolism of Los Angeles, a metabolism that extends to the watersheds of the Sacramento and Colorado Rivers and to the Owens Valley and High Sierras (Fig. 4). Building the 233-mile Los Angeles Aqueduct (LAA), for example, required the construction of 120 miles of railroad track, 500 miles of roads and trails, 240 miles of telephone line, and 170 miles of transmission line (Reisner, 1986). The relation- ships and interdependencies among and between these infrastructures represent a unique political ecology, one that materialized out of the political and economic support for William Mulholland's vision to bring the waters of the Owens Valley to Los Angeles. The social–ecological transformation of the Valley that followed was the result of failed protests, legal challenges and national laws, rules, negotiations, and agreements between Valley residents and the City of Los Angeles. With current concerns over carbon emissions, however, the low emissions burden of water conveyed via the LAA brings into contrast the contradictions between reducing emissions and the internal properties, politics, and

Figure 4. Map of water supply sources for the City of Los Angeles

contestations that are hidden or “black boxed” (Latour, 1987) when focusing only on the input–output analysis of reducing GHG emissions or supplying a city with water.

We investigate these aspects through a framework that utilizes industrial ecology (IE) and urban political ecology (UPE) to examine the energy and material flows of Los Angeles’s urban water metabolism. The approach integrates spatiality and critical theory from geography to develop a political–industrial ecology approach to the study of urban metabolisms. This is done by building a spatially-explicit LCA to model the embodied energy and emissions of Los Angeles’s water supply sources. The analysis is scaled down to the utility to provide a finer grained analysis of the city’s water supply metabolism and as a means to advance LCA by integrating spatial differentiation into the modeling process. While the GIS– LCA coupling provides a well-suited approach to explore the spatialized emissions and some environmental impact questions, it is limited in its ability to consider the socio-political dimensions of GHG emissions. To address this limitation, we link the LCA–GIS model with insights from political ecology to explore the planning contradictions that arise when managing water through the lens of carbon emissions. To do this, we interviewed water managers in Los Angeles and examined policy documents and newspaper articles to situate the urban metabolism within the everyday practices of the governmental agencies and societal groups who participate in (re)shaping it. By revealing the spatiality of material and energy flows and the internal and heterogeneous social, political, economic and ecological properties that (re)structure them, this approach helps open up the black box of both the input–output methodologies that underlie the measurement of GHG emissions and the processes that guide environmental decision-making.

The following section provides an overview of literature in IE and UPE, paying particular attention to how the metabolism metaphor is used in each field in order to develop the political–

industrial ecology approach. We then outline our method, which combines LCA and spatial analysis with interviews and document analysis to explore the "interwoven knots of social process, material metabolism and spatial form" (Swyngedouw and Heynen, 2003, p. 906) that shape Los Angeles's water supply metabolism. Section 4 presents and discusses the results of the spatially-explicit LCA of Los Angeles's water supply and compares it to conventional LCA approaches. The analysis provides a critique of conventional LCA approaches by revealing how decisions and assumptions about the scoping of system boundaries can alter the result of an LCA, but also advances the method by elucidating how spatial form influences the material metabolism of Los Angeles's water supply. Section 5 expands the analysis to the social processes that (re)structure Los Angeles's urban water metabolism.

2.2. Theoretical framings: urban metabolisms and sociotechnical systems

As mediators of resource consumption and disposal, socio-technical systems—the interrelated social and physical components of urban infrastructural networks—have multi-scalar and multi-sited effects on climate, biotic communities, and the health of humans and non-humans within and beyond the city, metropolis, and region (Bulkeley and Castán Broto, 2012; Bulkeley et al., 2013; Furlong, 2010; Hodson et al., 2013; Lawhon and Murphy, 2011; Mollinga, 2013). To grasp this dynamism, scholars have begun to point towards the value of developing integrated approaches that utilize urban metabolism as a conceptual framework, bringing together theory and method from industrial ecology, political ecology, and other disciplines (Castán Broto et al., 2012; Hodson et al., 2012; Kennedy et al., 2012, 2011; Newell and Cousins, 2014; Pincetl, 2012; Pincetl et al., 2012; Ramaswami et al., 2012). The utility of the urban metabolism concept is its ability to capture a range of perspectives that engage with urban sustainability while offering insights into how to transform production and consumption patterns in cities into more efficient and equitable ones. However, to be useful as an interdisciplinary boundary metaphor (Newell and Cousins, 2014), urban metabolism research needs to successfully integrate approaches and perspectives across fields. In this section, we focus our attention on the convergence of the metabolism metaphor between IE and UPE.

2.2.1. Industrial Ecology

Urban metabolism is typically defined among industrial ecologists as "the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Kennedy et al., 2007, 44). The term itself was popularized in 1965 by the sanitary engineer Abel Wolman after the publication of his seminal article in *Scientific American* where he quantified the metabolic inputs (water, food, and energy) and outputs (waste) of a hypothetical American city. The formal development of IE, however, was forged by physicists and engineers in the late 1960s in an effort to use "nature" as a model to research existing industrial systems and develop more efficient and resilient urban forms (Frosch, 1992; Jelinski et al., 1992; Newell and Cousins, 2014).

Industrial ecologists in the Wolman tradition apply mass-balance accounting methodologies such as material flow analysis (MFA) to quantify the "stocks" and "flows" of the urban metabolism (Baccini and Brunner, 2012; Baccini, 1996). MFA can be viewed as a methodology to quantify indicators of urban (un)sustainability that inform strategies to optimize resource use through efficiency gains, dematerialization, and waste reuse (Barles, 2009; Hodson et al., 2012). Influential case studies have examined a range of cities from Hong Kong (Newcombe et al., 1978; Warren-Rhodes and Koenig, 2001) and Tokyo (Hanya and Ambe,

1976) to Paris (Barles, 2009, 2007a, 2007b) and Vienna (Hendriks et al., 2000) among many other cities. This emerging school of research is demonstrating the robustness of MFA as a methodology to understand and quantify urban metabolisms.

Scholars in IE are beginning to utilize LCA in place of, or coupled with, MFA, as an alternative approach to quantify metabolisms. LCA, which traditionally focuses on the "cradle-to-grave" environmental impacts of products and processes (Guinée, 2002; Keoleian and Menerey, 1994), offers possibilities for more fully capturing "upstream" and "downstream" environmental impacts of resource flows that extend beyond urban borders (Newell and Vos, 2011; Pincetl et al., 2012a). The International Standards Organization (ISO) 14040 protocol demarcates a standardized set of rules and requirements for LCA procedure (Freidberg, 2013; Newell and Vos, 2011). The standard LCA method includes the definition of the goal and functional unit, delimitation of scope or system boundary, life-cycle inventory (LCI) or the accounting of pollution and resource extraction in each phase, and life-cycle impact assessment (LCIA) (Newell and Vos, 2011). The final LCIA stage focuses on improving the performance of the product or process in question.

2.2.2. Urban Political Ecology

In contrast, scholars under the banner of UPE have typically criticized the IE approach. For Erik Swyngedouw, "studies on urban metabolism have often uncritically pursued the standard IE perspective based on some input–output model of the flow of 'things.' Such analysis merely poses the issue, and fails to theorize the making of the urban as a socio-environmental metabolism" (2006b, 35). Other scholars such as Keil and Boudreau (2006, 43) point towards the "restrictiveness" of traditional IE urban metabolism studies in that they offer a weak analysis of the political context, capitalist economy, and social patterns that shape the metabolism. Gandy (2004) asserts that the "relational" notions of urban metabolism dominant in UPE are now more appropriate metaphorical conceptualizations of urban space than the "functional-linear" or neo-organismic ones that are derived from "technocratic urban models." The approach used by industrial ecologists is typically interpreted by UPE scholars as an apolitical platform, one undergirded by a logical positivism that typically leads to neo-Malthusian conclusions and outcomes (Harvey, [1974] 2001).

In place of input–output models based on the "flow of things", urban political ecologists frequently draw upon Marxist notions of metabolism to characterize the hybrid and relational aspects of economic, political, and ecological processes that form uneven urban social–ecological systems (Gandy, 2005; Heynen et al., 2006; Swyngedouw and Heynen, 2003; Swyngedouw, 2006a). Gandy (2002), for example, explores the production of "metropolitan natures" to demonstrate how nature is transformed by and enrolled into the political, economic, and social practices that shape New York City's form and function and its metabolic relationship to distal geographies. His exploration unveils how capitalist processes of urbanization link engineered systems conveying water to the ongoing transformations of distant natures and geographies. Similarly, Swyngedouw's (2004) analysis of water politics in Guayaquil, Ecuador moves beyond a singular focus on the flows of water by situating water in a "socio-environmental metabolism" that is entangled with the complexities of social power, control, and capital accumulation. Although not drawing on Marx, Cronon (1991) also shows how Chicago is a metropolis forged out of its metabolic relationship with its hinterland. Rather than accounting for the material inputs and outputs of the metabolic system, the focus in UPE is on the social and political processes and outcomes reconfiguring urban metabolic circulations in socially and geographically uneven ways.

2.2.3. Linking IE and UPE: Towards a political-industrial ecology

On the surface these approaches and perspectives may appear incompatible. We argue, however, that approaches from industrial ecology to quantify the various stocks and flows coursing into and out of the city and approaches from political ecology that focus on the politics, history, and economy can be used to gain new perspectives into nature-society relations. While IE may provide a latent set of quantitative methods for UPE to capture the broader impacts of resource flows and the environmental impacts of products and industrial processes, the measurement and modeling techniques lack critical insights into the historical, social, political, and economic mechanisms that influence metabolic urbanization. Adding a political ecology framework to traditional IE pushes inquiry towards an expanded approach to urban metabolisms that incorporates spatiality to develop more robust LCAs and includes a focus on issues of power in environmental decision-making to move beyond the apolitical tendencies of IE that focus narrowly on "win–win" scenarios between the economy and environment.

Practically speaking, in addition to a mere quantification of stocks and flows a political-industrial ecology refers to an analysis of the broader historical, political, social, technological and economic mechanisms shaping the relationships between a product, commodity or material process, its primary inputs and outputs, and the relevant social and ecological implications. The urban water metabolism of Los Angeles, for example, is dependent on energy inputs for water to circulate and flow within the hyrdosocial cycle, requires industrial and infrastructural processes to pump, treat, and distribute water, and emits carbon as a primary output. The metabolic circulation of water, however, is reliant on a set of social and political relations that is shaped and shaped by its relationship to water. Linking political and industrial ecology provides a compelling way to begin to think through these type of quantitative and qualitative socio-ecological transformations.

Taking a political-industrial ecology approach that couples LCA with GIS, for example, provides a quantitative method for spatializing the specific water, food, waste, and energy metabolisms that connect urban and rural space (Newell and Vos, 2011). This further develops the potential for spatial and quantitative analysis in UPE while enhancing core UPE insights into the co-production of urban and rural space. Other quantitative measures have been used within UPE to measure and quantify the metabolic transformation of urban forests (Heynen, 2006; Heynen, et al., 2006), the differences in air pollution monitoring techniques (Buzzelli, 2008), and the neighborhood level effects of urban densification and gentrification (Quastel et al. 2012). Through engagement with methods from IE, such as LCA, our approach provides an additional means to capture the social, political, industrial, and spatial variation of environmental impacts from material metabolisms, resource flows, products, and processes within and beyond the city and on urban socio-ecological systems. Specifically, we couple GIS and LCA to quantify the spatialized emissions of Los Angeles's water supply metabolism and utilize political ecology to explore the socio-political process that structure urban socio-natural landscapes.

2.2.4. Why Water

In cities like Los Angeles where the water supply metabolism extends to the watersheds of the Sacramento and Colorado Rivers and requires both local and imported sources (Fig. 5), the complexity of urban resource flows become apparent. Starting with water as the primary object

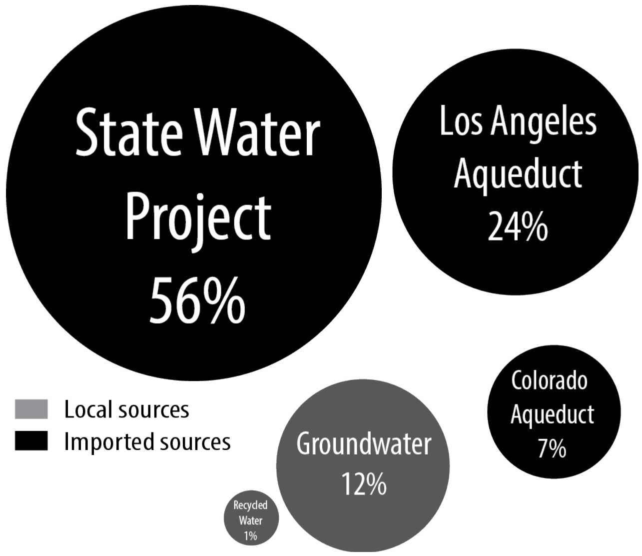


Figure 5. Water supply by percent quantity. *Source*: LADWP 2010a

of concern provides a bridge to explore linkages between two disparate approaches (IE and UPE) to understand the relationship between resource flows and urbanization. Water represents the largest component of all material flows within the urban metabolism (Decker et al., 2000; Kennedy et al., 2007), yet it is also one of the most political and contested objects of the urbanization process (Kaika, 2005; Swyngedouw, 2004). Furthermore, water flows present a geography that is nested within watersheds and sub-watersheds, thereby allowing urban water flows to be relatively spatially bounded, unlike most post-Fordist commodity chains and networks. Among other things, this enables industrial ecologists to locate and draw system boundaries in order to quantify the stocks and flows.

Moreover, as Matthew Gandy notes, "the history of cities can be read as a history of water" (Gandy, 2002, 22). Modernist theories of development in the nineteenth and twentieth centuries to rationalize the urban landscape involved the rolling-out of large socio-technical systems that influenced the form and function of the city. Water technologies and infrastructures, in particular, have received significant attention from urban political ecologists for their role in producing spaces of the modern city (Gandy, 2004, 2002, 1999; Kaika and

Swyngedouw, 2000; Kaika, 2005; Loftus, 2012; Meehan, 2013a; Swyngedouw et al., 2002) and in mediating relationships between the human and non-human world (Birkenholtz, 2013; Budds and Sultana, 2013; Kaika and Swyngedouw, 2012; Swyngedouw, 2009b). Studies of the Global North focus primarily on dams and large infrastructural systems or “mega projects” to supply and sanitize urban water (Gandy, 2002, 1999; Kaika and Swyngedouw, 2000; Kaika, 2005, 2003; Swyngedouw, 2013, 2007). In contrast, research centered in the Global South has examined tubewells, groundwater technologies, informal technologies of water provision, and the fragmentation of water supply networks (Birkenholtz, 2013, 2009a; Kooy and Bakker, 2008a; Meehan, 2013a, 2013b; Sultana, 2013, 2011).

Whether in the Global North, Global South, urban or rural, water technologies are developed, implemented, and contested in heterogeneous ways that reflect the social histories of place, situated networks of power and knowledge, and the discourses of development (Birkenholtz, 2013, 2009b, 2008; Rocheleau and Roth, 2007; Rocheleau, 2008; Sultana, 2013). The outcome is a hydro-social transformation that re-works the relationships between water and society in socially and geographically uneven ways. The “complex network of pipes, water law, meters, quality standards, garden hoses, consumers, leaking taps, as well as rainfall, evaporation, and runoff” (Bakker 2003b, 337) that comprise the hydrosocial cycle gives shape to how water circulates as a resource through nature and society. Urban water metabolisms, in other words, reflect technological, institutional, and individual practices as much as the hydrological cycle in a “socio-natural process by which water and society make and remake each other over space and time” (Linton and Budds, 2014, p. 6).

The metabolic circulation of water in and through urban space transforms social and physical environments, albeit with the aid of energy. The pumping of groundwater, recycling water, or desalinating water all depend on energy inputs to flow and circulate. The hydro-social cycle is thus highly entangled with issues of energy and infrastructure (McDonnell, 2014), which have material impacts on global climate change through their emissions burdens and on local ecologies and peoples during their construction, implementation and use phases. In California, nearly 20% of the total electricity consumption is devoted to the sourcing, collecting, transporting, and treatment of water (TCR and WEI, 2013). Water supplied to Southern California is especially energy intensive—approximately 50 times more so than to Northern California (CEC, 2005)—where an estimated one-third of household electricity use is devoted to water delivery (MWD, 1999). The broader impacts of the water-energy nexus are made relevant to planners and decision-makers through GHG accounting methods and supports low-carbon infrastructural developments. Re-shaping Los Angeles's urban water metabolism based solely on an IE carbon calculus, however, impedes considerations of power relations in environmental decision-making that can (re)distribute costs and benefits unevenly across race, class, and geography. In the following sections we provide an exploratory attempt for bringing together UPE and IE approaches to generate an urban political-industrial ecology of the metabolism.

2.3. Methods

We combine LCA and spatial analysis with interviews and document analysis to model the energy and emissions intensity of Los Angeles's water supply sources and to reveal its UPE. We first infuse spatiality into LCA by using GIS to "downscale" the modeling effort and compare and contrast it to the standard eGRID approach. This is done for multiple reasons. First, it offers the opportunity to open up the black box of the carbon modeling, measurement, and calculation process that drives urban climate governance by revealing the spatiality of carbon emissions.

Second, it pays attention to areal differentiation that can significantly alter the actual carbon footprint of water. This at once destabilizes the carbon footprint accounting process, but also advances the method by rendering it more detailed and sensitive to the particular sites where GHG emissions are produced. For example, conventional LCA approaches typically use LCIs consisting of activity data and emission factors that are essentially global or national averages or drawn from studies of Western Europe where LCIs are well developed (Curran, 2006; Newell and Vos, 2011). Consequently, the minimization of areal differentiation in the production of a LCA is not only a practice that is aspatial and "flattens" geography (Newell and Vos, 2011, 732), but also masks the uneven spatiality of urban carbon emissions among and between socio-economic classes (Rice, 2014).

Second, we utilize perspectives from UPE and qualitative interviews to explore the social and environmental dimensions typically lost in quantitative approaches to urban metabolisms. The goal is to reveal the contradictions that arise when governing water through the lens of carbon and energy emissions. The analysis includes considerations of the social and environmental justice issues of these flows of water and carbon as well as the social practices of water resource management. The way carbon is modeled and measured is certainly a technical project performed by expert communities, but the black boxed result is also a political project with the power to re-work socio-technical systems. Insights from political ecology provide a means to interrogate how decision-makers use carbon metrics and narratives of urban ecological security to re-shape urban metabolisms.

2.3.1. Methods for a spatially-explicit LCA of Los Angeles water supply sources

Some within the LCA community are slowly developing procedures to make LCIs more spatially-explicit, and a small cadre of LCA and IE scholars are exploring the potential of GIS–LCA hybridity to incorporate geographic variability through case studies of land-use change and biodiversity (Geyer et al., 2010), energetic utilization of biomass via conditioned biogas (Dresen and Jandewerth, 2012), energy crop production (Gasol et al., 2011), and the sourcing of material for building and road infrastructure (Reyna and Chester, 2013).

Efforts to model the energy intensity and emissions burden of water are not particularly new, nor are they new to the California region. Wilkinson (2000, 2007), for example, has examined the energy footprint of water utilities and regions of California. The utilities themselves have conducted and commissioned studies of the energy and/or emissions profiles for portions of their water distribution systems (IEUA, 2009; LADWP, 2010).

By coupling GIS and LCA, our study differs from these previous approaches in one significant way. We "downscale" to more accurately estimate the emissions associated with water supply. The default approach to obtaining the emissions factors of utilities is to use statewide, regional, or national averages (Marriott and Matthews, 2005; Soimakallio et al., 2011). Studies rely heavily on sources such as the Environmental Protection Agency's eGRID, a database that provides generalized emissions factors for electric power plants generating in the United States. In eGRID, California and portions of surrounding states fall within the CAMX (California-Mexico) Subregion. Essentially, energy and emissions factors are derived for CAMX by averaging energy and emissions profiles of plants for that entire subregion.

However, this emissions factor is not necessarily an accurate representation given that Los Angeles obtains water from five different sources across thousands of miles. The supply portfolios of California's utilities also vary significantly (Fig. 6). For example, Pacific Gas and

Electric (PG&E) relies heavily on hydropower; thus it has a cleaner emissions profile than the CAMX average. In contrast, the LADWP grid mix remains heavily reliant on coal, producing a dirtier emission profile than the CAMX average. We were interested, therefore, in better understanding how the different grid mixes and utility sources along the water supply system would affect the city's carbon footprint and the potential implications this has for managing the water-energy nexus. To evaluate the respective importance of downscaling to the utility scale we contrast the results of our GIS–LCA method with the standard accounting approach.

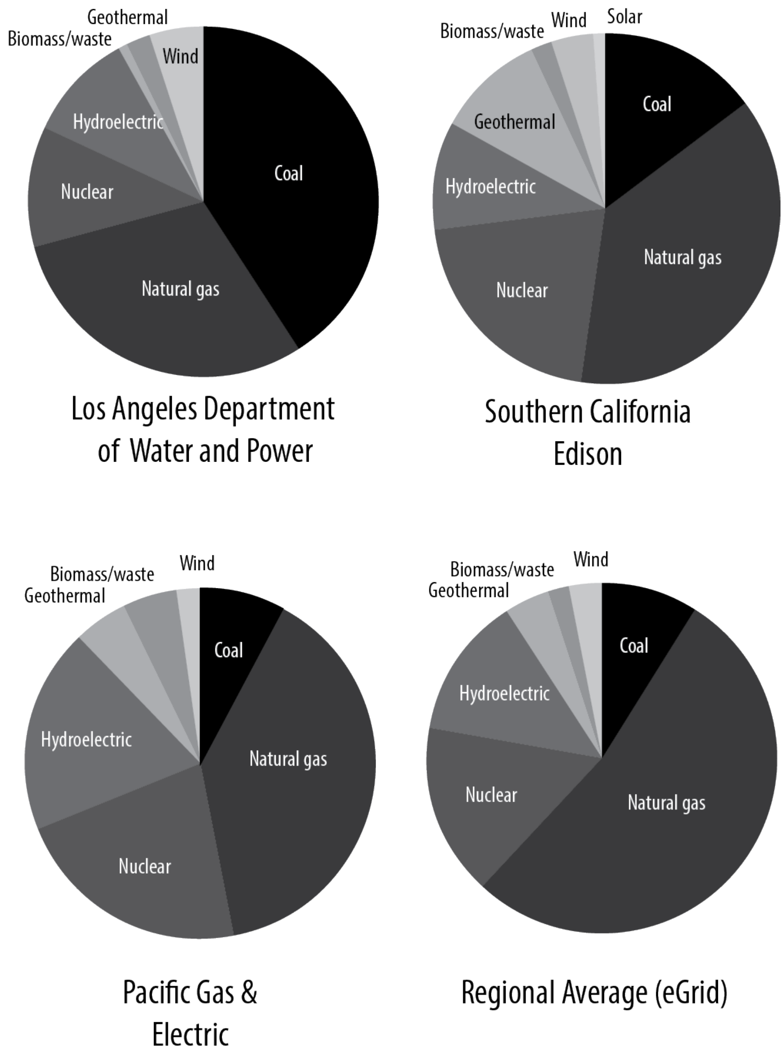


Figure 6. Grid mix portfolios of major utilities. *Source*: LADWPb; Southern California Edison 2010

2.3.1.2 System boundary and steps

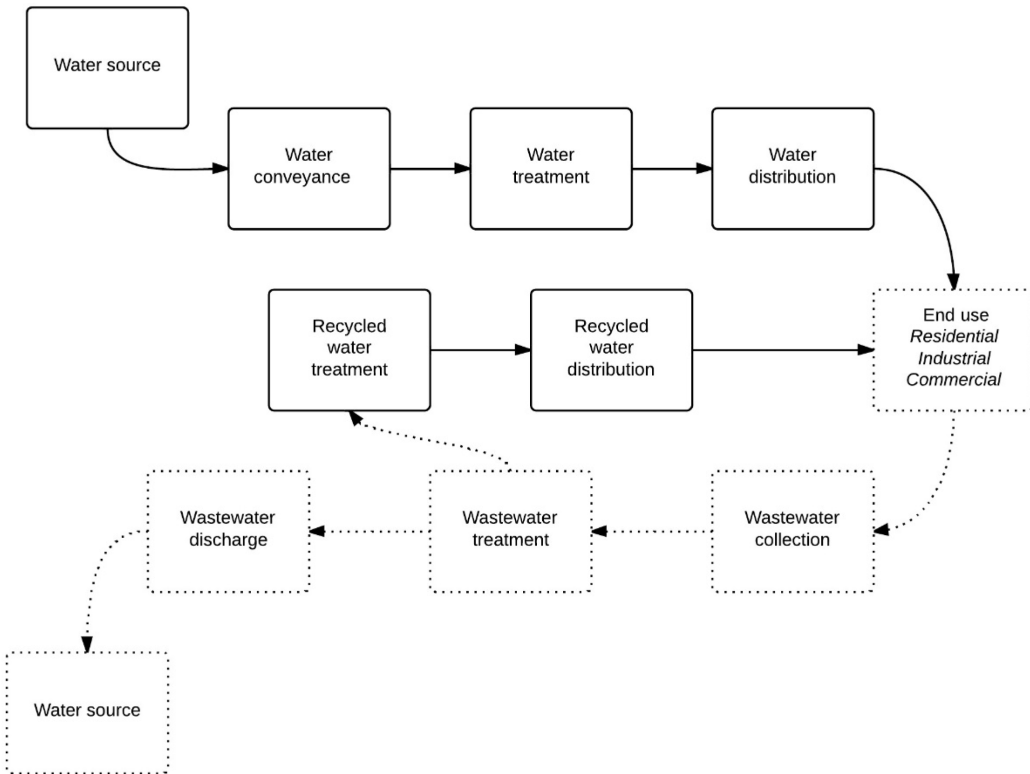


Figure 7. Water supply system boundary. Scoped around water conveyance, treatment, and distribution moving from source to end use, including recycled water. *Source*: Adapted from CEC 2005

We studied the portion of the water–energy nexus centered on providing water to consumers. The “system boundary” of the study is thus limited to three phases of water delivery: sourcing and conveying, treatment, and distribution to consumers (Fig. 7). We deliberately chose these phases as spatial variation can significantly influence them. However, this meant that other stages fell outside of the system boundary. For example, the “use” and disposal phases—or more properly, cleaning phases in the case of water—were excluded. In-home energy usage associated with heating and cooling water was also excluded, but it is widely recognized as the most intensive portion of the energy footprint of water. Our LCA also excluded the energy and emissions associated with the initial construction (e.g., energy embedded in the concrete used to construct aqueducts) and the “use” or maintenance phase of water infrastructure. In the case of infrastructure, the latter is typically much larger than the former. Reyna and Chester (2013) found, for example, the GHG emissions from the maintenance and rehabilitation associated with roads in Los Angeles County are more than four times higher than the emissions resulting from their initial construction, over the lifetime of the roadway network. These choices impose limits to the LCA analysis done, but the goal of this relatively simple LCA is to highlight how spatial variation and system boundary delineation can fundamentally change the carbon footprint of a product or process.

Our “functional unit” was one acre-foot (AF) of water delivered to Los Angeles and we measured the energy budget in terms of grams of CO_2e generated for each KWh. The activity data for the study—such as the quantity of water imported by source, energy intensity (KWh/AF), utility grid mix, water pumping, recycling, and treatment plant efficiency—came from a variety of sources, such as the LADWP Urban Water Management Plan (2010a). We developed emissions factors for the utility emissions and the energy sources in two primary steps:

1. *Assign specific utility for pumping and transport, treatment, and distribution phases.*

We used GIS to map the water supply infrastructure for the five water supply sources. Some of these data were publicly available; others were obtained from the LADWP and the Metropolitan Water District (MWD). Data on the locations of the pumping plants were obtained using physical maps from agency publications (CDWR, 2011; MWD, 2009) and the California Energy Almanac and geo-coded by cross-referencing the estimated X,Y coordinates in Google Maps. We then assigned each of these plants to a particular Electricity Utility Service Area (EUSA), a geographic area where a specific utility operates and supplies electricity. Los Angeles’s groundwater and recycled water supply sources fall entirely within the LADWP service area and were assigned emissions burdens accordingly. Information on which utility to assign to the treatment plant was based on written correspondence with MWD and LADWP officials. After the treatment phase, water is distributed uniformly throughout the city regardless of the source and requires the same amount of energy for all water sources (196 kWH/AF). Consequently, the sole utility assigned for the distribution phase is LADWP. Finally to determine the grid mix (coal, hydro, solar, etc.) for each utility and the corresponding emissions factors for each electricity utility we used state-mandated power content labels.

2. *Calculate the energy and emissions burden for the three life-cycle phases*

For this step, we multiplied the activity data and the emissions factor for each of the three phases. Each of the pumping and treatment plants has different efficiencies, measured in KWh/AF, as well as energy inputs for a specific volume of water. Emissions profiles for each pumping plant were also generated based upon the distribution of net electricity consumption that could be attributed to each EUSA based on the annual electricity usage. The Colorado River Aqueduct (CRA) and State Water Project (SWP) conveyance systems are coupled with power generation, making it necessary to determine how much electricity was self-generated. We did not give these conveyance systems emissions credits for the hydropower generated (and sold to partner utilities) based on the assumption that this hydropower would be credited in the utility's generation portfolio. Hydropower used by the conveyance systems for pumping water was added to purchased electricity from the EUSA in order to determine an overall emissions factor for both systems. SWP reports PG&E, California Independent System Operator, and Southern California

Edison as transmission providers; we assumed that daily spot purchases would be made on these grids.

2.3.2 Revealing the political ecology

In order to situate the quantitative measurement with the more qualitative aspects of water supply infrastructures we conducted 17 interviews, between December 2013 and June 2014, with water resource managers at city, county, and federal agencies and staff members of environmental NGOs. During these interviews we asked questions about the environmental, legal, political, and economic drivers of water sourcing and the role of new technologies and innovations in driving transitions. More specifically, the questions probed how sustainability was measured and calculated in terms of water resources and the impacts of these technologies and sourcing strategies on social and ecological systems. To better understand the everyday practices that guide the production and use of LCAs and the reshaping of urban metabolism, these interviews were supplemented with an analysis of policy documents, newspaper articles, and agency reports.

2.4. The spatialized energy metabolism of Los Angeles's water supply

The energy intensity of Los Angeles's multiple water supply sources is unequal and heterogeneous across phases of transportation, distribution, and treatment and source. As the LCA demonstrates, Los Angeles's geographically diverse water sources have widely varying energy and emissions profiles (Fig. 8). Water sourced from Northern California and the Sacramento Delta via the State Water Project (SWP) is the most expensive and energy intensive, requiring six pumping plants to carry it over the Tehachapi Mountains before it breaks into the

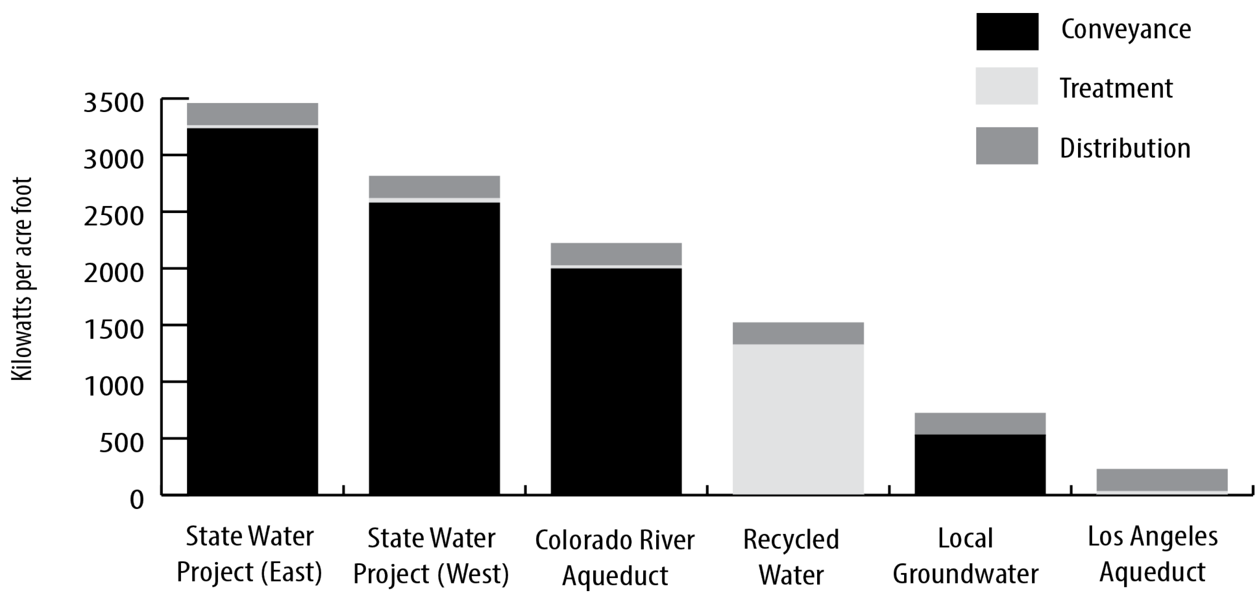


Figure 8. Energy intensity of water supply sources, by phase, for Los Angeles. *Source*: LADWP 2010a.

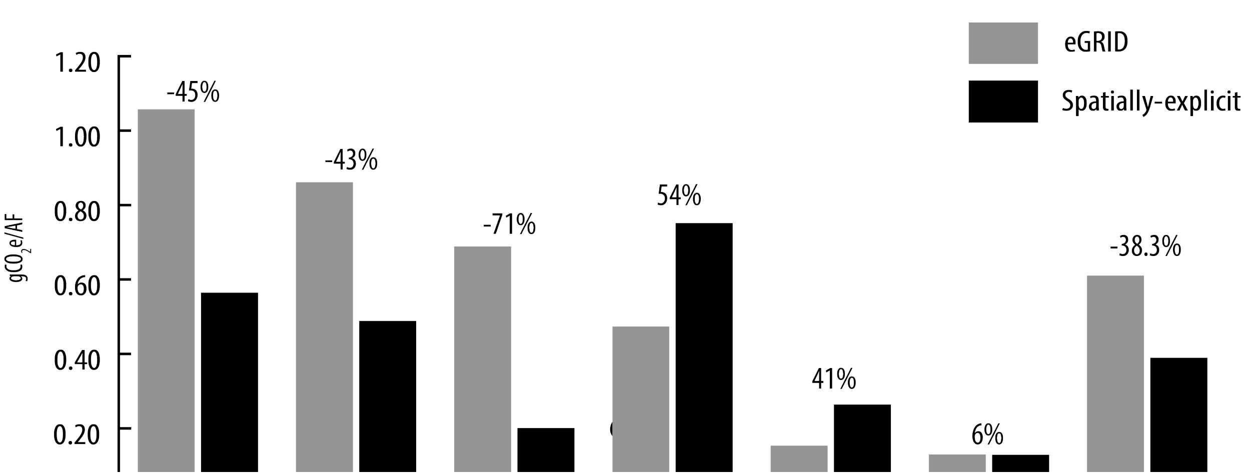
East Branch (3,459 KWh/AF) and the West Branch (2,817 KWh/AF). Water from the Colorado River (2,223 KWh/AF) is imported via the Colorado River Aqueduct (CRA) and requires five pumping stations to carry it to its terminus at Lake Matthews. In contrast, water sourced from the Eastern Sierra watershed and Owens River Valley via the LAA requires no net input of energy in the pumping and transport stages since the aqueduct is mainly gravity fed (230 KWh/AF). Other sources of water for southern California include local groundwater (726 KWh/AF) and recycled water from the San Fernando Valley (1,524 KWh/AF).

For all water sources combined, the transport stage represented 88% of the energy footprint, followed by distribution (10% of the total), and treatment (2%). Part of the reason for the enormous transport footprint is Los Angeles's reliance on water supply from two major sources—SWP (56% of total water supply) and CRA (7% of total). By contrast, the gravity-fed LAA aqueduct has no transportation footprint. Local recycled water has a large treatment footprint as the water has to be made potable. In our study, we did not do specific modeling for different types of treatment technologies for recycled water (i.e., stormwater vs. industrial); these are likely to have differing energy footprints, but with important implications due to the desire of water utilities to increase the portion of recycled water in the overall water supply portfolio.

Although we only looked at these three phases, other studies of cities with remote water supply sources indicate a similar profile for the transport stage (Stokes and Horvath, 2009; Wilkinson, 2000). This is in contrast to many other resources and products such as food (Basset-Mens and van der Werf, 2005; Weber and Matthews, 2008) and forest products (Gower, 2006; Newell and Vos, 2011; Subak and Craighill, 1999) that indicate that transportation emissions are a comparatively small portion of overall emissions. These latter findings counteract "buy local" narratives that pervade discourses about local food, which by overemphasizing transport as an emissions source, conflate "greenness" with local sourcing. In the case of water, however, the water–energy nexus presents a complicated relationship between energy emissions and the collection, treatment, transport and disposal of water across geographic space.

2.4.1. eGRID vs. Spatially-explicit accounting methodology

In terms of the emissions, the results of our spatially-explicit approach yielded a 38% lower emissions footprint than the eGRID approach (Fig. 9). It significantly reduced the emissions burden of water sources supplied by MWD, but increased the emissions burden of those sources supplied by LADWP. It was especially higher for groundwater (41%) and recycled water (54%);



this is due to the relatively dirty grid mix of LADWP as compared to the cleaner eGRID average and grid mix of MWD where over 50% of Los Angeles's supply comes from. In particular, recycled water had a greater emissions footprint per acre-foot than water from the Colorado River. This highlights the relative importance of energy supply sources for the particular utilities, so much so that it outweighs the energy intensity of long distance transport of water from the Colorado. The results support the findings of Weber et al. (2010), which demonstrate how electricity emissions can vary depending on the spatial scale adopted, from nation, state production, state consumption, to eGRID subregion, and based on Energy Information Administration data.

2.4.2 Opening up the Black Box

At a more general level, what this relatively simple calculus reveals is how decisions such as system boundary delineation and degree of areal differentiation incorporated into activity data and emission factors can significantly alter the result. The comparative analysis of the eGRID approach with our spatially-explicit model exposes how geographic variability in Los Angeles's water supply sources (re)shapes the emissions profiles for each supply source and illustrates the challenges of calculating precise carbon footprints. The approach reveals the indeterminacy of the overall footprint of water whereby assumptions (the non-spatiality) about the grid mix shape the result. The relative neglect of spatiality into LCA exemplifies how assumptions about the focus of scientific inquiry are often built into the models explaining it (Jasanoff, 2004), much like critical geographers have shown for obesity (Guthman, 2011), and often reflect the economic and political motivations that shape how spatiality and system boundaries are negotiated and created.

In this regard, our method offers a "hatchet" by providing a critique of conventional LCA approaches, but also offers a "seed" by stressing alternative ways to understand and measure urban metabolisms in Los Angeles and beyond (Robbins, 2012). This seed is not limited to improved, albeit more contingent, carbon accounting due to better areal differentiation through the LCA–GIS coupling. Rather, the insertion of spatiality into LCA provides an opportunity to point towards the spatial location of "hotspots," or the life-cycle phase with the greatest social and environmental impacts, along the supply chains. Similarly, spatially disaggregating carbon emissions can point towards important socio-economic differences among and between urban populations and point towards policy and outreach that targets those populations most responsible for carbon emissions. As such, these empirical observations open up a set of intellectual possibilities that allow the mapping out and contextualization of the key phases, network agglomerations, and hotspots associated with a political ecology of urban water metabolisms. If combined with GIS and theoretical framings such as those found in UPE, the LCA method has the potential to be used and deployed for progressive purposes rather than as a narrowly conceived and technocratic device in the promotion of ecological modernization (Desfor and Keil, 2004).

To further link the results of the LCA with political ecology, we turn to an analysis of the least energy intensive water supply sources and those central to Los Angeles's vision for enhanced urban ecological security: the LAA and local sources (groundwater and recycled water). Both of these supply sources, if viewed only through the lens of carbon emissions, would be the preferred choices from which to acquire and to develop future water supplies. However, using a carbon calculus to guide transitions to a more sustainable water supply is not so simple.

We argue that the insights of UPE help to move beyond the limited scope of an LCA perspective to urban metabolisms.

2.5. The UPE of Los Angeles's water supply metabolism

Throughout its development, water has featured prominently in Los Angeles politics and the formation of its geographies. How the socio-technical systems tasked with conveying water came into being, however, reflect the diverse ways that the social histories of place, networks of power, and discourses of development are implemented and fought over at specific sites and times (Sultana, 2013). As such, the water supply metabolism of Los Angeles cannot be understood outside of this context. We situate our analysis within the historical and geographical networks of power, people, and institutions that emerge to reshape Los Angeles's hydro-social metabolism. The approach challenges dominant explanations and proposes alternatives on how infrastructures and GHG emissions come to matter politically (Forsyth, 2003; Furlong, 2010; Meehan, 2013b). In this section we provide a brief history of the development of the LAA. We then direct our focus to current shifts and transitions in the governance of Los Angeles's water supply to reflect on historical and contemporary political ecologies of urban water.

2.5.1. LA Water: a brief history

On November 5, 1913, William Mulholland (in)famously proclaimed, "There it is. Take it." as water flowed through the LAA toward Los Angeles. For some, this was the instant that the modern city of Los Angeles was materially forged (Ulin, 2013). The socio-technical systems conveying water to Los Angeles, however, were discursively set into motion as early as 1904 when LADWP released its first report stating that "the time has come when we shall have to supplement the supply from some other source" (Klusmire, 2013; Reisner, 1986). By 1905, in an imperial quest for more water, city representatives began venturing to Owens Valley to buy parcels of land from local residents (McWilliams, 1949; Stringfellow, 2013). As McWilliams (1949) notes, Los Angeles had plenty of water, but speculation of future population growth fueled this water imperialism. Indeed, it was a project "founded in prospect," designed to meet the demands of an imagined future rather than the needs of the present (Kahrl, 1982).

The story of the LAA and the construction of large-scale technological infrastructures to convey water to Los Angeles's is well-documented (Kahrl, 1982; McWilliams, 1949; Reisner, 1986), but salient for this paper is how the transformation of Los Angeles's hydro-social environment involved the rolling-out of large socio-technical systems, producing new natures and new waterscapes by altering the flow, availability, and value of water in the process. The construction of the LAA certainly created new opportunities for long-term capital investment in Los Angeles, but the infrastructure also provided a key innovation that accelerated and structured the material metabolism of Los Angeles while increasing its presence and control over greater expanses of its hinterland. The production of this socio-nature emerged out of an uneven configuration of social, cultural, economic, and political power relations that reshaped Los Angeles's hydro-social metabolism.

Water scarcity issues were discursively constructed as the collective challenge facing California. This deflected attention away from issues such as social justice, land distribution, and the environment in places like Owens Valley while benefitting an elite syndicate of individuals in the San Fernando Valley. Negotiations over land and water rights between representatives of the City of Los Angeles and 1,800 farmers and town lot owners between 1905 and 1935 resulted in the acquisition of 95 percent of the farm acreage and 88 percent of the town properties in the

Owens Valley (Libecap, 2005). This enabled the City of Los Angeles to capture and control ever greater catchments of water resources, but the urban water metabolisms also disabled the social and environmental conditions of those residing in the Owens Valley.

However, an overlooked aspect of the development of the LAA was the role of hydropower. When Fred Eaton first ventured into Owens Valley, he was fully aware of the hydo-electrical potential an aqueduct would serve and oversaw that the LAA was designed to capture the economic aspects that would accrue if the potential of hydropower was realized (Kahrl, 1982). At the time, engineers estimated that the LAA would be capable of generating energy in excess to that being consumed in Los Angeles and neighboring cities (Kahrl, 1982). This economic potential of hydropower was not lost on Mulholland while pushing the project when he stated to the people of Los Angeles "I believe that the people have in the possible power development from the aqueduct an investment which 20 years hence will turn back to the city treasury the entire $24.5 million provided for the construction of the aqueduct with interest" (Heinly, 1910, 595).

Mulholland's vision to bring the water of the Owens Valley required a re-scaling of the "networks of interests" (Swyngedouw 2007) where the political and economic elites of Los Angeles could envision the potential of forging new spatial links between Los Angeles, the Owens Valley, and the San Fernando Valley. The primary focus beyond supply and economic development was the enviable fact that the water flowed "downhill." The metabolic inputs and outputs of energy and waste influenced the discourse driving the historical development Los Angeles water supplies and provides the historical linkage to the urban metabolization of water, carbon, and energy.

A similar logic focused on the water-energy nexus guides current efforts by the City of Los Angeles to reduce its reliance on imported sources of water while shrinking its carbon footprint. From the perspective of the carbon calculus, the LAA emerges as the most desirable form of water supply in terms of energy intensity and emissions burdens, but the lasting social and environmental justice issues bring into question the overall sustainability of such a project. A new scalar vision is currently re-shaping urban water infrastructures and metabolisms, which we turn to next.

2.5.2. Urban Ecological Security

In May 2008, the City of Los Angeles released the blueprint for their Water Supply Action Plan, titled *Securing L.A.'s Water Supply*. The emergent logic centers around increasing local water resources through an approach that includes investments in new technologies, rebates and incentives, the installation of "smart" technologies such as sprinklers, washers and toilets, long-term measures to expand water recycling, cleaning local groundwater supplies, and decreasing reliance on imported water (Villaraigosa, 2008). The goal of the program is to meet new water demands of 100,000 acre-feet per year through a combination of water conservation and water recycling programs. Other water supply initiatives, at a cost of roughly 10% of LADWP's annual budget, include stormwater capture, restoring the San Fernando Groundwater Basin, expanding groundwater storage, outreach, and expanding and enforcing prohibited uses of water (LADWP, 2013a).

These projects mark a transition from regional infrastructures to a distributed water framework that entails a re-scaling of ecological resources and infrastructures primarily through a market environmentalist framework to tackle both environmental and economic problems

(Bakker, 2005; Hodson and Marvin, 2009; Swyngedouw, 2013, 2007). The goals, according officials is to blend opportunities for economic growth with efficiency gains in water and energy use and environmental conservation to more adequately manage water resources at a local level to increase water independence and reliability. The allure of these type of frameworks, as Bakker 2005 543) suggests, "lies in the promise of simultaneously addressing and mobilizing water scarcity, in the pursuit of continued economic growth." The techniques utilized to support these water supply initiatives include cost-benefit analyses to direct funding, but also carbon footprint calculations to evaluate climate change adaptation and mitigation goals. What is unique in this approach is the recognition of the link between new investments in water supply infrastructure and GHG emissions.

A number of other regulatory, climatic, and political changes are also driving the development of local water sources and conservation measures (Hughes et al., 2013). Recent regulatory restrictions on importing water from the San Joaquin and Sacramento River deltas, for example, are driven by the enforcement of the Endangered Species Act to protect Delta smelt. However, other regulatory restrictions are the outcome of the LAA's lasting social and environmental impact on the Owens Valley. Owens Lake, which dried up as a result of losing its source to supply Los Angeles, is now a salt flat and major environmental justice issue causing respiratory problems in the nearby town of Lone Pine (Siegler, 2013). After extended litigation with local communities in the Owens Valley, the city finally agreed to the Owens Lake Dust Mitigation Project, but it requires up to 95,000 acre-feet of water annually, or roughly the same amount of water consumed by San Francisco each year, at a cost of $1 billion dollars a year (LADWP, 2013b). The Water Resources Control Board Mono Lake decision also limits the ability of LADWP to import water from the Mono Basin by requiring water to be allocated to restoring streams that fill Mono Lake (Villaraigosa, 2008). This reallocation of water for environmental mitigation and enhancement reduces the delivery of water from the LAA to roughly one-third of LADWP's supply (Villaraigosa, 2008). LADWP, however, continues to fight the regulatory drivers forcing the city to use water from the Sierras to control dust on the dried up Owens Lake (Sahagun, 2013).

Climate change is also presenting a challenge to water managers in Los Angeles by creating uncertainty in predicting future supply. Increased temperatures and weather extremes, reduced snow pack, and sea level rise are all likely effects of climate change in California (CDWR, 2008). Adding the effects of climate change to ongoing drought conditions, researchers say, is likely to cause severe decline in runoff with shortfalls in scheduled water deliveries (Ackerman and Stanton, 2011). The future amount of water available for human consumption is not likely to be the same, nor is it likely to be a linear projection of past trends. The Colorado River has undergone an historic drought that has brought increased attention to its changing hydrology and the potential climate change impacts on water supplies (CDWR, 2008). The coming together of a climate and water crisis is provoking city leaders to take bold actions to reduce carbon emissions and adapt to future changes (Villaraigosa, 2007). As multiple city officials noted, "reliability not sustainability" is often the driving motive to rework water supply systems and advance what appears on the surface to be more sustainable technologies that can drive mitigation and adaptation to climate change.

However, at the intersection of climate change and regional conflicts over water resources, a series of centralized and decentralized strategies emerge as a potential fix to the recurrent uncertainties surrounding water supply. Water capture and recycling technologies are technological fixes to overcome Los Angeles's water supply deficit, ones that allow policymakers to temporarily avoid serious consideration of the many long-term trade-offs between different values and uses of water such as future development and growth. As one water manager noted, "we all want more recycled water … we've [LADWP] been planning it, and [the increase] in recycled water is not necessarily a supply issue but part of an ongoing approach to accelerate local supply goals related to city policy that wants to reduce dependence on outside supply [from MWD]." With population growth expected to increase by approximately 367,300 new residents by 2035, meeting the future demands in supply that inherently accompany development and growth with local sources will allow the city to become more self-sufficient in water provisioning on a city scale (LADWP 2010a). The approach will also lead to considerable savings for LADWP as Los Angeles will be able to reduce the costs associated with purchased water from MWD as the city reduces external reliance on supply and builds up local centralized and decentralized systems. While guided by a market environmentalist framework, the socio-technical strategy combines ecological and water security priorities into LADWP's attempts to assure development and economic growth and build more resilient infrastructures.

Furthermore, the rolling-out of new technologies to supply water may also compound the water–energy nexus. As our analysis shows, the pumping of local groundwater supplies and recycling water are both more energy intensive than water conveyed by the LAA. Capturing water may present a means to secure more local water supplies, but the cleansing and recycling of the water for potable use may lead to an increase in carbon emissions. The outcome is an ironic situation whereby proposed solutions to water scarcity caused by climate change actually contribute to and potentially exacerbate the conditions creating climate change. One water manager said, "recycled water, in terms of energy, can be competitive with SWP," but tradeoffs inevitably emerge between maintaining a reliable supply and mitigating carbon emissions. This is especially true with respect to proposed desalination plants that increase local water capacity, but are highly energy intensive (LADWP, 2010). As another prominent water manager stated, "stormwater recharge and recycled water is certainly less intense than the CRA, but you still have to pump it back out with the well…It's actually more cost-effective to do groundwater desalinization [than recycled water]." Local groundwater supplies may certainly be less carbon intensive than water from the CRA, but in Los Angeles recycled water supplies become more energy intensive when emissions are made spatially-explicit and demonstrates the needs for more robust and spatially-explicit data for decision-making.

However, relying solely on the least energy intensive source of water presents a different set of planning contradictions. Water sourced from the LAA, for example, may present the least energy intensive form of water supply, but it is also a source permeated with a history of social and environmental injustices—past and present. From the "empire builders" who conspired to take Owens Valley water to the continued struggles over how to mitigate the environmental damages caused by diverting water out of the Owens Valley, the LAA continues to play a controversial role in the water politics of Los Angeles. The LAA is also a less resilient form of infrastructure due to seismic risk and reduced reliability on the snowpack in the Eastern Sierra (Davis and O'Rourke, 2011; LADWP, 2010). Reductions in the water conveyed to Los Angeles via the LAA due to environmental mitigation have the consequence of increasing Los Angeles's reliance on imported supplies from the SWP and the Colorado River through the CRA. The outcome increases Los Angeles's reliance on more energy intensive water supplies imported from MWD, thereby raising the overall energy intensity of Los Angeles's water supply.

Beyond efficiencies, however, water managers say that water recycling, stormwater capture, and other approaches to increase supply locally are generally always a money issue. In order to direct the funding of projects, LADWP has developed, or is developing, a range of master plans on topics from recycled water to stormwater to point towards what water managers describe as "all of the low hanging fruit." According to one official, projects for stormwater are likely to lead to some large centralized projects because "most rain falls in two weeks of the year and the city needs to grab large chunks of water." The goal, as another official noted, "is to go where the water is and develop centralized projects to capture it." For large-scale water managers in Los Angeles, these local solutions make the most economical sense—at least in the short term—and are indicative of the logic guiding urban environmental governance and management in Los Angeles.

2.6. Conclusion

Our analysis demonstrates the shortcomings of undertaking solely a LCA for a problem that is spatially complex and enmeshed within a set of socio-political and historical processes that have shaped Los Angeles's water supply metabolism. Typical IE assessments focus narrowly on the stocks and flows of resources, such as water, coursing through the city, thus restricting itself to mass-balance approaches and improving efficiencies of resource use while often ignoring the social, political, and historical processes that (re)shape urban metabolisms (Gandy, 2004; Keil and Boudreau, 2006; Newell and Cousins, 2014; Swyngedouw, 2006b). Rather than critiquing LCA as an aspatial and technocratic tool of ecological modernization, we harnessed the method to map out and think through the complex assemblages associated with conveyance, treatment, and distribution of water in Los Angeles. We argue that combining LCA with GIS not only spatializes the metabolic flows that assemble the city, but also provides an opportunity to link conventional IE approaches that focus on inputs and outputs to the political ecology of resource metabolisms. This political-industrial ecology broadens considerations of metabolisms, urban or otherwise, by being attentive to the quantifiable metabolic inputs and outputs of products and processes and how they are shaped by politics, history, and social power.

Provided the concerns of geographers in understanding the multiple dimensions of environmental change, establishing a political-industrial ecology provides an exciting opportunity to develop and consider sustainable transitions. Political ecologists have provided trenchant insights into the structures of power that shape relationships between nature, society, and technology (Birkenholtz, 2013; Heynen et al., 2006a; Meehan, 2013b), and the scalar and geographic dimensions of environmental decision-making (Cohen and Bakker, 2013; Heynen, 2003; Lawhon and Patel, 2013). We propose that by extending these insights to approaches in industrial ecology the field can provide important analyses to foster more sustainable and resilient futures. The challenge for future research is balancing between the social and political dimensions of environmental change and analysis and measuring the material impacts of (re)configuring urban metabolisms. As we have shown, utilizing the metabolism metaphor to engage with the strengths of IE and UPE provides a starting point for this type of analysis through a commitment to examine the social and political aspects of urban metabolisms, as well as their physical and quantifiable aspects. With few geographers engaging in this type of research, we see great potential for expanding these insights into wider investigations into the political and economic aspects shaping how geographic complexity is included, excluded, negotiated, and communicated in the production, application, and circulation of LCAs, in the development of spatially robust LCA–GIS analyses, in considering how politics, history, and social practices shape metabolic inputs and outputs, and as an important means in which to link political and industrial ecology to develop a political-industrial ecology.

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Chapter 3: Stormwater and the Politics of Urban Metabolism[3]

Abstract

This paper engages with emergent conceptualizations of political–industrial ecology to understand the politics surrounding how the volume, composition, and material throughput of stormwater in Los Angeles is calculated and applied by experts. Stormwater remains a fragmentary object of governance, however, just like the bureaucratic institutions assembled to control and manipulate its flows. For some, stormwater is a nuisance, flooding homes and polluting waterways, while for others it is a beneficial resource yet to be harnessed. The intent of this paper is to understand the technopolitical efforts designed to transform stormwater from a hazard or flood control problem into a resource. Specifically, it seeks to understand how the active processes of calculating the metabolic inflows and outflows of stormwater in Los Angeles serves as a way for the city to render value to the material flow of stormwater. The intent is to draw attention to the ways urban metabolisms are calculated in practice, what they do and do not include, and the role this plays in shaping resource governance. This process, I argue relies on understanding how stormwater management reflects the various forms of technical expertise, environmental conditions, cultural and political discourses, and social groups that are enrolled in its management. While the categories for liability and responsibility remain contested over time and space, it is shown that stormwater in Los Angeles needs to be understood in relation to the

[3] This chapter has been re-submitted to *Geoforum,* for a special issue, after favorable reviews.

ecological systems and scientific, political, and cultural practices designed to make it into a resource and align with existing patterns of growth and development.

3.1. Introduction

From droughts to deluges, the proliferation of water resource challenges associated with urbanization, climate change, and shifting patterns of population and consumption are creating new forms of water governance (Bakker, 2014; Eakin and Lemos, 2006; Gleick, 1998). Ongoing drought conditions in California, for example, has brought stormwater to the fore of policy-making as an underutilized resource instead of a nuisance or hazard to human and ecological health. In California, stormwater has primarily been managed as a flood control problem with over 1,300 local agencies—comprised of over 40 different governance arrangements—responsible for its management, including the Los Angeles County Department of Public Works, the Los Angeles County Flood Control District (LACFCD), and the City of Los Angeles (California DWR, 2013). This highly decentralized system across scales and functions of government created a spectrum of stakeholders competing to leverage their influence on policy making by narrowly focusing on specific issues of the problem (Hanak et al., 2011). Stormwater's rise to policy relevancy in time of drought, however, is emblematic of a broader shift in water resources management that advocates for more holistic and integrated methods to overcome the fragmented and complicated nature of water resource governance. In this paper, I examine the unfolding relationship between the volume and material flow of stormwater and the social, political, and technical practices involved in identifying stormwater as a "new" and underutilized water resource in Los Angeles.

To understand the shifting paradigm of stormwater governance in Los Angeles I engage with emergent conceptualizations of political–industrial ecology (PIE) (Cousins and Newell, 2015; Newell and Cousins, 2015). The framework is used to examine the social and political processes surrounding how the volume, composition, and material throughput of stormwater is calculated and applied by experts in order to make it into a resource. The metabolism metaphor has proven useful to explore the boundaries between political and industrial ecology. Industrial ecology applies the metaphor to describe cities as a particular type of industrial ecology, where the city is interpreted as a system of interconnected material and energy flows coursing into and out of the city (Castán Broto et al., 2012; Kennedy et al., 2011; Pincetl et al., 2012b). The aim of many of these studies is to measure and quantify the "stocks" and "flows" of the urban metabolism and inform strategies to optimize resource use (Baccini and Brunner, 2012; Haberl et al., 2004; Hodson et al., 2012). In contrast, political ecology uses metabolism to highlight how urbanization and the economy are characterized by the transformation of natural resources into commodities, infrastructures, and wastes, which are unevenly distributed—both socially and geographically (Newell and Cousins, 2015; Swyngedouw, 2006b). The goal for many urban political ecologist's is to reveal the political economic regimes, governance structures, and power relations conditioning the uneven geographical organization of urban metabolisms (Arboleda, 2016; Gustafson et al., 2014; Heynen, 2006b). At its core, the formulation of PIE offers, on the one hand, a relational way to map out and account for the composition, volume, and metabolic density of material flows, while on the other hand, a way to highlight the political and historical processes surrounding the production and governance of metabolic flows (Cousins and Newell, 2015).

In this paper, I suggest that PIE offers an approach to understanding how "new" types of resources form through an ongoing process that (re)arranges human, institutional, technological, and natural relationships. By extension this means paying attention the deployment of technology and technological expertise to achieve political goals, or what scholars broadly refer to as technopolitics (Freidberg, 2014; Hecht, 2009; Mitchell, 2002). Specifically, the paper examines how urban metabolisms are deployed as a volumetric approach to stormwater governance that achieves water conservation, security, and reliability goals. One of which is developing stormwater as a "new" form of supply (Carle, 2016; Gordan, 2016; NRDC, 2014a). I argue that this has relied on technopolitical interventions organized around overcoming problems related to the volumetric variability of water flowing and circulating into, through, and out of cities. I refer to this form of water governance as volume control.

The article's findings are based on archival research and over 40 in-depth interviews with water resource managers, engineers, city planners and officials, water suppliers, NGO representatives, and policymakers; attendance at conferences and workshops devoted to stormwater; and review of policy documents and reports. The following section places PIE in relation to other scholarship on socio-material flows, circulations, and metabolisms. In particular, it focuses on the utility of a PIE perspective to engage with the volume and circulation of material flows, as well as the social, political, and technical aspects of calculating and governing material flows. Section three provides historical details of stormwater management that inform the ways stormwater is problematized. This is important for providing context to the subsequent section, which shows how current institutions of water resource governance geared towards developing stormwater as a resource emerge from, but are also enabled and constrained by, past efforts to address water quality and quantity challenges. In other words, stormwater is shown as a problem and solution to ongoing efforts to address these water resource challenges. Section five then explores how the urban metabolism of stormwater is calculated and applied by water resource managers to govern stormwater and promote it as an underutilized resource capable of supplying adequate volumes of water to urban populations.

3.2. Political–industrial Ecology and Socio-Material Flows and Circulations

Concepts such as metabolism and circulation figure prominently in (urban) political ecology and resource geography to describe environmental change as a process of social and material transformation, or what scholars refer to as socio-material change (Lawhon and Murphy, 2011; Swyngedouw, 1996; Whatmore, 2006). Like other hybrid concepts, such as socionatures, socio-material connotes the coproduction of the natural, or material world, and society (Barnes, 2014; Castree, 2002; Swyngedouw, 1996). In other words, these concepts help scholars recognize diverse forms of human and non-human agency and interaction. Largely influenced by science and technology studies and various post-structural and post-humanist theories (e.g. DeLanda, 2006; Deleuze and Guattari, 1987; Foucault, 2007; Latour, 2005), a goal within much of this research is to show how resources such as water, oil, trees, and land are not simply "natural things" but are also "irreducibly social" in their ability to enable or constrain political and economic relations (Bakker and Bridge, 2006; Bridge, 2009; Latour, 2004a; Li, 2014).

A focus on the socio-materiality of resources foregrounds a relational perspective that brings attention to the assemblage of human and non-human ideas, capacities, and actions that shape social-ecological relationships (Farías, 2011; Karvonen, 2011; McFarlane, 2011; Swyngedouw, 2006a). Lawhon (2013), for example, identifies sources of "friction" (e.g. spatial configuration, regulation and enforcement, social norms, values and identity, biophysical limits and financial constraints) that reveals, but complicates, the distributed and unequal power relations that shape the circulation and metabolism of resources. Similarly, Anand (2011) develops the concept of "pressure" to understand how social and material claims are made to urban water infrastructure through heterogeneous relationships between political technologies, such as laws, as well as the politics of technology. Other scholars, such as Ranganathan (2015), have focused on the tensions between "flow" and "fixity" as a way to reveal the relational politics that assemble storm drains and produce urban flood risk. Yet others have shown the uncooperative nature of resources to commodification (Bakker, 2003b; Prudham, 2003; Sneddon, 2007). Despite diverse theoretical engagements, a common trend among research into socio-material politics is a focus on the biophysical characteristics and heterogeneous elements of the material world that enroll expert knowledge claims and technologies to render nature visible and governable (Landström et al., 2011; Latour, 2004b; Li, 2007a; Mitchell, 2002; Scott, 1998).

Yet despite substantial research into the socio-materiality of nature within (urban) political ecology, many questions remain largely unexplored. For example, how much of a resource—at what volumes, densities, masses, or qualities—flows and circulates through a system, urban or otherwise? In other words, what is the volume and structure of socio-material flows and how might geographical research better account for social and material flows simultaneously? Typically when urban political ecologists engage with the actual volumes, weights, units, or quantities of socio-material flows they inform critique, not analysis. Swyngedouw (2006), for example, points towards the industrial ecology accounting of Toronto's urban metabolism as an uncritical exercise—useful in its quantification, but lacking in its ability to do more than simply pose the issue of resource consumption. While I agree with Swyngedouw that industrial ecology inadequately theorizes processes of urbanization and the transformation of nature, one is left wondering to what extent the actual mass, density, or volume of urban metabolic throughput matters in shaping socio-material flows and social-ecological outcomes. Similarly, the more quantitative approaches taken by scholars, such as Heynen (2006), typically portray the metabolization of nature in terms of land use land cover change across an area or spatial extent. Although this work is incredibly useful and important for understanding the relationships between economic, cultural, and political processes in shaping environmental change, work in this tradition needs to equally consider the politics of circulation and metabolism in terms of the volumes of resources that flow, are captured and secured, or are transformed (Bridge, 2013; Elden, 2013). As (Elden, 2013, p. 49) notes, "volume matters because of the concerns of power and circulation." PIE offers just one avenue to explore the volume and structure of socio-material flows, as well as the technopolitical practices utilized to measure, control, and contain the volume of flows of materials and commodities.

Emergent scholarship working at the intersection of political ecology and industrial ecology, as well as ecological economics, is providing a potential means to better account for the complex relationships between social organization and material flows (Kallis et al., 2013; Martinez-Alier et al., 2010; Newell and Cousins, 2015; Pincetl et al., 2012b). Approaches to combine these fields of study are at times complementary, other times integrative, and yet other times critical (Breetz, *in review*). For example, Baka and Bailis (2014) integrate industrial ecology methods and political ecology perspectives through a comparative energy flow analysis that examines the energy security impacts of growing biofuels on potentially marginal lands. Similarly, Bergmann and Holmberg (2016) utilize a multi-regional input-output model to relationally examine and quantify the connections between land and distant populations mediated through globalized production networks and exchange. Yet other scholars take a more critical approach to their engagement with industrial ecology, or what might be termed critical industrial ecology (Bridge and Jonas, 2002; Huber, 2010). Freidberg (2014), for example, analyzed how life cycle assessments (LCA) form the basis of a "footprint technopolitics" centered around the ways corporate food retailers and manufacturers utilize footprints to govern supply chains and promote ideas of sustainable food. Beltrán and Velázquez (2015) also take a critical approach to the virtual water concept to argue that it distorts understandings of socio-economic systems as simple material flows rather than complex systems. Other critical approaches include research into how the metrics of life cycle analysis obscure environmental justice impacts (Mulvaney, 2014) and the contribution eco-industrial parks may offer to sustainable development (Gibbs and Deutz, 2005). Still, other approaches remain more complimentary, such as Demaria and Schindler's (2015) utilization of urban metabolism as a way to focus on the actual material flows, as well as a means to contextualize conflicts over waste-to-energy transitions.

This paper expands upon this work by focusing on the ways experts have sought to control, manipulate, and manage the volume and material flow of water in order to organize it as a beneficial resource. In this way, my approach is both critical and complementary, as it seeks to understand the relationship between the actual volume and composition of material flows, as well as the social contexts in which urban metabolisms are calculated, applied, and implemented to achieve water conservation, quality, security, and reliability goals. The following section traces the historical arrangement of laws, technical expertise, environmental conditions, cultural and political discourses, and social groups that assembled stormwater as an object of environmental governance, but also rendered it multiple things. The section shows how stormwater's variability in time and space has enabled and constrained attempts to bring it under control through efforts to map, quantify, and make the volumes of stormwater flows governable (Linton and Budds, 2014; Scott, 1998).

3.3. A Brief History of Stormwater in Los Angeles

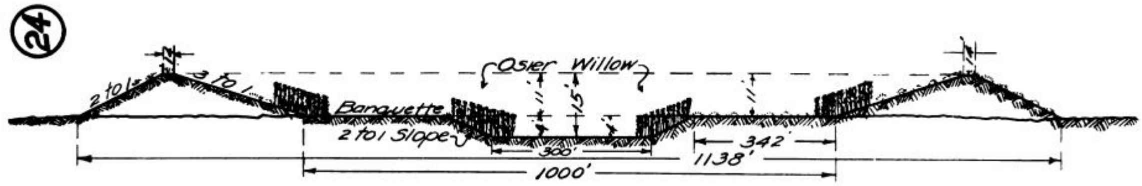
An elaborate and complex set of infrastructures provides Los Angeles with water supply and flood control. The engineering of Los Angeles's water infrastructure has focused on controlling how and where water flows by substituting a disorderly nature with a rationalized human landscape. The approaches Los Angeles would ultimately take to control and govern stormwater, however, are rooted in a complicated water rights system. Los Angeles asserted pueblo water rights following the Treaty of Guadalupe Hidalgo, which concluded the Mexican-American War in 1848, and recognized all property and water rights established under Spanish and Mexican Law (Hundley, 2001). By claiming pueblo rights, Los Angeles was able to secure water rights to the Los Angeles River and the runoff of the entire watershed, including the hydrologically connected groundwater in the upper Los Angeles River Basin (Hanak et al., 2011).

The specifics of flood control, however, can be traced back to the Gold Rush when hydraulic mining brought increased attention to flooding in the Sacramento Valley where mining debris clogged river channels, exacerbating the impacts of annual flooding on farmlands and communities (Hundley, 2001). Rather than placing responsibility with the state, however, California's legislature initially devolved responsibility for flood control to the counties, which took a localized and laissez-faire approach (Hanak et al., 2011). The logic was that farmers looking out for their own self-interest would provide the flood control needed to keep floodwaters off their plots. The most dramatic step the state would take in this era, however, would be the Green Act of 1868, which further decentralized the reclamation system by integrating swampland and public land laws into a single bill (Hundley, 2001). The passage of the act removed the ability for counties to examine the plans of individual reclamation districts and the rules on the number of acres of swamp and overflowed lands that an individual could purchase (Garone, 2011). This spurred the growth of localized reclamation districts by allowing landowners to join together to fund projects, but consequently promoted monopoly of landholdings (Hundley, 2001).

Early flood control in Los Angeles mirrored that across California, in that stormwaters were typically managed as floodwaters. While early floods, like the Great Flood of 1862, left considerable damage in their aftermath, it was not until the devastating and costly flood of 1914 that consensus among public officials and citizens galvanized to frame stormwater as an object of urban environmental governance (Los Angeles Times, 1914; Reagan, 1915; United States Army Corps of Engineers. Engineer Office, 1915). Despite lower volumes of stormwater runoff in the 1914 flood than in previous floods, the difference between the 1914 flood and earlier ones, Orsi (2004, p. 12) notes, is that "it struck a radically different ecosystem." The rapid urbanization of Los Angeles in the early 20th century increased the amount of impervious surfaces and placed development in floodplains, increasing the volume of stormwater runoff capable of inflicting damage. Flood responses prior to the flood of 1914 could not be more different either. Instead of relying on the fragmentary flood control efforts of landowners and small flood control districts, efforts shifted towards establishing a centralized authority capable of developing a comprehensive flood control plan for Los Angeles County (Orsi, 2004).

In the wake of the 1914 floods, a technopolitical order was institutionalized to address the "flood menace" (LA County Board of Engineers, 1915; United States Army Corps of Engineers. Engineer Office, 1915). In March 1914, the County Board of Supervisors appointed a team of engineers to devise a flood-control plan (ibid.). Reflecting the cultural and political atmosphere of the Progressive Era, the answer to overcoming the flood menace rested with the objectivity of experts (Orsi, 2005). In the year that followed, the engineers tasked with controlling the flow of stormwater through Los Angeles, mapped, measured, surveyed and calculated the volumetric throughput of stormwater—from the mountainous watersheds out to sea (LA County Board of Engineers, 1915). In effect, they were taking a volumetric approach to calculating the urban metabolism of stormwater as they crafted their system boundaries around the mountains and watersheds of the region and carefully projected future rainfall and the volume and velocity of runoff (ibid.). Based on their calculations, and numerous interviews with elders from the region depicting past floods, the appointed engineers concluded that Los Angeles would continue to experience damaging floods about every 3.25 years if they did not control the stormwaters (LA County Board of Engineers, 1915; Reagan, 1915).

Yet disagreement ensued over the best ways to manage the flows of water, with two competing visions of flood control emerging (Los Angeles Times, 1915a) . One, based on scientific and engineering rationality, focused on controlling segments of the watershed upstream (LA County Board of Engineers, 1915). The other, promoted by James W. Reagan, Chairman of Committee Upon Flooded and Menaced Areas, focused on downstream approaches and was based on numerous interviews with regional elders who shared their past experiences with floods in the region and their opinions on how to control the floodwaters (Figure 10) (LACFCD, 1917; Reagan, 1915; United States Army Corps of Engineers. Engineer Office, 1915). In the absence of consensus over a single best comprehensive flood control plan, the County Board of Supervisors agreed to both plans, designating a “majority report” based on the recommended strategies of the engineers and a “minority report” based on Reagan’s recommendations (Los Angeles Times, 24



Fall 825 feet per mile, or 1 in 640 S= 00156 N=.025

PLATE 29.

Depth in feet	Area in Sq. Ft	R.	Velocity Feet Per Sec.	Capacity Cu Ft Per Sec.
8.5	5793	5.6	7.6	44000
8.0	5280	5.1	7.1	37400
7.5	4769	4.65	6.7	31900
7.0	4259	4.20	6.3	26800
6.5	3751	3.70	5.7	21300
6.0	3244	3.20	5.2	16800
5.5	2739	2.70	4.6	12600
5.0	2235	2.20	3.95	8830
4.5	1733	1.75	3.35	8050
4.0	1232	3.90	5.9	7260
3.0	918	2.95	4.85	4450
2.0	608	1.97	3.65	2220
1.0	302	.99	2.25	680

Depth in feet	Area in Sq. Ft	R.	Velocity Feet Per Sec	Capacity Cu Ft Per Sec
15.0	12595	11.8	12.1	152000
14.5	12063	11.3	11.8	142000
14.0	11532	10.8	11.5	132000
13.5	11003	10.4	11.3	124000
13.0	10475	9.9	11.0	115000
12.5	9949	9.5	10.7	106000
12.0	9424	9.0	10.3	97100
11.5	8901	8.5	9.9	88100
11.0	8379	8.0	9.5	79500
10.5	7859	7.5	9.1	71500
10.0	7340	7.0	8.7	63900
9.5	6823	6.6	8.4	57300
9.0	6307	6.1	8.0	50500

Note: Banquette of Major Channel and inner slopes of dykes to be sodded to Arunda Arenia (Grass used for the protection of dykes in Holland)

The Sketch above is not drawn to scale.

The capacity of the channel at a depth of 4.5' is taken as the mean between the calculated capacities at 4 and 5 foot depths.

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Tentative Study of Cross-section of proposed Diversion River Channel for the combined waters of the Los Angeles River and Rio Hondo from the Stewart Bridge to Alamitos Bay.

Prepared for J W REGAN June 1915 C.X.J. Del.

Figure 10. Controlling flood volumes. This figure outlines a proposed flood control channel. As described by Reagan, the table in the figure "shows that floods with a volume up to about 7,000 cubic feet per second (which is a volume or stage not common, as the ordinary or common winter floods will be found to be below this volume, while the floods of the great inundating class are usually many times this volume) can be taken care of within the inner channel." *Source*: Reports of the Board of Engineers Flood Control to the Board of Supervisors, Los Angeles County California (1915).

1915a; Orsi, 2004). To carry out the plan, the Los Angeles County Flood Control District formed with Reagan as its first chief (Los Angeles Times, 1915b). Regardless of the political and technical differences, the development of a centralized authority and comprehensive plan helped set into motion the development of a "hydraulic society" intent on defining water resource challenges as technical problems to be solved by engineers (Hundley, 2001; Orsi, 2005; Worster, 1985).

Over the next 20 years the LACFCD remained dysfunctional and incapable of providing the amount of flood control desired to protect development and keep pace with economic growth in the region. As Orsi (2004, p. 77) notes "the 1914 vision of hydraulic order had mutated into a technocratic nightmare." As a result, the Army Corps of Engineers (ACoE) would join with the LACFCD in 1935 (Trask, 1936). With the passage of the Federal Flood Control Acts of 1936 and 1938 this partnership would bring technical expertise and leverage federal money towards establishing a hydrologic order through large-scale engineering projects focused on minimizing the loss of land for development (Mount, 1995). While alternatives did arise, the partnership with the ACoE would re-inscribe a technopolitical order leaving political and non-technical aspects outside their scope—in particular hazard zoning or the use of parks as flood control (Hise and Deverell, 2000). With the passage of the Flood Control Acts of 1936 and 1938 redefining the role of the ACoE to address flood control, the LACFCD and the ACoE would roll out a comprehensive flood control system known as the Los Angeles County Drainage Area (LACDA), which includes five flood control reservoirs, 90 debris basins, and 458 miles of improved channels (California DWR, 2013). Rather than devise a solution that used parks and nature for flood control, the more technical solutions of the engineers maintained developable land for the city's growing real estate market (Hise and Deverell, 2000).

The approaches discursively defined stormwater as a flood control problem, resulting in material changes on the landscape and a reworked hydrology geared towards mitigating flood risks, rather than capturing supply. The channelization of the Los Angeles River, for example, removed any semblance of its natural artifice in place for a flood control system intent on removing stormwater from the city as quickly and efficiently as possible (Figure 11). Flood control and water supply, however, were both assembled by marshaling the financial and technical expertise of the federal government, notably the ACoE, placing them in a tenuous and conflicting relationship that continues to this day. As both water suppliers and flood control managers have become more dependent on the utilization of multipurpose reservoirs their

Figure 11. The Los Angeles River near the LA neighborhood of Atwater Village. *Source*: Author.

objectives diverge, with flood managers relying on empty reservoirs to capture large volumes of runoff and storm flows while water suppliers desire full reservoirs to maintain reliable volumes of water supply during dry periods (Hanak et al., 2011). This combination of a nineteenth-century water rights system and twentieth-century infrastructure and management system rendered stormwater multiple things.

Furthermore, as the federal government provided the resources to dam and channel waterways between the 1940s and 1960s, the LACFCD undertook the development of spreading grounds for water conservation and the construction of storm drains—neither of which fell under the mission of the ACoE (Orsi, 2005). Prior to a 1952 bond measure that authorized the LACFCD to undertake a storm drain program the construction and operation of storm-drains were under the purview of municipalities (Morris et al., 2012). With the passage of a 1952 bond measure, and additional ones in 1958, 1964, and 1970, the Flood Control District initiated the construction of more than 2,000 miles of underground plumbing to convey large volumes of urban runoff into the concrete channels designed by the ACoE (LACDPW, 1996). Meanwhile, the spreading grounds gathered water diverted from flood control basins, where it then percolated into groundwater storage, despite flood control being physically and administratively separated from the politics of water conservation (Orsi, 2004).

Further complicating matters are three constitutional reforms—Propositions 13, 218, and 26—that severely limit the ability of local agencies to raise funds. Marking a major turn towards neoliberal governance, Proposition 13 capped local property tax rates, the principal source of funding for local government (Boudreau and Keil, 2001; McCarthy and Prudham, 2004; Simon and Dooling, 2013). Consequently many public agencies, including the LACFCD, saw their budgets slashed. With almost their entire budget dependent on these tax revenues, the LACFCD could no longer fully operate and maintain the LACDA, and they were eventually absorbed into the county's Department of Public Work in 1985. Furthermore, new tax increases to address stormwater challenges are unlikely due to Proposition 218, which requires any new or increased general tax or property-related fee to be approved by a majority or supermajority vote, while Proposition 26 raises voting requirements for most state and local regulatory fees from to a two-thirds majority vote (Hanak et al., 2011). This severely limits the flexibility of water utilities and public agencies to raise funds and address funding gaps, such as water resource planning.

While neoliberal reforms like Proposition 13 highlight the "rolling back" of public expenditures, more recent shifts towards integrated water resource planning is characterized by the "rolling out" of new institutions to address the limitations or failings of previous reforms (Peck and Tickell, 2002). These approaches enroll and assemble actors across multiple domains and functions of governance to consolidate environmental management. Notable is the Los Angeles Integrated Resources Plan (IRP). Adopted in 2006 the IRP brings together water supply, water conservation, water recycling, runoff management, and wastewater facilities planning through a regional watershed approach (LA City, 2014). The effort continues to broadly manage all types of water as "One Water" to facilitate projects capable of accruing multiple benefits, from cost-savings and water conservation to reductions in imported water supplies and managing runoff (LA City, 2015). Other programs such as Enhanced Watershed Management Plans (EWMP) and Integrated Regional Water Management (IRWM) also encourage more hybrid approaches to address deficiencies in water quality and quantity. These programs share a focus on watershed-scale analyses that are science-driven, market oriented, and participatory.

The historical legacy of stormwater management continues to influence and complicate current efforts geared towards organizing stormwater as a resource. From a fiscally constrained and fragmentary system of governance where actors disagree on the very definition of stormwater, to an infrastructural system designed to convey rather than capture volumes of runoff, stormwater continues to pose many challenges of governance. The following section builds on these insights to show how the problematization of stormwater centers on resolving constraints imposed by these historical circumstances as well as ongoing struggles centered on water quality and quantity.

3.4. Problematizing Stormwater

In Southern California, developmental pressures and ongoing concerns over drought, water supply, and water quality has drawn attention to stormwater, as both a problem and a solution to these ongoing struggles, but avoids many long-term trade-offs between different values and uses of water (Cousins and Newell, 2015). Problematizing stormwater, however, is not just about describing how and why stormwater becomes a problem, but also how problematization shapes governmental interventions aimed at developing solutions. Stormwater is part of a suite of emerging local water supply options in Los Angeles, but in order for stormwater to materialize as a resource, it needs to be acknowledged as a remedy to ongoing water resource challenges and constraints. In this section I focus on current issues that enroll stormwater as an object of concern to direct interventions aimed at achieving water quality and quantity goals.

3.4.1. Deficiencies in quantity and quality

Los Angeles is subject to significant challenges in maintaining reliable supply and improving water quality. Since the early twentieth century Los Angeles has put together and maintained a water supply metabolism that draws on local sources as well as imported sources from the Eastern Sierra Nevada Mountains, the Sacramento-San Joaquin Bay Delta, and the Colorado River. Increasingly many of these supply sources are progressively becoming more expensive for the Los Angeles Department of Water and Power (LADWP) to maintain, are becoming limited by legal and environmental regulations, and impacted by climate change. Water imported from the Sacramento-San Joaquin Bay-Delta through the State Water Project (SWP), for example, presents many reliability challenges due to pumping restrictions enforced through the Endangered Species Act to protect Delta Smelt and other regulations to protect the Bay-Delta ecosystem (MWD, 2010). As a response LADWP is looking to reduce their dependency on imported water supplies they purchase from MWD from 52% to 24% (LADWP, 2010). As one NGO official noted,

> We can't keep taking water from other places because we're crashing their ecosystems. These are critical ecosystems. The estuaries and the deltas mitigate climate uncertainties.

> They serve a function. We have to let them rebound, which means we can't keep stealing or buying their water. We can't do that, which means we have to be locally sustainable. (interview, NGO official 1, June 2014)

For many, taking water from the Colorado River or the Bay-Delta, using it once, and then discharging it into the ocean does not make sense, nor is it responsible. It is at this intersection, however, that stormwater becomes part of the solution. As an LADWP official noted, “We know we’re never going to get off of MWD water because we’re just too big, but let’s see how much we can do locally [through stormwater] and that’s what a lot of our recent planning has been about” (interview, April 2015).

Water supplied via the Los Angeles Aqueduct (LAA) is also facing reductions due to Owens Lake dust mitigation. After the construction of the LAA, Owens Lake lost its source to Los Angeles and now presents a major environmental justice issue in nearby communities such as Lone Pine (Cousins and Newell, 2015). According the United States Environmental Protection Agency (EPA), the highest levels of particulate matter measured at the PM-10 standard in the US reside in the Owens Valley (EPA, 2015a). Particulates at the PM-10 standard are 10-microns or smaller and are particularly hazardous to human health; capable of penetrating deep into the respiratory tract. In 1999, the EPA approved a plan for LADWP to control dust at Owens Lake (LADWP, 2013b). LADWP primarily uses flood control measures as part of their Owens Lake Dust Mitigation Project, but it requires up to 95,000 acre-feet of water annually at a cost of $1 billion dollars a year (LADWP, 2013b). This has facilitated LADWP to develop other water sources locally and overcome supply issues by finding alternative methods for mitigating dust, such as using tractors to turn moist lake bed clay into furrows and clods of dirt (Sahagun, 2014).

Groundwater contamination in the San Fernando Basin also presents significant challenges. LADWP, for instance, suspended groundwater pumping from highly contaminated regions, which has reduced pumping in the San Fernando Basin by 40% (LADWP, 2010). To increase local groundwater production, however, more stormwater must be captured and infiltrated. Without a clean basin, a city official notes, "the full potential of stormwater is unlikely to be realized." The official goes on to state,

> The San Fernando Valley can infiltrate like crazy. [But] not everywhere, [because] it's got contamination problems… [But] we are trying to capture [stormwater] and infiltrate it because we have huge storing capacity in the San Fernando Valley… and we have a lot of sandy soils in the washes where the rivers and streams come off of the mountains and you have ideal soils for percolation, storage, and pumping back up. (interview, June 2014)

For this manager, and many others, the San Fernando Valley is the "biggest storage tank" for the City of Los Angeles and it needs to be made a functional asset again. With rights to pump 87,000 AF/year from the San Fernando Basin, cleaning up the basin to enhance stormwater capture is an important means to secure adequate volumes of water and maintain reliable supplies.

Increasing exposure to climatic changes, including droughts and floods, also problematizes traditional water supply sources and has driven LADWP and other water agencies to weigh in on the increasing uncertainty for water supply and quality, flood management, and ecosystem functions wrought by climate change in the region (Cousins and Newell, 2015; Hughes et al., 2013). Water resource managers acknowledge that climate change is already affecting water resources in California, as evidenced by changes in snow pack and river flows, and is leading managers to take bold steps to reduce GHG emissions and find new supplies, especially in the face of ongoing drought. For example, significant and ongoing investments in monitoring, researching, and understanding the connection between a changing climate, water resources and the environment are leading many officials to tout stormwater as an adaptation strategy. As one water resource expert claimed,

> [with] climate change, we're going to see more severe flooding, more peak flows and [green infrastructure] practices are a great way to address some of that and reduce the amount of flooding that may damage a property, but with the drought there is also a water supply connection and in Southern California in particular [stormwater] has a greenhouse gas and climate change connection because if I can capture the runoff here and supply it locally we don't need to import the water. You reduce energy use. (interview, NGO official 4, June 2014)

It is at this intersection of climate change and uncertainties over water resources, however, that a series of centralized and decentralized strategies to capture stormwater emerge as a potential fix to recurrent water supply dilemmas, but delay important policy decisions that explore the long-term trade-offs between different values and uses of water such as future development and growth (Cousins and Newell, 2015). Other questions also remain on who owns the groundwater rights.

Many of the short-term challenges to water supply reliability also entail efforts to address deficiencies in water-use efficiency and water conservation. While improving efficiency and conservation goes beyond stormwater to include recycled water and other forms of water, the challenges for water supply agencies like LADWP and MWD are in reducing demand. Part of that is driven by State imposed conservation goals to reduce demands by 20% by 2020, but it is also an important means for LADWP to address deficiencies is water supply reliability (LADWP, 2010; MWD, 2010). LADWP implemented a two-tiered rate water structure and programs to provide incentives to install efficient technologies such as low-flow toilets, showerheads, and faucets. The rate structure requires customers to pay more when they exceed a volume of water determined by their location and household size and can be adjusted during times of drought to direct conservation efforts (Hughes et al., 2013). Other efforts also involve financial incentives and rebates, such as the "Cash in Your Lawn" incentive which pays three dollars a square foot to customers to replace their grass with drought tolerant and water-wise landscaping (LADWP, 2014). Despite these efforts, says a top activist and leading conservation proponent, "We need better conservation. We could do a heck of a lot better than we're doing with conservation and capturing stormwater… because right now we're more regional rather than distributed. We can increase awareness about water issues through community engagement around [distributed] LID projects" (interview, NGO official 1, June 2014).

Finally, deficiencies in quality result from impairments to local water bodies, which in turn reduce reliability in supplies. Discharges of pollutants from urban runoff into surface waters is the leading cause of water pollution in Southern California and is highly regulated in order to be in compliance with water quality regulations mandated by the CWA (Geosyntec, 2014; Hughes et al., 2013). Following changes to the CWA in 1987 the state and regional water quality boards issued permits for MS4 discharges, as well as stormwater discharges from construction and industrial sites. The 2012 permit set limits, or Total Maximum Daily Loads (TMDLs), on 33 contaminants, including coliform bacteria, lead, zinc, mercury, and nickel (California Regional Water Quality Control Board, 2013). These regulations have often led to controversy over liability, such as the Natural Resource Defense Council's US Supreme Court case against the Los Angeles County Flood Control District (LACFCD), which found LACFCD liable for stormwater pollution flowing into the Los Angeles and San Gabriel River (Boxall, 2014). Controversy aside, however, stormwater capture programs implemented to meet MS4 permit requirements decrease the load of pollutants discharged into water bodies by retaining stormwater runoff and recharging groundwater. As one EPA official noted,

> The primary cause of water quality impairments are discharges from the MS4 permit and although water quality is what we have the direct statutory authority over, we recognize that here in Southern California one of the big advantages of doing green infrastructure and stormwater infiltration is replenishing groundwater supplies. (interview, June 2014)

As another water resource expert noted, “[stormwater management] started with the water quality piece and then all the light bulbs went off. It’s like, "Well, if you're [going to] spend billions of dollars capturing runoff and cleaning it, shouldn't you make use of that?" (interview, NGO official 3, June 2014) This marks one of the major paradigm shifts in stormwater management, which is the shift from just water quality to incorporating water supply as a value in addition to water quality.

While this section focused on the water resource challenges that frame stormwater as both a problem and a solution, the next section focuses on the governmental and calculative practices that render value and uses to stormwater in order to overcome deficiencies in quantity and quality. Specifically, it details the volumetric approaches that frame interventions to secure, capture, and cleanse the flows of stormwater in order to manage it as a resource.

3.5. Rendering stormwater metabolisms visible and governable

On May 18, 2013 Jose Solorio, then a California State Assembly member and chair of the State of California’s select committee on regional approaches to addressing the state’s water crisis, spoke at a legislative hearing on the future of stormwater capture, storage, and supply. During this meeting he described how over the last decade the issue of stormwater has “transformed from a water quality problem to a water supply opportunity” (Solorio, 2012). Recasting stormwater as an untapped resource confronts established notions of how stormwater should flow. As described in the previous section, the problem for government officials is one of circulation. How should stormwater circulate or not circulate in order to harness it as a resource? For water resource managers, engineers, planners and policy makers, stormwater must be framed as a technical issue in order to resolve this question and distinguish stormwater as a new and underutilized resource (Li, 2007a, 2007b). The value of stormwater, however, comes from the ability to measure the volumes of stormwater flows and make them comparable to other forms of water sources, such as imported water from MWD (Robertson, 2012). In this section I focus on the calculative practices and inscription devices, legal mechanisms, and residential programs that are enrolled to develop stormwater as a "new" resource.

3.5.1. Calculating and inscribing stormwater metabolisms

Mass balance approaches, typical of industrial ecology, work as a governance tool by enabling the flows of stormwater to be measured and calculated. This provides decision-makers with the data and inscriptions needed to communicate the volume of stormwater available for capture and to maintain environmental flows. The data and inscriptions, however, also work to justify interventions that discursively redefine stormwater as a resource and materially re-work the physical infrastructure of the city in order attain more sustainable forms of water resource governance. Establishing interventions to improve the circulation of stormwater, however, requires elements to be translated (Latour, 1987), offering new interpretations of stormwater as well as new social and material relationships that shape the flow of stormwater. Efforts to increase stormwater capture in Los Angeles will help illustrate this process.

The interim report of LADWP's Stormwater Capture Master Plan, which is part the City of Los Angeles's IRP, calculates the metabolic inflows and outflows of stormwater within Los Angeles in order to inscribe stormwater's underutilization (Geosyntec, 2014). As Figure 12 shows, the average annual inflows of stormwater are 831,400 AF. The bulk of this incoming flow into Los Angeles leaves as surface discharge (44%) or evapotranspiration (45%). The remaining 365,000 AF, however, represents the potential for where increased stormwater capture lies. As one LADWP official noted, "we needed to know what kind of flows were available for capture, we can't capture every drop because if we did that, that would mean during any rain event the flow in the LA River would be zero or would be at the baseline limits, but we want to

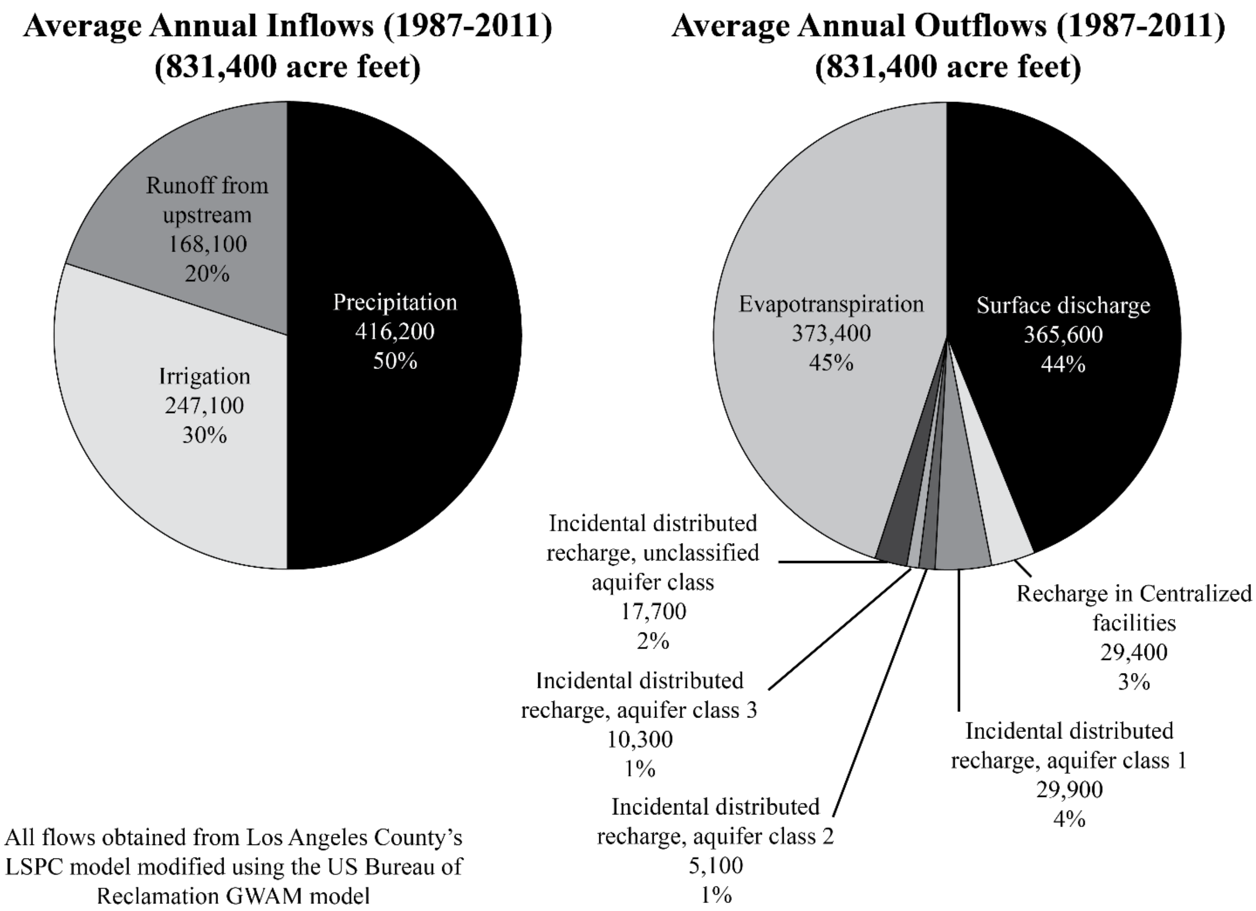

Figure 12. Flow distribution of average annual inflows and outflows of stormwater in the City of Los Angeles between 1987 and 2011. This figure is adapted from original in order to convert to grayscale. *Source*: Stormwater Capture Plan Interim Report (Geosyntec, 2014).

capture as much as we can" (interview, June 2014). It is clearly not feasible or desirable to capture all existing runoff, but these calculations enable officials to see stormwater as an underutilized resource and focus their efforts.

This is further reinforced by total capture scenarios that display the average annual capture for existing, conservative, and aggressive conditions. These are further broken down into categories by aquifer and between distributed capture and centralized capture. The aggressive scenario predicts an additional 141,800 AF capture in centralized facilities and 51,700 AF in distributed BMPs. Under this scenario, 21% of stormwater inflows would be discharged as surface runoff and 33% would be captured. The Stormwater Capture Master Plan proceeds to quantify the lifecycle costs of each scenario, thus assigning a dollar value to the volume of stormwater captured based on program type. This is a business case approach to managing stormwater that reflects broader trends of market environmentalism in the water sector (Bakker, 2014). As described by one city official, "We do a cost-benefit analysis, rate of return, first payback, cost acre-foot, and do a business case. Every project goes through that analysis. Even if they are little bit above the MWD rates we see in the long term a payoff because MWD rates will increase at about 5% a year" (group interview, April 2015). The distributed stormwater capture projects identified by the Stormwater Capture Master Plan, however, remain largely in excess of the full-cost per AF of imported water and this has directed decision-making towards centralized facilities for capture in Los Angeles (Geosyntec, 2014).

More broadly, these calculations, measurements, and inscription devices have material effects, which influence the ways stormwater circulates as a metabolism through Los Angeles. They operate by organizing the circulation stormwater by marking divisions between beneficial and harmful circulations, and by maximizing beneficial flows while diminishing harmful ones.

(Foucault, 2007, p. 18). Figure 13, for example, shows the long term (by 2099) potential average annual capture volume for each scenario broken down by aquifer and between distributed capture and centralized capture. Visually, the image brings attention to the vast potential of stormwater capture. Roughly, 193,500 AF of “underutilized” stormwater exists for capture under an aggressive scenario. Given Los Angeles’s average water supply between 2006 and 2010 was 621,700 AF per year, stormwater represents a potential to improve the “beneficial circulation” of local water supplies, increasing future water reliability while reducing dependence on purchased water from MWD. The inscriptions of stormwater, however, also draw attention to the differences between the ability of distributed systems versus centralized facilities to capture volumes of stormwater. This leads officials to evaluate stormwater capture projects primarily in terms of their ability to maximize the circulation of stormwater into their supply portfolios, or in terms of costs per AF of water. As one state water manager noted, “in the end water agencies will pay for the big [centralized] captures and will use the little [distributed] captures largely in a PR sense” (interview, July 2014). The desired outcome is to rework the circulation of stormwater away from local water bodies towards centralized facilities where large volumes of stormwater can be utilized as a supply source while simultaneously appealing to the desires of the population. This allows officials to diminish harmful flows by simultaneously addressing water resource constraints and environmental concerns, along with climate change, through attempts to secure the volumes of water necessary for continued economic growth (Cousins and Newell, 2015; Hodson and Marvin, 2009).

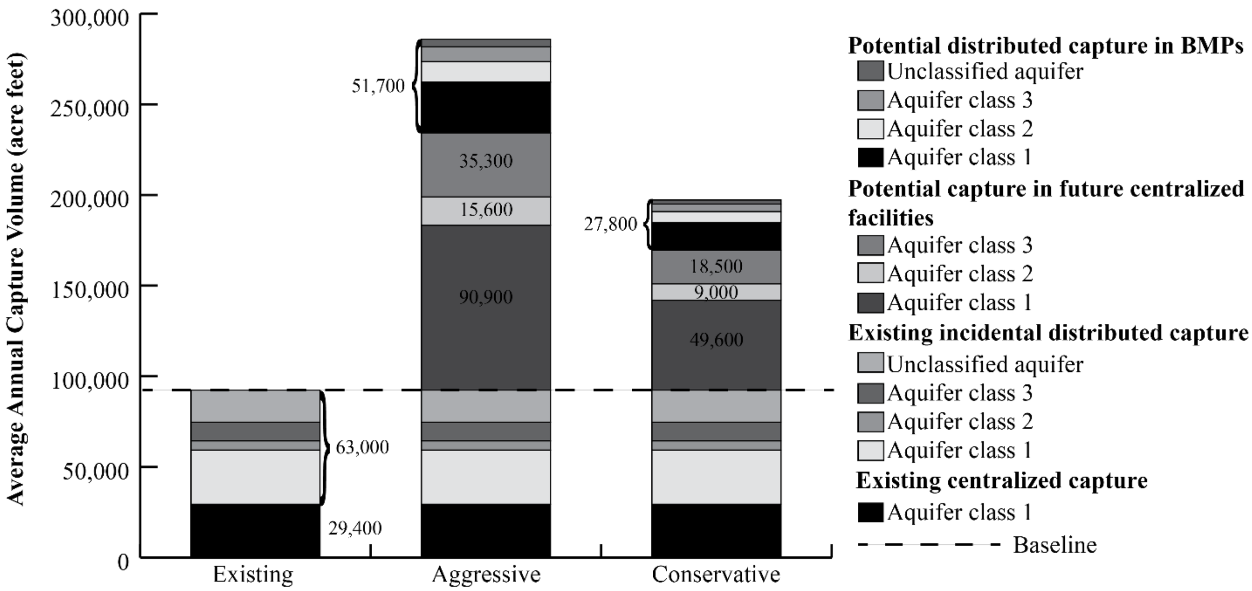

Figure 13. Average annual stormwater capture volume under existing, aggressive, and conservative scenarios. This figure is adapted from original in order to convert to grayscale. *Source*: Stormwater Capture Master Plan Interim Report (Geosyntec, 2014).

While these bureaucratic calculations offer ways of seeing and classifying, they also hinder alternative visions and ways of seeing. Those tasked with analyzing how stormwater flows through Los Angeles are working to identify the proper ways of governing stormwater—in in the public interest and with concerns for equity and justice—but they are also reframing stormwater governance as a matter of technique (Li, 2007a). Consequently, questions posed on the proper manner of dealing with stormwater become matters of expertise and avoid tricky political-economic questions regarding different values and uses of water. Reducing pollutant loads, improving water quality, and implementing distributed community based projects become relegated as ancillary benefits through programs directed at capturing and securing large volumes of stormwater. However, to fully realize the potential volume of stormwater flows, legal and bureaucratic mechanisms need to be reworked and citizens encouraged to contribute to the stormwater efforts offered by local and state agencies. I turn to the former next.

3.5.2. Enrolling the law

Redefining stormwater as a resource requires the enrollment of legal and bureaucratic mechanisms to direct who is liable for managing stormwater and establishing the types of actions that can be taken to capture the flows of stormwater and shape its value. For example, Los Angeles County Flood Control District et al. *v* NRDC et al. (2013) has received a lot of attention for directing responsibility for high levels of pollution in the Los Angeles and San Gabriel Rivers. The case, initiated by NRDC, Los Angeles Waterkeeper, and other environmental groups sought to hold LACFCD liable for discharges of pollutants that exceeded provisions under the CWA. In Los Angeles, stormwater is channeled through a MS4, and between 2002 and 2008 the monitoring stations set up along the Los Angeles River and San Gabriel River to test levels of pollutants to meet the standards of its National Pollutant Discharge Elimination System (NPDES) permit detected discharges from the MS4 system that contributed to an exceedance of water quality standards. In order to discharge pollutants, the person or entity seeking to make a discharge must comply with the NPDES, which establishes permits that set limits on the type and quantity of pollutants allowable. In January 2013 the Supreme Court of the United States ruled in Los Angeles County's favor on what constitutes a discharge of pollutants, but the United States Court of Appeals for the Ninth Circuit reversed, in part, and sided with the NRDC. The decision forces Los Angeles County and the LACFCD to address pollution in the Los Angeles and San Gabriel Rivers.

While the law is enrolled to direct liability, it is also enrolled to redefine stormwater. This discursive transformation scopes the possibilities of material form, such as infrastructure, and the organization of material flows, such as volumes of stormwater. In this way, social and material relations shape and are shaped by how water flows through the waterscape (Bakker, 2003a;

Linton and Budds, 2014; Worster, 1982). In California strict regulation limits how revenues are raised to address stormwater. As noted earlier, stormwater fees are difficult to establish in California due to Proposition 218, which requires local governments to obtain 2/3 public approval for a new fee or tax. This is a difficult barrier to overcome, whereby the meaning of stormwater needs to be discursively redefined in order to capture its value and remove obstacles to funding.

At the state level, the passage of Assembly Bill 2403 in June 2014 clarified parts of Proposition 218, which differentiated water supply—which is not subject to public vote—and stormwater management, which was defined as a waste and pollution problem. This amends the law to include stormwater as a water supply issue rather than a water quality issue. Specifically, "“water” means any system of public improvements intended to provide for the production, storage, supply, treatment, or distribution of water, including, but not limited to, recycled water and stormwater intended for water service" (Rendon and Mullin, 2014). This discursive redefinition of water not only formally clarifies the definition of "water" under Proposition 218 to include urban runoff and all other potential sources of water, but also enables the material transformation of infrastructures designed to capture and reuse stormwater and urban runoff. As one expert close to the process noted,

> The drumbeat has been going on for a while, and I think there are a lot of factors. I think a lot of discussion about the Bay Delta and what needs to be done there, so then you get into like, 'Well, we have water supplies here, why not utilize these?' Climate change, obviously we're in a drought, we were in a drought in 2008. I think that brings [stormwater] into the conversation…and I am happy to see the state treating stormwater as a resource rather than a nuisance. (interview, NGO official 2, June 2014)

Beyond facilitating the development of local water supplies, AB 2403 also allows agencies to mitigate the amount of pollution impairing local water bodies.

Similarly, at the federal level, a barrier with the ACoE had to be removed in order transform stormwater into a resource. Specifically, the *Water Resources Reform and Development Act of 2014* (WRRDA) discursively set into motion changes that enable agencies to utilize stormwater as a resource. In part, the WRRDA helps resolve some jurisdictional barriers. As one expert from the ACoE mentioned:

> We don't own or control the water [behind our dams]. That's one of our biggest challenges. We don't have a water supply mission. We use our dams for flood control. So now what we're trying to do is make these dams operate in such a way we can actually start to capture some of that stormwater [as a supply source]" (interview, April 2015).

The passage of WRRDA, nonetheless, allows the ACoE to reorient their dams not only for flood control but also for water retention and supply. As one state water resource expert noted, "[WRRDA] allows the ACoE to target drought stricken regions like Los Angeles and help facilitate groundwater recharge… The program provides municipal wide plans for stormwater technologies like [green infrastructure]" (interview, July 2014). Projects designed for capturing stormwater are now specified by Congress as eligible for funding assistance, "codifying a practice that is already allowed under EPA guidance" (NRDC, 2014b, p. 8). The ACoE is now able to operate their dams for stormwater capture and collaborate with supply agencies in order to utilize volumes of stormwater as a resource and drive adaptation efforts.

3.5.3. Enrolling citizens

In LADWP's (2015) Stormwater Capture Master Plan there is a focus on citywide ordinances and rebates to incentivize stormwater capture projects and programs such as rain barrels, rain gardens, cisterns and other residential improvements. These distributed projects enroll citizens into programs designed to conserve and capture stormwater. With ongoing water supply challenges, capturing and harvesting rainwater helps conserve drinking water supplies and improve water quality. Approaches capable of achieving multiple-benefits is a key component of the City of Los Angeles's strategy to meet water quality standards in MS4 permits and maintain water supply reliability in the face of many climatic uncertainties. Strategies in Los Angeles are oriented towards enhancing water resources through individual water-use practices as a means to maintain water reliability and achieve water quality and quantity goals.

Enrolling citizens for enhanced water governance is based on the categorization and quantification of urban residential water-use in order to direct their behavior. For LADWP, the primary ways the urban residents are categorized is based on AF/year potential from water conservation solutions such as rain barrels and cisterns. LADWP (2010) projects that by 2035 there will be 10,000 AF per year of additional water conservation through these technologies. To seize this potential LADWP is offering rebates and other financial incentives to direct individual behaviors, which reflect broader trends in the marketization of water (Bakker, 2014, 2005; Meehan and Moore, 2014). As Meehan and Moore (2014, p. 422) note, "rebates and incentives encourage greater individual (or household) involvement and introduce market-based principles into the management of water, reflecting the broader shift toward the 'neoliberalization' of water management."

These efforts introduce an economic valuation of stormwater capture at the household scale, but they are unevenly introduced and accepted. As one community organizer noted, "there is a class of NIMBY. But in terms of 'not in my backyard', it is in your backyard for the most part. I mean, the urban acupuncture stuff is quite literally in your backyard and your front yard." The lack of acceptance the organizer goes on to explain is attached to a 'love of your lawn' but is confident in the ability to change social behaviors around water use and management. As the organizer goes on to explain "[why] do you think people are putting pesticides and fertilizers in their lawns to begin with? That's a total management of social behavior" (interview, NGO official, June 2014). For this organizer, offering rebates and incentives is a means of fostering this change in social behavior. Officials at LADWP agree. As one city official noted, "We are branding the Stormwater Capture Master Plan as a product to validate and influence stakeholder concerns" (group interview, April 2015). Local citizens are encouraged to participate in the development of the Stormwater Capture Master Plan, albeit within a limited political agenda structured around consensus formation, sustained technocratic management, and changing social behavior and perspectives at the household scale.

Among the incentive and rebate programs is the City's Rainwater Harvesting Program (City of Los Angeles, 2009: 1), which defines rainwater harvest, a term synonymous with stormwater capture, as: "the process of intercepting rainwater from a roof (or other surface) and putting it to beneficial use... homeowners gain an extra water supply while simultaneously reducing the pressure on our limited water supplies." This definition links individual practices to the broader goals of LADWP's Stormwater Capture Master Plan and conservation efforts, while offering guidance and technical information on disconnecting downspouts and installing rain barrels and rain gardens. The program offers rebates of up to $500 per rain garden and $75 per rain barrel, with a maximum rebate of $1,000 per household. To be eligible for the rebate, the rain garden must capture stormwater from at least a 500-square feet of catchment area and the roof must have existing gutters. The numbers and calculations are inserted into the full-cost pricing models utilized by LADWP and signal a shift towards individual responsibility for managing stormwater.

3.6. Conclusion

This article examined the ways stormwater has shifted from a flood control problem to a resource in Los Angeles. Specifically, by invoking the emerging role of stormwater in environmental governance, it reveals how "resources are not: they become" (Zimmerman, 1933 cited in Bridge, 2009: 1220). Establishing stormwater as a resource has relied on a diverse set of actors who have discursively redefined stormwater through legal and bureaucratic mechanisms, calculated and inscribed the metabolic inflows and outflows of stormwater, cashed in their lawns, bought rain barrels, or constructed various forms of infrastructures to organize the flow and circulation of stormwater. Collectively these actions have constructed stormwater as an underutilized resource capable of resolving deficiencies of water quality and quantity. These deficiencies, however, have been shaped as much by humans as their non-human counterparts. Drought, Delta Smelt, dust storms, and pollutants are as much a part of the set of the social, political, and technical relationships that render particular volumes of water open to governmental intervention.

The findings further reveal that what qualifies stormwater as a resource or a hazard varies over time and space, and thus like any object of technopolitical intervention is dynamic and only a semi-stable configuration of human and non-human alignments (Deleuze and Guattari, 1987). In California, the formulation of stormwater as a resource has relied on its ability to fit many existing technopolitical arrangements, while also solving problems of water quality and quantity. Understanding how elements of nature come to fit particular technopolitical goals, however, allows for further explorations into how nature is defined, governed, and produced. As this article has shown, taking a PIE approach allows for explorations into how circulations of resources are influenced by a heterogeneous set of actors; some political, others ecological, and yet others technical (Newell and Cousins, 2015). Many questions remain, however, from how social categories like stormwater come to embody different notions of urban development and resilience, to how different subjectivities towards stormwater governance are produced and structured through their daily interactions with different volumes of stormwater.

Finally, amidst the inevitable uncertainty of water resource flows in Los Angeles and ongoing policy discussions articulating the ongoing drought as the new normal, it is important to reflect on the broader significance of this case. While this study examined how urban metabolisms are deployed as a volumetric approach that structures stormwater governance interventions, many other parallels exist conceptually that seek to rearticulate wastes as resources (Meehan et al., 2013; Moore, 2012), and others that explore the technical practices of resource governance (Akhter and Ormerod, 2015; Alatout, 2009; Birkenholtz, 2015; Perramond, 2016). Cities across the globe also have stormwater challenges that are rooted in their history of development and are looking at new ways to govern and control it (Karvonen, 2011; Meehan, 2014; Porse, 2013; Smith, 2001). In this article, however, PIE is used as an analytic to explore the social, political, and technical practices through which resource governance is achieved, questions typical of political ecology, as well as the volume and composition of material flows, questions more typical of industrial ecology. The challenge for future research will lie in developing approaches that at once allow for a critical industrial ecology, but also looks to find complementary and integrative approaches to explore the voluminous and embodied nature of resources.

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Chapter 4: Uncertain flows: Framing Stormwater Governance in Los Angeles

Abstract

Water has featured prominently in the development and politics of Los Angeles, from acquiring waters from the Owens Valley to channelizing and concretizing local waterways to mitigate flooding. Los Angeles in many ways has continuously been involved in overcoming dilemmas in water quality and quantity, and increasingly the region is under pressure to capture more stormwater to improve water security, flood control, and water quality. The means to accomplish this, however, are not evenly distributed across stakeholders and have the potential to cause conflict. In this paper, I explore how stakeholders involved in stormwater management in different contexts (e.g. policy makers, scientists, planners, engineers, and community leaders), understand stormwater problems, their perspectives and preferences towards solutions, and how these perceptions relate to one another. To do this I draw on Q-methodology to reveal the shared and competing social perspectives on the changing role of stormwater in environmental governance. The results indicate four primary perspectives on stormwater governance in Los Angeles: Market Skeptic, Hydro-managerialist, Market Technocrat, and Regulatory and Administrative Technocrat. Actors within these perspectives tend to agree that more integrated approaches are needed across all of the institutions and sectors concerned with the management of water and that science and data driven approaches should guide the process. Disagreement across perspectives stems from competing infrastructural visions, the role of market and economic incentives, and how they understand the role of new institutions and rules to govern

stormwater. It is shown that stormwater embodies a fluid set of meanings, problems, and solutions, which are framed differently across stakeholders and may impede the development of collaborative approaches and institutions capable of ensuring long-term success.

4.1. Introduction

Stormwater management is emerging as a critical issue facing cities due to increasing populations, development pressures, aging infrastructure, and the potential impacts of climate change on precipitation patterns (Bierbaum et al., 2012; Carmin et al., 2012; van de Meene et al., 2011). Along with rising temperatures and sea level rise, the anticipated increase in extreme drought and storm events associated with climate change are likely to have profound effects on the full range of water management activities, requiring adaptive responses (EPA, 2014; Hanak and Lund, 2011; IPCC, 2014). Scholars have suggested that climate change will entail an entire reworking of stormwater management (Carlson et al., 2015; Milly et al., 2008; Pahl-Wostl, 2007). One way water managers are beginning to address this is by developing new technologies and management strategies to capture, recycle, and utilize stormwater as a beneficial resource instead of treating it as a flood control hazard or as contaminated runoff. Rather than relying on traditional approaches employing logics of efficiency to convey water away from cities as quickly as possible in a centralized manner, many cities have begun to implement stormwater infrastructure through distributed or decentralized strategies to manage stormwater runoff closer to its source through low impact development (LID) and green infrastructure (Brown et al., 2013; Karvonen, 2011; Loperfido et al., 2014).

These distributed and decentralized techniques present important tools for climate change adaptation planning and take on a variety of forms and names (Bell, 2015; Marlow et al., 2013;

Tompkins et al., 2010). Sustainable urban water management (SUWM), sustainable urban drainage systems (SUDS), integrated water resource management (IWRM), water sensitive urban design (WSUD) and enhanced watershed management planning (EWMP) have all been used to connote aspirations for changes in urban water management. While many of the details of these approaches may differ, they share a generalizable goal to manage the urban water cycle to garner multiple benefits rather than single purpose targets typical of traditional approaches (Marlow et al., 2013). Stormwater management, for example, is increasingly looking to achieve both conveyance and infiltration to resolve water quantity and quality problems through site design strategies that replicate the functionality of the ecological and hydrological landscape of pre-urban conditions (EPA, 2001; Grimm et al., 2008; Pataki et al., 2011).

Many of these approaches rely on hybrid governance arrangements (Ferguson et al., 2013; Porse, 2013; van de Meene et al., 2011). The rationale is based on the recognition that no single agency or governmental entity retains the skills and capabilities to address the multiple and complex facets of environmental problems, such as stormwater (Lemos and Agrawal, 2006). While it is becoming apparent that actors and organizations in multiple domains are needed to resolve these important environmental dilemmas, controversy remains as a result of water's multiple roles and functions in society as a flow resource. Water is also at once fixed to land through water rights and geographical features, such as lakes and rivers, but it is also mobile, capable of flowing across political boundaries or being transferred between basins. As Bakker (2014: 471) notes of water, "it is simultaneously an economic input, an aesthetic reference, a religious symbol, a public service, a private good, a cornerstone of public health, and a biophysical necessity for humans and ecosystems alike." The norms associated with each of these roles and functions directly and indirectly influences how local officials and residents develop their stormwater management practices (Carlson et al., 2015; Greenaway et al., 2005). Some institutional norms lead actors to approach stormwater through technocratic or managerial approaches to improve social, environmental, and economic sustainability, and yet other norms lead to grass-roots or bottom-up approaches to improve resource governance. The result presents difficulties for establishing new governmental, institutional, and technological structures to re-work the value of stormwater.

Given the diversity of governance approaches and perspectives to manage stormwater, and the difficulties this presents for collective action, exactly how do competing perspectives and institutional relationships relate to one another and influence how stormwater is understood, managed, and controlled? Some scholars have argued that the formation of 'discourse coalitions' link seemingly disparate actors around shared narratives or framings to foster changes in environmental governance and policy making (Bulkeley, 2000; Hajer, 1995). Research has also shown that practitioners and decision-makers construct different meanings of environmental problems and solutions in sometimes contradictory and diverse storylines that may necessitate social learning (Aldunce et al., 2015). Others, however, have warned that these discursive alliances often reflect idiosyncratic perspectives that reveal deeper divisions between power and knowledge (Robbins, 2006). Yet others have shown that actor disagreement does not deter collaboration, but it does make synergistic environments potentially more difficult to come by (Lansing, 2013). To describe this phenomena of collaboration without consensus, scholars often point towards the creation and use of boundary objects to bridge diverse social worlds by enabling dialogue across groups around a shared but flexible item or concept, such as watersheds or water quality (Cohen and Bakker, 2013; Freitag, 2014; Star and Griesemer, 1989). While decision-making and collaboration is often messy and filled with uncertainty (Kingdon, 1984), it is also an arena where the evolving relationship between power and governance reworks the subjective relationships between people and the material world (Lemos and Agrawal, 2006; Agrawal, 2005).

To understand the relationship between different forms of environmental action and thought, this paper examines "expert" (policy makers, scientists, engineers, etc.) understandings of how stormwater governance should proceed. Using Q-methodology, I identify four social perspectives that align around developing more integrated approaches across all of the institutions and sectors concerned with the management of water and utilizing science and data-driven approaches. Perspectives diverge around differing opinions of infrastructural interventions, the role of economic approaches, and the need for new institutions and rules. I suggest that disagreement may not deter integration and collaboration, but without addressing contestation over key knowledge claims about how stormwater governance should proceed, broadly accepted outcomes may remain elusive.

4.1.1. Framing stormwater and environmental governance in Los Angeles

Stormwater is an often overlooked aspect of Los Angeles's history and politics of water resources development. Urbanization, however, greatly influenced the local hydrological cycle. The expansion of impervious surfaces and the channelization of waterways to handle increased surface water flows and to mitigate flooding profoundly altered drainage patterns, impacted water quality, and reduced groundwater recharge (Dallman and Spongberg, 2012). Typical of many cities, urban stormwater drainage in Los Angeles utilized engineered systems to encourage flood protected development through the use of drains, pipes, and floodwater channels.

Increasingly, the Los Angeles region is under pressure to capture more stormwater to augment supplies while reducing flood impacts, as well as to meet water quality regulations under the Clean Water Act. In 1987 the Clean Water Act was amended to require the Environmental Protection Agency (EPA) to issue National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater permits for discharges from large Municipal Separate Storm Sewer Systems (MS4s). The NPDES permits are designed to ensure that stormwater discharges into rivers, lakes, or the ocean meet water quality standards. The California State Water Resources Control Board issues NPDES Permits for Los Angeles requiring a decrease in pollutants in stormwater and urban runoff. The MS4 permits are the main regulatory mechanisms used to address water quality and among stakeholders are typically considered the primary drivers of whether a specific stormwater abatement goal is met or not. For some stakeholders, the MS4 Permit presents major challenges due to the extensive monitoring requirements and the incorporation of Total Maximum Daily Load (TMDL) regulations that are likely to involve costly control measures to ensure that municipalities are not exceeding the maximum amount of pollutants a water body can receive. Yet for others, the MS4 Permit represents a transformative moment in the way stormwater is managed and regulated by providing incentives for integrated water resource planning and management.

Given the context of current and future water scarcity in the region, successfully integrating stormwater into supply sources will be key for sustaining human, economic, and ecological health. The efficient use of stormwater, as having value as an economic input and having social-ecological benefits, is one strategy many are advocating for as a means to meet the dual water supply and water quality challenge in Los Angeles. The demands of the approach on the city to invest in ways to capture, cleanse, and restore water, while mitigating flood risk, generates a range of vested and interested actors in the future of stormwater, each with their own distinct preferences and perspectives. These range from market based approaches like mitigation banking to citywide ordinances and rebates to incentivize stormwater capture projects, as well as reforming current regulatory structures.

Mitigation banking schemes focus on developing private markets to encourage investments in green infrastructure and on leveraging private capital to reach clean water goals. The credit banking schemes work by allowing developers to meet LID requirements established under the MS4 permits by paying into a bank. Advocates argue that they offer numerous benefits to market participants by allowing property owners and developers to buy and sell credits in a manner that allows them to determine the most cost effective means for achieving stormwater mitigation goals (LABC, 2015; Valderrama et al., 2013). The objective is to provide an off-site alternative that allows developers and agencies to meet some or all of the stormwater regulatory requirements. Critics maintain that by allowing developers and property owners to purchase credits to meet LID requirements under current MS4 permits some actors are able to avoid implementing on-site mitigation measures, which can be time-consuming and unpredictable (Lave, 2012). These schemes present important differences in stakeholder perceptions of whether stormwater mitigation should occur off-site or on-site, and the complicated nature of establishing environmental governance schemes that bring together different levels of government and the private sector (Robertson, 2012, 2004).

Similarly, centralized approaches versus decentralized approaches towards stormwater capture and abatement divide actors. Centralized approaches focus on structural features that promote conveyance and retention. These include sewers and catchment basins along with treatment facilities, and in Los Angeles where most of the rain falls within a short seasonal timeframe, many actors focused on supply see these as the most desirable option to capture large amounts of run-off. As one state actor noted, “you need big to capture big” (interview, July 2014). In contrast, many NGOs, non-profits, and other organizations focused on water quality tend to prefer distributed or decentralized approaches, which include bioretention ponds and other features typically associated with green infrastructure that can capture stormwater at its source. While a shift from large centralized infrastructural systems to more distributed technologies is widely accepted as a key component to more sustainable water management (van de Meene et al., 2011), differences in actor preferences in Los Angeles present some contention among actors on the preferred means of capturing and cleansing stormwater.

Furthermore, emerging governance approaches such as IWRM or so-called ‘One Water’ approaches are also perceived unevenly among actors. The goal of IWRM is to promote the coordination and management of water, land, and related resources to advance economic and social welfare as well as maintaining the integrity of vital ecosystems (GWP, 2000; Mitchell, 2005). Informed by previous IWRM efforts, Los Angeles is implementing a One Water LA plan as a means to integrate the management of the City’s water resources and water infrastructure in an environmentally, economically, and socially beneficial manner (LA City, 2015). While actors have a hard time disagreeing with any of these goals, many differ on the effectiveness or the means of achieving the goals of more sustainable and integrative approaches. Previous research has shown that collective agreement on the goals of government but disagreement on the means to achieve them can be held together by IWRM plans working as boundary objects (Ward, 2013), but this case demonstrates the complicated nature in which environmental governance unfolds as competing actors vie for position and power to achieve their goals.

There is also a focus on improving current city ordinances to encourage transitions at the household scale. For example, LADWP's (2015) Stormwater Capture Master Plan establishes citywide ordinances and rebates to incentivize stormwater capture projects and programs such as rain barrels, rain gardens, cisterns, and other residential improvements. Many of these distributed projects focus on enrolling citizens into programs designed to conserve and capture stormwater. With ongoing water supply challenges, capturing and harvesting rainwater helps conserve drinking water supplies and improve water quality. Approaches capable of achieving multiple-benefits is a key component of the City of Los Angeles's strategy to meet water quality standards in MS4 permits and maintain water supply reliability in the face of many climatic uncertainties.

As a whole, governance approaches to stormwater tend not to fit simple categories or descriptions, but instead vary across the range of actors (Karvonen, 2011; van de Meene et al., 2011). In the following sections this article reveals how social categories like stormwater come to embody different notions of urban development and resilience and how different subjectivities towards stormwater governance are produced and structured through their daily interactions with stormwater.

4.2. Q-methodology

Q-methodology is used to reveal different social perspectives, attitudes, or understandings about a specific issue or topic in a structured and statistically interpretable form (Eden et al., 2005; Robbins and Krueger, 2000; Watts and Stenner, 2012). As Barry and Proops (1999, p. 339), note, the goal of Q-methodology is to elicit "the variety of accounts or discourses about or around a particular discourse domain, theme, issue, or topic." Q-methodology thus differs from traditional survey approaches by its concern with eliciting the *range* of perspectives about a topic among the population, rather than the distribution, or balance, of perspectives across the population (Cuppen et al., 2010). Q-methodology proceeds by asking a set of purposively chosen respondents to complete a rank-ordering exercise, referred to as a Q-sort, comprised of the full range of discussions about the topic. Data from the Q-sorts are then analyzed with factor analysis, which creates a number of groupings that revel shared framings about a topic and allows for interpretation (Davies and Hodge, 2012).

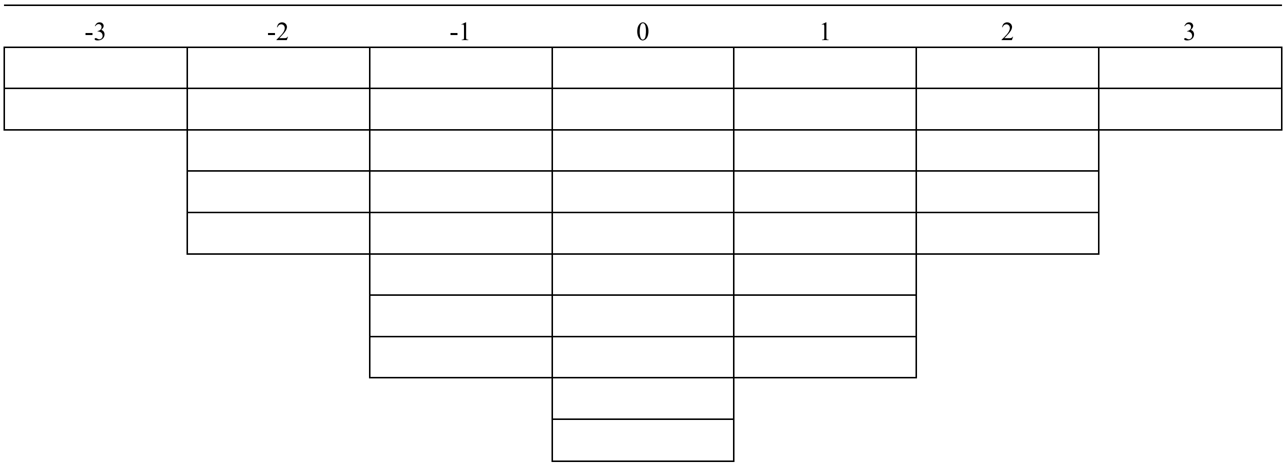
Following well-established Q-methodology procedures (e.g. Barry and Proops, 1999; Watts and Stenner, 2012; Webler et al., 2009), I outline my approach in three broad phases. Having already selected stormwater as a topic of interest, phase one involved the creation of a concourse of statements (the Q-set). Statements were collected from semi-structured interviews, academic articles, newspapers, policy documents, and NGO publications. Interviewees were purposively chosen based on their knowledge and experience with the topic and to reflect the broadest possible range and diversity of expertise and viewpoints, including non-profit and NGO leaders, and, county, state, and federal officials. From these sources, statements continued to be collected until a 'saturation point' was reached and the addition of new statements no longer contributed new perspectives (Eden et al., 2005; Glaser and Strauss, 1967). Through a structured process focused on capturing perspectives of how stormwater should be managed and perspectives of current approaches, 40 representative statements were chosen. The final number of statements is consistent with recommendations in the literature suggesting a Q-set between 20 and 60 statements (Webler et al., 2009).

The second phase involved selecting participants (P-set) and conducting the Q-sorts. Participants were purposively chosen to ensure the widest range of experiences and perspectives possible (Brannstrom, 2011; Brannstrom et al., 2011; Fisher and Brown, 2009; Robbins, 2006).

This is typical of Q-methodology, which is concerned with revealing the diversity and range of viewpoints rather than the representative distribution of beliefs across the population (Webler et al., 2009). The 27 respondents chosen, which is consistent within the literature, included a subset of the original interviewees and new participants recommended through a snowball sample (Swedeen, 2006; Webler et al., 2009). Some of the original interviewees were not available during the timeframe to conduct the study. The Q-sorts were administered in April 2015 via Q-Assessor software (http://q-assessor.com), a tool specifically designed for online Q studies. Some Q-sorts were administered in-person using an iPad, while others were conducted remotely at the convenience of the respondent. Utilizing both face-to-face and online Q-sorts is supported in the literature (Cairns and Stirling, 2014; Gruber, 2011) and have shown no significant difference in the validity of face-to-face sorts versus those carried out remotely by mail or online (Cairns and Stirling, 2014; Reber et al., 2000; Tubergen and Olins, 1978). Once participants agreed to the study, an online interface presented respondents with a grid organized in a quasi-normal distribution and asked them to sort statements along a scale from +3 (most agree) to -3 (most disagree) (Fig. 14). This forces respondents to reflect on the placement of each statement and make priorities in their rankings.

Phase three utilized PQMethod software for factor analysis in order to reveal shared points of view and common patterns among the Q-sorts. Factor analysis works by mathematically creating new variables, or factors, that explain variation among many variables (the Q-sorts/respondents). In this study, I used centroid analysis, over principal components analysis, because it offered more options for data exploration and is the only factor analytic technique available across other dedicated platforms for Q-methodological analysis (Watts and Stenner, 2012). By default, centroid analysis produces an unrotated factor matrix with seven

Figure 14. Quasi-normal distribution chart for Q-sorts. Each respondent places a single statement in each box.



extracted factors. Not all extracted factors, however, can explain variance. Four factors were retained based on the Kaiser-Guttman criterion, which posits that factors should only be retained if they have an EV of 1.00 or above (Guttman, 1954; Kaiser, 1960; Watts and Stenner, 2012). This cut-off point ensures that every extracted factor represents more than one Q-sort. The unrotated factors were then rotated using varimax rotation. This common Q-methodology procedure extracts all significant factors and produces a factor solution that maximizes the amount of explained variance and the number of individuals associated with only one factor (Setiawan and Cuppen, 2013; Webler et al., 2009). The result produces an idealized sort, or factor array, for each factor, which defines a distinct social perspective or knowledge group (Barry and Proops, 1999). These ideal types were then interpreted and refined based on six follow-up interviews and respondent comments provided at the end of the Q-sort, which asked each respondent to explain the statements they most agreed and disagreed with.

4.3. Results

Results of the factor analysis determined four factors, or knowledge groups, representative of the range of variability in expert viewpoints. The four groups—Market Skeptic (F1), Hydro-managerialist (F2), Market Technocrat (F3), and Regulatory and Administrative Technocrat (F4)—account for 57% of the variance (factor characteristics summarized in Table 1). The distinguishing statements for each group are shown in Table 2, represented as an idealized sort for each group, indicating an association with specific perspectives and preferences towards stormwater problems and solutions. Actors across these groups tend to agree that more integrated approaches are needed across all of the institutions and sectors concerned with the management of water, but they exist along a spectrum in their commitment towards certain claims regarding the management of stormwater. Disagreements across perspectives also exist along a spectrum and arise over differences in the process and outcomes of more integrated approaches (e.g. types of infrastructure, the role of market and economic incentives, and the role of new institutions or rules to govern stormwater).

Table 4. The factor characteristics for each rotated factor.

Factor Characteristics	Factor			
	F1	F2	F3	F4
Eigenvalue	5.198	2.791	3.813	3.063
No. of defining variables	9	4	3	4
Composite reliability	0.973	0.941	0.923	0.941
SE of factor scores	0.164	0.243	0.277	0.243
% total variance	19.992	10.737	14.665	11.783

Table 5. Factor array showing idealized Q-sort for each factor, or knowledge group, in Los Angeles

Statement		Factor			
		F1	F2	F3	F4
1.	One of our biggest barriers is increased regulation.	-3	**<u>1</u>**	-3	-1
2.	Implementation is a barrier in large part due to NIMBY type of concerns. People do not want to be liable.	0	1	1	-1
3.	We lack the data needed for the adoption green infrastructure and to accurately quantify its performance.	0	**<u>2</u>**	-1	0
4.	The trouble within the city is that we're so congested and built up we don't have the space for many types of green infrastructure; space is a significant limitation.	-2	2	**<u>0</u>**	3
5.	Climate uncertainty is the most difficult challenge for proactive adaptation planning for stormwater management.	0	0	0	**<u>-3</u>**
6.	Land-use change presents the most difficult challenge to stormwater management.	-1	-1	0	**<u>0</u>**
7.	I think there is a cultural problem. Stormwater engineers see only engineering solutions and green infrastructure is not part of that.	0	**<u>-3</u>**	0	0
8.	Getting people to apply to incentive programs is problematic because people don't care about stormwater management and lack knowledge of water issues.	0	**<u>-3</u>**	-2	1
9.	We need stricter laws and regulations to address stormwater because change is not going to happen voluntarily.	2	1	2	0
10.	Failure to address stormwater, like climate change, is a fault of political leaders; they are the ones who need to be educated and incentivized to innovate.	0	-1	0	-1
11.	Science and data should direct decisions on stormwater and infrastructure. We need data driven and fact-based approaches drawing on the best available science and engineering.	2	1	1	3
12.	Development of a tradable credit system, with appropriate regulatory safeguards, will encourage investment in green infrastructure and help deliver stormwater mitigation at the lowest possible cost.	-1	1	**<u>3</u>**	1
13.	We need market based approaches and fewer government interventions and regulations to finance stormwater management.	-2	0	-1	-2
14.	Stormwater management needs economic instruments to put a value on stormwater and make it a resource rather than a hazard.	1	1	3	2
15.	Corporations and private interests should have the chance to develop their own targets for stormwater abatement.	-3	**<u>1</u>**	-1	-1
16.	A mitigation bank for stormwater will help foster public-private partnerships to address stormwater by allowing developers to meet LID requirements by paying into that bank.	**<u>-1</u>**	0	2	1
17.	Stormwater, or water more generally, should not be guided by market, economic, or financial principles.	1	-2	-2	0
18.	Waste water, water supply, flood water, water quality and all of that stuff is just water. If you just think of it as one water then you can manage it much more efficiently.	3	**<u>-2</u>**	0	2
19.	We don't need more integrated approaches. We need better enforcement of existing regulations and improvement of local codes and ordinances; integrated water resource planning is not the answer	**<u>-2</u>**	-1	-1	-2
20.	An integrated management approach is critical. There needs to be a shift towards more integrated approaches across all of the institutions and sectors concerned with the management of water.	3	2	2	2
21.	We need stormwater fees. Municipalities need fees and cost sharing plans.	2	0	1	2
22.	Stormwater fees are not feasible, nor are they enough for successful implementation in the long term. Stormwater fees are problematic.	-1	-1	-3	-3
23.	Stormwater needs to be held and used on-site; there are too many concerns about unregulated off-site mitigation.	0	-1	-1	1
24.	Stormwater mitigation should be able to occur off-site; it offers more flexible opportunities. Off-site approaches lead to better outcomes than on-site.	-1	**<u>0</u>**	1	-2
25.	We need to maintain the narrative of engagement by redefining city services and bringing the expertise to the neighborhoods. We need a grass roots community driven approach to create better outcomes.	1	0	2	0
26.	Homeowners need to be educated and they need to educate each other about the benefits of improved stormwater management. They need to be the targets of interventions because community driven approaches tend to be more effective than data driven approaches.	1	0	0	1

27	Local residents' contributions to decision-making usually show a lack of expertise, are not factual, or biased.	0	0	-2	-1
28.	Big systems and dams or reservoirs are important for floods and stormwater mitigation, but after the rain, how you handle that water is important for water quality and/or supply.	1	3	1	1
29	Centralized urban water systems are maladapted to address climate change impacts and environmental stressors.	**<u>1</u>**	-1	0	0
30.	Larger centralized projects for handling and capturing stormwater are typically more cost-efficient than trying to treat it at thousands of small sources. Centralized stormwater projects make more financial sense than distributed and decentralized stormwater projects.	-1	**<u>3</u>**	-1	-1
31.	LID offers economic benefits, such as deferring or even replacing costly large grey stormwater infrastructure projects. LID is more cost effective than gray infrastructure.	2	**<u>0</u>**	2	2
32.	Resilience of urban water systems will be improved by moving away from the centralized model and using more distributed solutions like green infrastructure.	1	**<u>-2</u>**	1	1
33.	Distributed projects are not effective; they don't scale up across the city or to other sites and will never meet the level of stormwater abatement and/or capture needed.	-2	-1	-1	-1
34.	As we build green infrastructure we are going to change the nature of neighborhoods. We are going to push working class people out as we build more economic development around green space.	-1	-1	-2	-2
35.	For every dollar we spend on a water quality project that's one less emergency service dollar, recreation dollar, or funds for other services. It's hard to justify money for stormwater management.	-2	-2	-1	0
36.	I'm really opposed to creating new institutions or rules to manage stormwater. There are too many agencies and there is too much diversity already.	-1	**<u>2</u>**	-2	0
37.	I think there definitely will be a need for new institutions and rules to manage stormwater.	1	-2	1	-2
38.	With many community groups and NGOs there are issues with them maintaining the infrastructure or with them focusing too narrowly on certain issues.	0	1	0	-1
39.	I think there's enough NGO capacity within the city to have a better coordinated and more strategic approach to green infrastructure.	0	0	0	1
40.	Rather than focusing on new development, we need to focus on the existing development and encourage retrofitting. Only looking at new developments hurts us.	2	2	1	0

Bold underlined are distinguishing statements (significant at $p<0.05$)

4.3.1. Factor one: The Market Skeptic

While incorporating more integrated approaches is a shared sentiment across all knowledge groups, the Market Skeptic shows a stronger commitment towards approaches that are integrated, but also driven by stronger rules and regulations rather than market approaches. Respondents who loaded high on this viewpoint include two people affiliated with academic institutions in Los Angeles, six people from environmental NGO's, and one official from the Los Angeles County Flood Control District (LACFCD). This group also contains actors who are often in conflict over the role of liability in stormwater management. One respondent, a water resource expert for the Natural Resources Defense Council (NRDC), loaded on this factor alongside an official from the LACFCD. These two groups went to court over liability for discharges of pollutants into the Los Angeles and San Gabriel Rivers that exceeded provisions under the CWA; the rulings eventually forced Los Angeles County and the LACFCD to address pollution in the two rivers. Post-sort interviews reveal that a shared dissatisfaction with current regulations and a desire for more clear and strict rules and regulations brings these two actors together.

A distinctive perspective among this group is that centralized urban water systems are maladapted to address climate change impacts and environmental stressors (#29, +1). The problem, as one NGO official noted, is that centralized infrastructure is "typically single purpose and usually destroys or eliminates other services." Distributed green infrastructure projects are the preferred option for stormwater as the respondent goes on to say "because [green infrastructure] and distributed stormwater projects seek to preserve multiple benefits and services" (Respondent 14, April 2016). As a result, green infrastructure and LID projects are typically viewed as a more cost-effective approach by preserving and allowing ecological processes to provide water retention, filtration, and bioremediation services. While space for these projects is recognized as a significant hurdle for implementation within the city, it is not recognized as a major limiting factor (#4, -2). A shared sentiment among the group is that effective green infrastructure can occur in small spaces and creative solutions can be developed to scale-up distribute stormwater projects to fit into the available spaces in the city (#33, -2).

This group of actors also shows ambivalence in comparison to other groups in terms of their perception of incentive programs. They neither agree nor disagree that getting people to apply to incentive programs is problematic because people do not care about stormwater management or lack knowledge of water issues (#8, 0). Actors in follow-up interviews agree that people tend to respond well to incentive programs in southern California but more distributed green infrastructure projects are still needed to engage community members in their neighborhoods about retaining and using stormwater.

What is unique about this perspective, however, is that it rejects market-oriented approaches over improved rule making and regulations. In contrast to the other knowledge groups, they agree that stormwater, or water more generally, should not be guided by market, economic, or financial principles (#17, +1). Corporate or private actors are also seen as unfit actors to have input on stormwater abatement targets they are held accountable to. For many in this perspective, too many loopholes in the current regulatory structure already exist for regulated parties to escape responsibility. Market Skeptics also disagree that the development of a tradable credit system, with appropriate regulatory safeguards, will encourage investment in green infrastructure and help deliver stormwater mitigation at the lowest possible cost (#12, -1). Similarly, they do not view the development of a mitigation bank for stormwater management as a way to foster public-private partnerships to address stormwater by allowing developers to meet LID requirements by paying into a bank (#16, -1). Overall, Market Skeptics tend to be cautious of market oriented approaches and allowing corporate and private interests to influence stormwater management. As one NGO official noted:

> Corporations and private interests are looking to maximize profits or minimize costs and not sustain the health of the watershed that is being managed. It is understandably difficult to attach an economic cost to the value of a healthy watershed system. Corporate or private interests should be the last to have input on stormwater abatement targets they are held accountable to. (Respondent 18, April 2015)

4.3.2. Factor two: The Hydro-managerialist

The Hydro-managerial perspective favors large centralized projects for stormwater capture and market and data driven approaches for its management. Actors also support integrated approaches but do not see 'one water' approaches as the answer (#18, -2). Collectively, this group includes of four respondents. Three of these respondents work in different capacities for LADWP in regards to stormwater. The other respondent formerly worked for a large water utility, but now is a director of a non-profit that focuses on water resource issues.

A distinguishing perspective among this group is that larger centralized projects for handling and capturing stormwater are typically more cost-efficient than trying to treat it at thousands of small sources and that they make more financial sense than distributed and decentralized stormwater projects (#30, +3; #31, 0). As one official noted after the sort, "I strongly agree that centralized projects are much better at handling stormwater cost-effectively compared to distributed projects and LID. This is easily seen as a cost-benefit analysis when considering [the] amount of water capture [for flood control] and infiltrated [for water supply]" (Respondent 12, April 2015). This respondent's viewpoint is supported in LADWP's Stormwater Capture Master Plan, which indicates many of the centralized projects are more cost-effective (Geosyntec, 2014). The preference for centralized projects, however, is much more rooted in their potential for providing water supply benefits. This perspective views big systems such as dams and reservoirs as important for flood control and stormwater mitigation, but how that water is handled after the rain is important for water supply (#28, +3), regardless of whether it is on-site or off-site. Moving away from the centralized model towards distributed capture projects is not perceived as a way to improve the resiliency of urban water systems (#32, -2).

To accomplish stormwater management goals related to both water quality and quantity, the Hydro-managerialist perceives increased regulation as a significant barrier (#1, +1). This includes approaches that perceive wastewater, water supply, flood water, and water quality as 'one water' (#18, -2). Respondents are also opposed to creating new institutions or rules to manage stormwater in a diverse landscape where too many agencies a perceived to exist already

(#36, +2). As city official respondent noted, “I am opposed to creating another agency to manage stormwater. There is already enough redundancy and the primary agencies routinely work together” (Respondent 11, April 2015).

As an alternative, the Hydro-managerialist perceives market approaches and improved data as the means to foster more effective stormwater management. Respondents in this group agree that decision-makers lack the data needed for the adoption green infrastructure and to accurately quantify its performance (#3, +2). As a result, the Hydro-managerialist tends to disagree that engineers do not see green infrastructure as part of the solution (#7, -3), but instead as one respondent noted, “when it comes to decision-making, particularly of public funds, measurable and tangible benefits are much easier to argue for” (Respondent 12, April 2015). In lieu of improved data, the Hydro-managerialist sees market based approaches as a key mechanism fostering transitions. This may also include allowing corporations and private interests an opportunity to develop targets for stormwater abatement (#15, +1). Actors disagree that getting people to apply to incentive programs is problematic because people do not care about stormwater management or lack knowledge of water issues (#8, -3). Rather a shared sentiment among the group is that incentive programs are successful ways to encourage distributed projects, improve knowledge, and not place a fee on taxpayers who may not understand the benefits of stormwater fees.

4.3.3. Factor three: The Market Technocrat

This group reflects a commitment towards market environmentalism. The viewpoint shares a preference for market-oriented approaches with the Hydro-managerialist, but differs in its preference for new institutions. Three respondents’ sorts correlated significantly with this group.

One participant is an official with LADWP, another is a stormwater specialist with the US EPA, and the final respondent is a staff attorney with the NRDC.

For those committed to this position, resolving stormwater problems is centered on developing proper environmental regulations and market mechanisms to effectively meet stormwater goals. Respondents agree that stormwater management needs economic instruments to put a value on stormwater to make it into a resource (#14, +3). A preferred approach is the development of a tradable credit system, with appropriate regulatory safeguards, to encourage investment in green infrastructure (#12, +3). Similarly, respondents sharing this view see the development of a mitigation bank for stormwater as an important means to foster public-private partnerships to address stormwater by allowing developers to meet LID requirements by paying into a bank (#16, +2). Not surprisingly then, the Market Technocrat also agrees more strongly than the other groups in allowing stormwater mitigation to occur off-site (#24, +1). The development of off-site mitigation credit and banking programs are advocated for by both the NRDC and the US EPA, indicating that these perspectives reflect their structural position rather than an idiosyncratic position (Brannstrom, 2011; EPA, 2015b; Lansing, 2013; Robertson, 2004; Valderrama et al., 2013).

The resulting picture of stormwater management is one of developing off-site mitigation and credit trading programs capable of expanding the green infrastructure retrofit market (Valderrama et al., 2013). The problem for this group is not a lack of data or too many rules (#3, -1). Instead the problem is developing the right set of new institutions and rules, along with stormwater fees, to effectively provide the financial tools necessary to fund and manage stormwater (#36, -2; #22, -3). As one respondent noted: “fewer government regulations is not going to solve our stormwater issues. Stormwater fees are based on a service that is necessary and can provide a source of funds for improvement projects. Stormwater fees can also be structured in a way to incent positive behaviors" (Respondent 8, April 2015). In this regard, respondents in this view see engaging community actors, primarily through incentives and other market approaches, as a key to fostering better outcomes (#25, +2).

The Market Technocrat is also unique in its relative ambivalence towards approaches that view wastewater, water supply, flood water, and water quality as one water (#18, 0). In follow-up interviews, a shared sentiment was that integrated approaches are necessary, but 'one water' approaches will not be effective without the proper financial instruments and incentives to foster successful management. Respondents are also ambivalent in their attitudes around adequate space in the city (#4, 0).

4.3.4. Factor four: The Regulatory and Administrative Technocrat

This group is focused on addressing land-use challenges in the near term and utilizing data-driven approaches to manage stormwater. Four respondents' sorts correlated significantly with this group, including an official affiliated with the City of Los Angeles' Stormwater Program, an official with the US Bureau of Reclamation, a member of the State Water Resources Control Board, and an official with the *City* of *Los Angeles* Bureau of Sanitation. What defines this group, however, is an "administrative rationalism" that emphasizes expert control in problem solving through traditional bureaucratic and regulatory structures and agencies (Dryzek, 1997).

In this view, stormwater problems are a product of too few regulations and approaches to alter land-use. The Regulatory and Administrative Technocrat perceives land-use as one of the most difficult challenges to stormwater management (#6, +1). In particular, finding space within the city to implement green infrastructure or other forms of LID to mitigate stormwater is perceived as a significant limitation (#4, +3). One respondent noted in a post-sort interview, “more work needs to be made to integrate land-use planners and City planners with water purveyors to fully integrate watershed management for its resilience” (Respondent 17, April 2015). For those sharing this viewpoint, incorporating the water purveyors is vital for proper stormwater management, as they have a set of customers to which fees can be assessed and incentive programs directed. This overcomes concerns among this group about the allocation of funds across other city services such as emergency services and recreation (#35, 0), of getting people to apply incentive programs (#8, +1), and over the feasibility of stormwater fees (#22, -3).

Resolving stormwater problems are about utilizing data driven and fact-based approaches to ensure that stormwater discharges generated from various land uses do not exceed MS4 regulatory requirements (#11, +3). The Los Angeles MS4 permit, for example, states that, “Permittees shall coordinate with the local water purveyor(s), where applicable, to promote landscape water use efficiency requirements for existing landscaping, use of drought tolerant, native vegetation, and the use of less toxic options for pest control and landscape management.” In particular, the Regulatory and Administrative Technocrat prefers establishing land-use approaches that hold and retain water on-site rather than off-site in order to achieve these goals (#23, +1; #24, -2).

A distinguishing perspective of this group, however, is their strong disagreement with the statement that climate uncertainty is the most difficult challenge for proactive adaptation planning for stormwater management (#5, -3). These respondents understand that climate change is going to present many challenges in the future, but it is perceived at a longer time-scale. As one respondent noted, “Climate uncertainty is not important to me at this time, as it potentially may become a problem, but only in the very long term. The real challenge is to figure out what to do over the next 10-20 years, and, in short, make sure that it will work" (Respondent 27, April 2015)

The resulting picture of stormwater is one of resolving land-use liabilities in the near term and establishing the proper regulations and relationships to meet requirements in the Los Angeles MS4 permit. Climate change, while a concern, is a longer-term challenge. Their current concerns are over utilizing the best available science and data to direct decision-making in a way to meet regulatory requirements and justify public expenditures on infrastructure to manage stormwater. 'Holistic planning,' as one respondent noted, is vital for the future as "addressing one issue will have implications for other categories of water, integrated management is necessary to be cost-effective and efficient" (Respondent 27, April 2015).

4.5. Actor discourse divergence

The results indicate important divergences in conceptual framings among actors. First, there is a division amongst the actors in the way they perceive and understand the role of new institutions and rules to govern and manage stormwater (#37). Social perspectives appear split with the Market Skeptic and Market Technocrat favoring new institutions and rules while the Hydro-managerialist and Regulatory and Administrative Technocrat seem relatively opposed to new institutions. Similarly, there is a lot of variability among actors who are opposed to creating new institutions or rules due to the amount of institutional diversity that already exists (#36). The most striking difference is between the Hydro-managerialist and Market Technocrat. The Market Technocrat shares with the Market Skeptic an understanding that current regulations are not satisfactory or strict enough and allow pollution at levels that endanger the environment and human health. In contrast, the Hydro-managerialist sees too much redundancy in current institutional frameworks and perceives some regulations as hindering other priorities, such as water supply. Interviews suggest this is a major source of contention among and between governmental and non-governmental agencies. While actors across perspectives agree that funds for stormwater should ensure multiple benefits—flood control, water supply, water quality, and urban greening—disagreement emanates from the perceived rigor of new and current institutional frameworks. Opposition by NRDC staff, for example, on new rules to capture and reuse stormwater in Los Angeles County stems from the way the new rules diminish the state's ability to enforce water quality standards (Morin, 2015).

This is mirrored in disagreement among actors over rules and regulations presenting barriers to management (#1). The Market Skeptic presents some interesting contradictions in regards to this, which could also partly explain some of the disagreement over the role of new institutions. The Market Skeptic perceives increased regulations as a barrier to proper stormwater management while also maintaining that stricter laws and rules are also needed. This is an interesting paradox and is revealing for important reasons. Post-sort interviews indicate that increased regulations are often a barrier when it comes to increasing water supply, but to drive water quality and conservation measures, stricter laws and rules need to be put into place. In other words, rules and regulations both enable and constrain some actors, such as the supply agencies who feel that regulatory pressure may diminish the amount of water they can import but also require firmer rules to drive water quality and conservation measures.

Yet for others, disagreement on the role of new institutions is simply a matter of process. As one NGO official noted, "integration of institutions that work separately or at cross-purposes is the first step. New institutions come second" (Respondent 9, April 2016). One such institutional mechanism to foster integration and guide environmental action is the development of 'one water' approaches. The goal is to render greater financial resources available across all sectors concerning water resource management by developing projects that are multi-beneficial. Actors across all social perspectives agree that more integrated approaches are necessary (#20), but again the Hydro-managerialist shows a contradiction in statements and disagrees with the statement that one-water approaches are a more efficient approach (#18). This disagreement is most prevalent between the Market Skeptic and the Hydro-managerialist, where the perspectives diverge on concerns over water quality and water quantity. In post-sort interviews a city official indicated that "one water lingo [is] not the answer. The money is there from the agencies and the planning is taking place already" (Respondent 23, April 2015). Others indicated that managing stormwater for multi-beneficial use is the goal of both integrated approaches and 'One Water' approaches. When supply agencies, like LADWP, look to invest in a project, however, they have to analyze the cost specifically for water supply benefits. As one city official noted

> We do not quantify any other benefits such as water quality, habitat restoration, flood control, etc. Not that those aren't important, if a project has multi-benefits, the more attractive it looks. But we primarily focus at volumes of water being produced for water supply. That's how we're able to justify expenditures to our governing board. (Respondent 11, June 2014).

While the Hydro-managerialist welcomes integrated or 'One Water' approaches, perspectives focused more strongly on supply rather than water quality presents mixed perspectives, where the suppliers tend to only view these projects positively when it meets a certain water supply benefit.

Disagreement also stems from competing infrastructural visions. Not surprisingly, the Hydro-managerialist prefers large centralized projects for handling and capturing stormwater while the other groups tend to prefer decentralized approaches (#30). This is a serious point of contention between social perspectives. Hydro-managerialists rely on their cost-benefit analyses to argue for their cost effectiveness and role in increasing supply. As noted earlier, however, water quality and other benefits are not quantified into these metrics. This leads some actors to claim for the effectiveness of large-scale infrastructure while others are arguing that such claims "have no foundation in reality" (Respondent 39, April 2015). The other perspectives perceive distributed options as the most cost-effective way to achieve multiple benefits. Yet some disagreement remains in regards to whether projects should manage stormwater on-site or off-site via centralized regional projects (#24). Centralized regional projects would be capable of capturing larger volumes of water, but many actors (F1; F4) are concerned over liability and legal challenges to successfully implement off-site approaches. Perspectives seem split over the ability of infrastructural projects to capture enough water to provide a supply benefit with those concerned over liability and legal challenges related to water quality.

Finally there are important differences between social perspectives on the role of market and economic mechanisms to manage stormwater. Those that took a positive and optimistic stance towards market and economic approaches were mixed in their professional backgrounds, but post-sort interviews reveal a shared sentiment among all groups except the Market Skeptic that improved stormwater management is about developing the proper economic incentives (F2, F3, and F4). Instead, the Market Skeptic maintained a more pragmatic and skeptical vision towards the difficulties and limits of market and economic approaches. These actors tended to have backgrounds in academic institutions or positions that frequently put them in contact with them. Post-sort interviews suggest that this gives them a better understanding of the difficulties of attaching an economic value to a healthy watershed. This does not mean that these actors are universally opposed to market and economic incentives—household incentives were generally viewed positively—but they are skeptical towards approaches that may produce outcomes for actors to disproportionately profit. The differences are focused at the scale of management where incentives geared towards transforming stormwater into a resource at the household scale is positive, but market approaches at larger scales are viewed less favorably. Disagreement over the role of mitigation banking for stormwater is revealing in this regard (#16).

4.6. Actor discourse convergence

The results indicate that some perspectives on stormwater governance flow across disparate groups, both within and outside of formal institutions. Specifically, evidence suggests that IWRM is at the confluence of multiple perspectives on stormwater management. Actors across all perspectives resolutely agree that more holistic and integrated approaches are needed across all of the institutions and sectors concerned with the management of water (#20). Science and data driven approaches, however, are considered the primary techniques required to successfully integrate approaches (#11). As one NGO official noted,

> Science is objective and should always drive sound decision making. That being said, additional data and science-based recommendations are needed to further the integrated, distributed, and green infrastructure approach. Integration or 'one water' is key, but it's only as good as its components. (Respondent 25, April 2015)

The degree to which each of these 'components' aligns across perspectives varies, however. The results indicate that how one comes to know and interact with stormwater through their structural position influences how they perceive stormwater. This lends some support to assertions that an actor's perspective towards an environmental issue is structural rather than idiosyncratic (Brannstrom, 2011; Lansing, 2013). As Brannstrom (2011: 543) notes, however, "structural position might help predict an actor's support for a social perspective, but the articulation of the ideas is idiosyncratic, particular, and based on broader knowledge claims." The implications for successful integrated approaches is understanding the specific issues where overlap occurs and where opportunities for boundary crossing exist (Ward, 2013).

Some of the key components that actors broadly agree on are the multiple benefits distributed LID or green infrastructure offers cities as they scale up these approaches and the role of large technical systems such as dams to mitigate stormwater impacts (#31; #33; #28,). While the Hydro-managerialist shows a stronger preference for large centralized systems to generate supply and some ambivalence towards distributed LID, respondents indicated in post-sort interviews that their focus is typically on volumes of water produced for water supply. Projects that offer multiple benefits are desirable, but other benefits such as water quality, habitat restoration, and flood control typically are not quantified by the large supply agencies like LADWP. This orients their vision towards approaches that marshal stormwater as a supply. The fact that they see distributed projects as desirable and scalable, however, offers an important common ground for actors to come together.

Another component actors tend to agree on is the need for economic instruments to put a value on stormwater and begin to utilize it as a resource (#14). This is a key issue underlying many of the positions actors take. For instance, while actors tend to agree that cities need stormwater fees (#21), the Hydro-managerialist's ambivalence towards them is not driven by a perceived lack of need. Instead, stormwater fees are perceived as part of a larger set of economic instruments that, as one respondent noted, "can be structured in a way to incent positive behaviors [in people and institutions]" (Respondent 8, April 2015). In addition to creating economic instruments to put a value on stormwater, actors see a need for stricter laws and regulations to address stormwater because they do not see change as happening voluntarily (#9). The Market Skeptic and Market Technocrat most strongly share this sentiment and although the Regulatory and Administrative Technocrat ranked it as neutral, one respondent noted in a post-sort interview that increased regulation is needed alongside financial mechanisms to utilize stormwater as a resource. This indicates a broader perspective across groups of finding a balance between increased regulations and market approaches to manage stormwater. As one actor noted, “regulations are crafted to respond to societal needs when the market is either ineffective or hostile to resolutions; [increased] regulations are often necessary” (Respondent 1, April 2015).

Interestingly, however, actors tend to be ambivalent towards the role of NGOs and do not perceive green infrastructure and LID to potentially impact the character of neighborhoods (#34; #39). Actor responses towards the role of NGOs were surprising considering that many of the respondents work for NGOs. In post-sort interviews, however, the answer became relatively straightforward: stormwater is perceived as a jurisdictional issue and NGOs cannot change the handling of stormwater without some of those issues being resolved. More critical, however, is agreement among actors that urban greening efforts are unlikely to alter the character of neighborhoods as more cities build more economic development around green space. This is contrary to evidence that has shown how urban greening can have unintended consequences such as gentrification (Wolch et al., 2014). The outcome is troubling and raises concerns about current approaches, which may not adequately integrate the concerns of community members and groups in a way that protects communities while providing the social and ecological benefits of increased urban green space.

4.7. Conclusion

This article explored how various stakeholders involved in stormwater management in varying capacities, from state bureaucrats to local community leaders, understand stormwater problems, their perspectives and preferences towards solutions, and how these perceptions relate to one another. As this study demonstrated, stormwater embodies a fluid set of meanings, problems, and solutions, which are framed differently across stakeholders. Four dominant perspectives on stormwater management in Los Angeles emerged from the analysis. While stakeholders tended to agree that more integrated and data driven approaches are needed to achieve better outcomes, disagreement still arises over the means to achieve those goals. Important differences exist in terms of utilizing market mechanisms, such as mitigation banking, the cost-effectiveness of different types of infrastructure, and the role of new institutions and rules. Some of these differences are not surprising (e.g. those concerned about supply vs. those concerned about other aspects of stormwater), but some alignments are surprising (NRDC and LACFCD in F1). What is important is that heterogeneity in stakeholder perspectives is shown to play out both structurally and idiosyncratically. In other words, they are based on variable and situated experiences that reflect one's structural position as a state bureaucrat or non-profit leader, but also their individual experiences.

Amidst growing uncertainties over water resource flows in Los Angeles, and developing policy discussions articulating the ongoing drought as the new normal, it is important to reflect on the broader significance of this case. Given the context of future water scarcity and changes in the size and frequency of storms across California (Hanak and Lund, 2011), effectively integrating stormwater into current water management schemes will be crucial for both human and ecological health. The challenge will lie in developing collaborative approaches and institutions capable of ensuring success rather failure. Discursive agreement may not be necessary for some of the stakeholders in Los Angeles to collaborate, but establishing long-term success may very well be dependent on overcoming these differences. This study indicated some important points of convergence and divergence in stakeholder perspectives that may impede or facilitate more desirable social and ecological outcomes in the ways stormwater is managed.

One of the central questions moving forward is in what ways will the power of some discourse coalitions legitimize some types of interventions as salient and credible while dismissing others (Cash et al., 2003; Hajer, 1995; Robbins, 2006). With current trends in environmental governance moving towards hybrid forms that bring together groups that transcend traditional organizational structures to include both public and private entities, it is yet to be seen how more sustainable outcomes will be achieved through current configurations of knowledge and power. With most governance decisions occurring within existing infrastructural, political, and fiscal constraints, challenging some of the dominant and centralized approaches may prove difficult, despite efforts to be more integrated and holistic. As this study has shown, many differences across groups concerned about stormwater exist, and exactly how governance systems will adapt to these changing social, political, and climatic realities is yet to be seen.

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Chapter 5: Stakeholder perspectives of stormwater in Chicago

Abstract

This article examines the ways stakeholder preferences and perspectives of stormwater management converge and diverge in Chicago. With a greater emphasis on broad stakeholder participation in urban environmental governance and decision-making, accommodating and moderating multiple and competing perspectives will become a greater part of urban green-space planning. Decision-makers must choose how resources are to be allocated to manage stormwater and decide among the multiple and sometimes conflicting options available to reduce the impact of stormwater at different sites across the city and region. Using Q-methodology, this paper seeks to understand the disparate understandings of how to best manage stormwater in the city. The results reveal two dominant perspectives towards stormwater management approaches in Chicago: the Infrastructural Interventionist and the Institutional Interventionist. The first strongly views stricter laws and regulations developed in tandem with science and data-driven approaches as the best way to improve stormwater management. The second desires new rules and institutions to foster integrated management approaches, as well as more robust economic instruments capable of assigning a monetary value to stormwater, as critical to resolving stormwater problems. Conflicting points of perspective arise around the preferred type of infrastructure to be implemented to deal with stormwater and how it is to be developed. Understanding how these two social perspectives interact and conflict is important in considering

the actions that will ultimately be undertaken to direct landscape changes capable of resolving the multiple challenges Chicago faces in managing stormwater.

5.1. Introduction

On September 13, 2008 Chicago experienced a storm event that dropped nearly seven inches of rain on the city in a 24-hour period. The record setting storm event produced massive flooding, causing 10,000 homes to be evacuated and $155 million in damage (Changnon and Westcott, 2002; Changnon, 2010). More recent storm events have occurred with nearly equal devastation. Storms in April and June of 2013 inundated the city causing evacuations, road closures, and the Governor to declare a state of emergency for 44 counties across the State of Illinois. While it is difficult to assign a single storm event to climate change, these record setting storms are indicative of what Chicago is likely to experience on a more frequent basis as a result of climate change (Emanuel, 2014; IPCC, 2014). Annual precipitation is projected to increase by as much as 20%, with an increasing fraction of this rainfall occurring in high-intensity events, resulting in serious implications for flood control and stormwater management in the city (Hayhoe, et al., 2007).

Urbanization also brings an increase in hard or impervious surfaces. By some estimates these surfaces can comprise as much as 67% of the urban land area (Gartland, 2008; Matthews, et al., 2015). This human alteration to the hydrology of the urban environment, along with climate change, is likely to only exacerbate many of the stormwater challenges Chicago already faces, such as combined sewer overflows (CSOs) and flooding. CSOs occur when the volume of water entering exceeds the capacity of the sewage treatment plant. This is a significant concern given that storm events producing as little as .67 inches of rain in 24 hours can overwhelm the existing stormwater infrastructure and result in CSOs that dump a mixture of untreated sewage and stormwater runoff into the Chicago River and Lake Michigan (Dorfman and Mehta, 2011). CSOs are a considerable problem in Chicago with 2,036 discharge events occurring in 2009 alone (NRDC, 2010). In Chicago, the increased magnitude of flooding and CSO events can be attributed to alterations of land-surface wrought by urbanization and the history of stormwater management policy (Ntelekos, et al., 2010).

Traditionally Chicago dealt with stormwater by undertaking massive engineering efforts. Initially driven by outbreaks of epidemic diseases, Chicago began developing methods to reduce the flow of polluted water into Lake Michigan, where the city drew its drinking water. Notably, in 1900 the Chicago Sanitary and Ship Canal was built to reverse the natural flow of the Chicago River. Instead of flowing into Lake Michigan, the Chicago River now flows away from Lake Michigan and into the Des Plaines River, a tributary of the Mississippi River. While this solution resolved some of the pollution problems in Lake Michigan, it did little to reduce the load of sewer systems during rain events, which became inundated, causing CSOs. In order to provide a floodwater outlet and reduce the load of the sewer systems during rain events the Metropolitan Water Reclamation District of Greater Chicago (MWRD) began constructing the Tunnel and Reservoir Plan (TARP) in 1972. The TARP is designed to capture, convey, and store combined sewage during storms through a series of deep rock tunnels and surface reservoirs, which later channel this water towards treatment plants when capacity becomes available (Malec, 2003). Although construction launched in 1975, many factors have delayed completion and it is not expected to be finished until 2029.

Chicago is also working to comply with National Pollutant Discharge Elimination System (NPDES) Phase II requirements. NPDES is a permitting program administered under the Federal

Clean Water Act (CWA). While the initial focus of the program was to reduce industrial point sources of pollution, efforts have expanded to bear upon stormwater pollution, attempting to manage it at discharge points, typically sewer outfalls (White and Boswell, 2007). Phase II of the CWA requires public education and outreach, public involvement, illicit discharge detection and elimination, construction site runoff control, post construction runoff control, and pollution prevention as ‘minimum control measures’ (EPA, 2005). In Chicago the MWRD is in charge of treating the city’s sewage and stormwater runoff at seven treatment facilities and maintaining compliance with NPDES Phase II requirements. Efforts have focused primarily on stormwater control areas, such as areas relying on separate storm sewers and riparian areas that allow stormwater to flow directly into water bodies (Powers and Emanuel, 2014).

The city has been successful at implementing both structural and non-structural best management practices (BMPs) to treat stormwater runoff. Non-structural BMPs utilize ordinances and education initiatives to improve water quality while structural BMPs entail physical changes to infrastructure or the landscape to reduce the impact of stormwater runoff, such as dry basins, wetlands, filter strips and other forms of green infrastructure (Kaplowitz and Lupi, 2012). Chicago has been able to utilize green infrastructure’s broad appeal to implement a number of projects and programs capable of enhancing water quality in the city, such as the Stormwater Ordinance, the Green Roof Initiative, and the Green Alleys Program. These investments in stormwater management are popular among decision-makers and technocrats due to their ability to garner multiple benefits, increase the city’s resilience to extreme rain events and climate change, and reduce the burden of stormwater flows on the sewer system (Emanuel, 2014).

Not all stormwater BMPs and forms of green infrastructure, however, are capable of adequately addressing the range of pollutants or hazards inherent to a particular watershed; they also vary considerably in cost and expertise to implement and maintain (Kaplowitz and Lupi, 2012). Moving forward, decision-makers must choose how resources are to be allocated to manage stormwater and decide among the options available to reduce the impact of stormwater at different sites across the city. One of the constraints decision-makers and planners face is generating the funds to build green infrastructure. In Chicago, stormwater is the only major infrastructure system not paid for through user fees, but instead is funded through general revenue. Decision-makers are also faced with gaps surrounding the costs and benefits to manage stormwater through green infrastructure, including maintenance costs, and how the cumulative effects of many small-scale, decentralized, and distributed projects across the city will impact stormwater flows (Emanuel, 2014). Despite these unknowns and constraints, many within the city are looking towards replacing some of Chicago's impervious surfaces with porous pavement, bioswales, rain gardens, and other forms of green infrastructure to lessen the pressure on the stormwater treatment facilities and reduce the number of CSOs (Dorfman and Mehta, 2011). With limited resources and diverging views on the efficacy of green infrastructure, however, there is an inherent conflict about what stormwater is, how resources are to be allocated to manage it, and the best way to do so.

Various approaches and perspectives have been used to understand the perspectives and preferences of those involved in environmental governance and decision-making and how they come to make decisions. Kaplowitz and Lupi (2012), for example, used a choice experiment to reveal stakeholder preferences for BMPs to address stormwater. Their results found that stakeholders hold clear preferences for some types BMPs over others. Homeowner's, for example, were found to prefer management plans with high levels of streambank naturalization in their alternative management plans. Similarly, Byrne et al. (2015) surveyed green-space users to understand how their knowledge about climate change and adaptive responses shapes their attitudes towards green infrastructure as an adaptive response to climate change. The findings suggest that green-space users favor tree planting if they perceive climate change to be economically disruptive. Dobbie and Green (2013) also surveyed public perceptions of wetlands to understand the different landscape characteristics that guide the way people see and interpret the environment. Relatedly, Matthews et al. (2015) used a combination of interviews and literature review to identify the barriers and drivers of adopting green infrastructure. While these studies have proven useful for revealing how various stakeholders understand and perceive the environment, little work has sought to clarify how these perceptions relate to one another, interact, and potentially conflict.

This article addresses this gap by utilizing Q-methodology to explore the converging and diverging preferences and perspectives of stormwater management options in Chicago. With a greater emphasis on broad stakeholder participation in urban environmental governance and decision-making, accommodating and moderating multiple and competing perspectives will become a greater part of urban green-space planning. This article reveals two dominant perspectives towards stormwater management in Chicago. The first strongly views stricter laws and regulations, combined with data-driven approaches, as the best way to improve stormwater management in Chicago. The second desires more integrated management approaches and more robust economic instruments capable of assigning a monetary value to stormwater as critical to resolving problems related to stormwater. Understanding how these two social perspectives interact and conflict is important to understand the actions that will ultimately be undertaken to direct landscape changes capable of resolving the multiple challenges Chicago faces in managing stormwater.

5.2. Methods

This study uses Q-methodology to examine and compare the multiple ways stormwater management options are perceived and understood. Q-methodology works by revealing different social perspectives, attitudes, or understandings about a topic in a structured and statistically interpretable form (Robbins and Krueger 2000; Watts and Stenner 2012; Eden, et al. 2005). Instead of measuring how particular views are distributed across the population and relate to demographic or other variables, Q-methodology uses factor analysis to reveal the patterns in the ways people structure their world-views (Webler et al., 2009). This allows the researcher to identify shared and competing framings about a topic.

Q-methodology follows a number of well-established guidelines that include: 1) identification of a discourse, or domain of subjectivity; 2) collection of statements and creation of the concourse, 3) development of the Q-set, also known as the Q-sample, 4) participant selection (P-set); 5) Q-sorting exercise; 6) statistical analysis; and 7) interpretation (Robbins and Krueger, 2000; Swedeen, 2006; Watts and Stenner, 2012; Webler et al., 2009). Following these guidelines, this research took part in three primary phases. During the initial phase, a concourse of statements was constructed from academic articles, newspapers, policy documents, NGO publications, and semi-structured interviews with key actors involved with stormwater management. Typical of Q-methodology, interview subjects were purposively selected to represent the range of expert viewpoints on stormwater management in Chicago and the region, including non-profit and NGO leaders as well as city, county, state, and federal officials. Statements continued to be collected and gleaned from interviews until a 'saturation point' of

376 statements was reached. At this point the inclusion of additional statements did not increase the diversity of statements (Eden et al., 2005; Glaser and Strauss, 1967). The statements were then coded into four domains—goals, barriers, preferred management approaches, and definitions of stormwater. The final concourse, or Q-set, consisted of 40 representative statements, which aligns with recommendations in the literature (Webler et al., 2009).

During the second phase, 15 participants were selected to carry out the Q-sorts. These participants were purposively chosen to ensure the widest range of experiences and perspectives in relation to stormwater in Chicago (Brannstrom, et al., 2011; Brannstrom, 2011; Fisher & Brown, 2009; Robbins, 2006). Participants included a subset of the original interviewees and new participants recommended through a snowball sample. The Q-sorts were administered in April 2015 via Q-Assessor software (http://q-assessor.com), a tool specifically designed for online Q studies. Some of the Q-sorts were administered in-person using an iPad while the others were conducted remotely at the convenience of the respondent. While Q-sorts have traditionally been conducted in person, the use of both face-to-face and online Q-sorts is supported in the literature (Cairns and Stirling, 2014; Gruber, 2011). Studies have shown there to be no significant difference in the validity of face-to-face sorts versus those carried out remotely by mail or online (Cairns & Stirling, 2014; Reber, et al., 2000; Tubergen & Olins, 1978). Once participants agreed to take the study the online interface presented respondents with a grid organized in a quasi-normal distribution and asked them to sort statements along a scale from +3 (most agree) to -3 (most disagree) (Table 6). This forces respondents to reflect on the placement of each statement and make priorities in how they rank the statements.

In the third phase, the Q-sorts were analyzed with PQMethod software to identify common orderings of statements and indicate shared points of view and subject positions. The factor analysis works by mathematically creating new variables, or factors, that explain variation among many variables (the Q-sorts). This study used centroid analysis in order to find common

Table 6. Quasi-normal distribution chart

Disagree			Neutral			Agree
-3	-2	-1	0	1	2	3

patterns among the different Q-sorts. While there are no set rules on how many factors to extract this study used the Kaiser-Guttman criterion to identify a number of extracted factors. The Kaiser-Guttman criterion posits that factors should only be retained if they have an eigenvalue (EV) of 1.00 or above (Guttman, 1954; Kaiser, 1960; Watts and Stenner, 2012). Using this criterion, two factors were chosen for extraction. The factors were then rotated using varimax rotation. This common procedure in Q-methodology produces a factor solution that maximizes the amount of explained variance and the number of individuals associated with only one factor (Setiawan and Cuppen, 2013; Webler et al., 2009). The result produces an idealized sort for each factor, which is meant to represent a distinct social perspective or knowledge group (Barry and Proops, 1999). These ideal types were then interpreted and refined based on follow-up interviews and comments provided at the end of the Q-sort, which asked each respondent to explain the statements they most agreed and disagreed with.

5.3. Results

The factor analysis revealed two factors or knowledge groups that make up the dominant perspectives of those involved in stormwater management. The first, the Infrastructural Interventionist (F1), sees stricter laws and improved science as necessary to rework urban stormwater infrastructure. The second, the Institutional Interventionist (F2), perceives the development of new institutions to foster integrated water resources management and economic instruments to put a value on stormwater as necessary to address stormwater problems. Combined, the two factors explain 42% of the variance (Table 7). Respondent's perspectives and preferences towards stormwater management come together around developing integrated approaches that are capable of utilizing market, economic, or financial principles. Disagreement in stakeholder preferences and perspectives revolve around the role of infrastructure and how it is developed and implemented. Specifically, social perspectives diverge over the role of large infrastructural systems in mitigating stormwater. This section provides an overview of each factor. Appendix A shows an idealized sorting pattern for each group across all the statements.

Table 7. Factor Characteristics for Chicago

Factor Characteristics	Factor	
	1	2
Eigenvalue	3.221	2.654
No. of defining variables	7	6
Composite reliability	0.966	0.96
SE of factor scores	0.186	0.2
% total variance	23.01	18.962

5.3.1. Factor One: Infrastructural Interventionist

The Infrastructural Interventionist supports stricter laws and regulations in tandem with data-driven approaches as the primary means to achieve improved stormwater management (#9: +3; #11: +3). Respondents who loaded onto this factor, or knowledge group, include a diverse set of governmental and non-governmental actors. In total seven people loaded onto this knowledge group. One official from the EPA represents a perspective from a federal agency. Three others represent city officials; one a city water engineer, another a city planner, and the other a city parks official. The remaining three represent officials from prominent NGOs in Chicago. Table 8 indicates the distinguishing statements that define this group.

Table 8. Infrastructural Interventionist distinguishing statements

Group One: Infrastructural Interventionist		
Statement (significant at p>0.05)		Rank
3.	We lack the data needed for the adoption green infrastructure and to accurately quantify its performance.	-2
4.	The trouble within the city is that we're so congested and built up we don't have the space for many types of green infrastructure; space is a significant limitation.	-1
7.	I think there is a cultural problem. Stormwater engineers see only engineering solutions and green infrastructure is not part of that.	1
9.	We need stricter laws and regulations to address stormwater because change is not going to happen voluntarily.	3
11.	Science and data should direct decisions on stormwater and infrastructure. We need data driven and fact-based approaches drawing on the best available science and engineering.	3
14.	Stormwater management needs economic instruments to put a value on stormwater and make it a resource rather than a hazard.	2
15.	Corporations and private interests should have the chance to develop their own targets for stormwater abatement.	-3
16.	A mitigation bank for stormwater will help foster public-private partnerships to address stormwater by allowing developers to meet LID requirements by paying into that bank.	2
21.	We need stormwater fees. Municipalities need fees and cost sharing plans.	2
22.	Stormwater fees are not feasible, nor are they enough for successful implementation in the long term. Stormwater fees are problematic.	-2
28.	Big systems and dams or reservoirs are important for floods and stormwater mitigation, but after the rain, how you handle that water is important for water quality and/or supply.	2
29	Centralized urban water systems are maladapted to address climate change impacts and environmental stressors.	0
32.	Resilience of urban water systems will be improved by moving away from the centralized model and using more distributed solutions like green infrastructure.	0
34.	As we build green infrastructure we are going to change the nature of neighborhoods. We are going to push working class people out as we build more economic development around green space.	-2

Beyond implementing data-driven approaches and advocating for stricter laws and regulations to manage stormwater, a shared sentiment among Infrastructural Interventionists is to apply economic principles to stormwater management. Actors strongly agree that economic instruments are needed to put a value on stormwater in order to treat it a resource rather than a hazard (#14: +2). This is reflected in their support for mitigation banks to foster public-private partnerships that allow developers to meet LID requirements by paying into a bank (#16: +2). In addition to developing economic instruments to manage stormwater actors are in favor of developing stormwater fees and cost sharing plans for municipalities (#21: +2).

When it comes to infrastructure many see large infrastructural developments as key ways to mitigate the impacts of stormwater and flooding depending on how that water is utilized (#28: +2). The sentiment among Infrastructural Interventionists is that large centralized projects can foster beneficial uses of stormwater as long as the systems are not overwhelmed. This is one reason why many of the respondents in this group see a cultural problem with the way engineers develop solutions to stormwater management that often does not include green infrastructure (#7: +1). A largely shared opinion among those in this group is that the data exists for the adoption of green infrastructure and to quantify its performance (#3: -2), but many of the institutional and cultural barriers to implementing green infrastructure need to be overcome. This partially explains the relative ambivalence, or lack of agreement or disagreement, towards a preferred approach, whether centralized or decentralized. For example, this group does not agree or disagree with the statement that centralized urban water systems are maladapted to address climate change impacts and environmental stressors (#29: 0), or resilience of urban water systems will be improved by moving away from the centralized model and using more distributed solutions like green infrastructure (#32: 0). Stormwater for this group is primarily about getting the proper mix of infrastructural solutions as well as government actions and market mechanisms to manage stormwater and then applying science to direct where to make interventions in the system. Receiving input from corporations or private interests would only hamper this process (#15: -3).

Stormwater fees are also perceived as a feasible approach for long-term and successful stormwater management rather than being problematic (#22: -2). This is mirrored in the shared sentiment among many of the actors in their disagreement that it is hard to justify money for stormwater management due to it potentially taking away funds from other services such as recreation or emergency management. Stormwater fees are seen as an important step towards setting up specific funds for stormwater management, which may in turn provide other services such as recreation or more green space. This is one reason why many of the actors see spending on stormwater as justifiable in the long-term.

Interestingly this group disagrees with the idea that cities are too congested and built up for many types of green infrastructure (#4: -1). A commonly held perspective is that roads and rooftops represent a significant amount of space to implement green infrastructure, but when designing larger catchment areas, space may become hurdle to green infrastructure. Respondents in this group also tended to disagree that implementing green infrastructure and developing green initiatives within the city has the ability to alter the socio-economic dynamics of neighborhoods and lead to green gentrification (#34: -2).

5.3.2. Group Two: Institutional Interventionist

The Institutional Interventionist perceives integrated management approaches as well as developing economic instruments to put a value on stormwater as critical to resolving problems related to stormwater (#20: +3; #14: +3). In total, five respondents loaded onto this factor or group. One works for a prominent national environmental organization, another works for the

State government, two work for local environmental NGOs, another works for the Cook County, and the remaining respondent works for the Metropolitan Water Reclamation District of Greater Chicago. Table 9 provides an overview of statements associated with this group.

Table 9. Institutional Interventionist distinguishing statements.

Group Two: Institutional Interventionist		
Statement (significant at p>0.05)		Rank
1.	One of our biggest barriers is increased regulation.	-2
4.	The trouble within the city is that we're so congested and built up we don't have the space for many types of green infrastructure; space is a significant limitation.	1
11.	Science and data should direct decisions on stormwater and infrastructure. We need data driven and fact-based approaches drawing on the best available science and engineering.	2
14.	Stormwater management needs economic instruments to put a value on stormwater and make it a resource rather than a hazard.	3
20.	An integrated management approach is critical. There needs to be a shift towards more integrated approaches across all of the institutions and sectors concerned with the management of water.	3
30.	Larger centralized projects for handling and capturing stormwater are typically more cost-efficient than trying to treat it at thousands of small sources. Centralized stormwater projects make more financial sense than distributed and decentralized stormwater projects.	-2
32.	Resilience of urban water systems will be improved by moving away from the centralized model and using more distributed solutions like green infrastructure.	2
33.	Distributed projects are not effective; they don't scale up across the city or to other sites and will never meet the level of stormwater abatement and/or capture needed.	-2
35.	For every dollar we spend on a water quality project that's one less emergency service dollar, recreation dollar, or funds for other services. It's hard to justify money for stormwater management.	-3
37.	I think there definitely will be a need for new institutions and rules to manage stormwater.	2
40.	Rather than focusing on new development, we need to focus on the existing development and encourage retrofitting. Only looking at new developments hurts us.	2

In addition too more integrated approaches and placing a value on stormwater, this group has a preference for more distributed projects. They agree that urban resiliency is likely to increase by moving away from a centralized model and adopting alternative solutions like green infrastructure (#32: +2). This is reflected in their disagreement with the statement that distributed projects are not effective, do not scale up, and will not meet the level of stormwater abatement needed (#33: -2). Similarly, this group disagrees with the perspective that larger centralized facilities are more cost-effective and make more financial sense than distributed and decentralized projects (#30: -2). While sufficient urban space to implement green infrastructure is perceived as a limitation (#4: +1), they see retrofits on the existing built environment, in tandem with newly installed green infrastructure, as a means to overcome some of these limitations (#40: +2).

A common position among the actors is that these decisions should be data driven and fact based (#11: +2), but improved science and data will not be sufficient to garner significant change. Instead, the data-driven approaches need to be linked with improved, and possibly new, institutions and rules to manage stormwater (#37: +2). Like the Infrastructural Interventionist, the Institutional Interventionist disagrees that one of the biggest challenges is increased regulation (#1: -2) and that it is hard to justify money for stormwater management (#35: -3). What sets this perspective apart, however, is their sentiment towards creating institutions and rules that foster integrated approaches. This will lead to garnering multiple benefits and reduced costs, as one respondent noted in a post-sort interview, because “integration leads to synergistic design which saves money, provides greatest benefits, and meets the needs of the community.” The respondent goes on to note that it is becoming easier to justify money for stormwater management due to an increased awareness among people “that there are other benefits besides just managing stormwater that they can get from their investments” (Respondent 40, April 2015).

5.4. Points of Agreement

Actors’ perspectives and preferences towards stormwater management tend to converge around developing approaches that are integrated and capable of utilizing market, economic, or financial principles (#20: +2, +3). Additionally, it is a commonly shared perspective across both factors that both market forces and increased regulation are necessary for effective stormwater management, which explains why respondents tend to disagree that one of the biggest barriers is increased regulation (#1: -2). This is important as it provides a common foundation that both perspectives can draw from and potentially come to an agreement on. As one respondent explains, "existing regulations are clearly not enough to effectively manage stormwater. While improvements to local codes and ordinances are needed, this has to be part of an integrated approach to maximize benefits and efficiently manage water as a resource" (Respondent 1, April 2015).

As means to foster integrations, both factors lean towards developing economic instruments capable of placing a value on stormwater (#14: +2, +3; #17: -1, -1). Respondents tended to favorably view the development of a tradable credit system to encourage investment in green infrastructure at the lowest possible cost (#12: +1, +1). Part of this is driven by a vision of sustainability that reflects a balance among the three pillars of sustainability—the economy, the environment, and equity. As one stormwater professional lamented, "If there is an economic driver people respond to that. All too often we are only driven by that and nothing else, but slowly we're moving to recognize that sustainability is a three legged stool and economics is just one of those legs and the others should get equal weight" (Respondent 32, May 2015). Scientific and data driven approaches, however, should guide decisions capable of balancing all aspects of sustainability (#11: +3, +2).

Both groups strongly disagree that every dollar spent on a water quality project represents fewer dollars for emergency services, recreation, or funds for other services (#35: -3, -3). As one respondent explains:

> Water quality projects, and the money to pay for them, can help reduce the need for emergency services by improving flood prevention and mitigation. They can also improve recreational opportunities, create jobs, and provide many other benefits. It's easy to justify money for stormwater management because insufficient management of stormwater is extremely costly. (Respondent 1, April 2015)

As another respondent goes on to note, citing New York and Philadelphia as examples,

> They did a triple bottom line analysis that showed that for every dollar they invest in green infrastructure, they're gonna see two dollars in benefits. That's everything from reduced urban heat island effect, improved stormwater controls, reduced mortality, reduced absenteeism, improved school performance. (Respondent 37, August 2015)

In addition, actors view green infrastructure or LID as the approach that offers the most economic benefits by deferring investments in large grey infrastructure projects or replacing it entirely (#31: +1, +1).

Actors also tended to disagree that stormwater fees are problematic and not a feasible approach to achieve long-term success (#22: -2, -2). As one respondent noted,

> Municipalities need fees and cost sharing plans. Development needs to be ultimately responsible for its own actions and displacement of water, whether you are a mega church with a sea of parking, or a road, it will happen when cities stop taking responsibility for everyone's hair-brained development schemes. (Respondent 3, April 2015)

In Chicago, stormwater is the only major infrastructure system that is not typically paid for through user fees. For many of the respondents the failure to implement fees for stormwater is the fault of many of the political leaders in Chicago who may not be knowledgeable about stormwater issues or have the incentive to innovate (#10: +1, +1).

While respondents in both groups were inclined to agree that political leaders needed to be more informed and that fees and economic measures need to be utilized, they tended to be ambivalent towards community driven interventions aimed at homeowners (#26: 0, +1). Similarly, actors often remained neutral over questions aimed at the capacity of NGOs to better address stormwater issues and implement green infrastructure (#39: 0, -2). As one respondent, a director of a local NGO, noted, “NGOs are never going to be able to change the handling of stormwater – this is a jurisdictional issue in Illinois, where we have given every small municipality the ability to do whatever they want” (Respondent 3, April 2015). The respondent was clearly talking about the role of NGOs more broadly across the state of Illinois, but saw a role for NGOs to partner with and do outreach to decision makers at the city, state, and if necessary federal level. This also helps explain the indifference among many of the respondents in directing outreach and education at the household and community level because it is believed that efforts should be directed at government officials with the decision making capacity to implement changes.

5.5. Points of Disagreement

The results indicate important points of difference between factors. Conflicting points of perspective primarily center on infrastructure and its development and implementation. In particular, social perspectives diverge over the role of large infrastructural systems in stormwater mitigation and its role for water quality and supply (#28: 2,-1). This presents the biggest point of disagreement between both groups. Conflicting points of perspective primarily center on infrastructure and its development and implementation. In particular, social perspectives diverge over the role of large infrastructural systems in stormwater mitigation and its role for water quality and supply (#28: 2,-1). This presents the biggest point of disagreement between both groups. The other points of disagreement between the factors are revealing this this regard. Infrastructural Interventionists favor large infrastructure, but also perceive there to be a cultural problem where engineers only see engineering solutions (#7: +1, -1). In contrast, the Institutional Interventionist does not strongly perceive a cultural division, but views large infrastructure with more skepticism. These contradictory positions defy any simple division between knowledge and preferred infrastructural type, perhaps indicating that differences may not be as fixed as the analysis shows.

Further examining the statements showing the most variance in scores, what is revealing is not necessarily a set of polarizing visions, but one factor strongly holding a position while the other factor maintains a more neutral position. The Institutional Interventionist, for example, strongly holds that the resilience of urban water systems will be improved by moving away from the centralized model and by embracing green infrastructure, but the Infrastructural Interventionist remains neutral on this point (32: 0, +2). Similarly, the Institutional Interventionist more strongly shows a need to focus on existing development while the Infrastructural Interventionist remains more noncommittal to this approach (40: 0, +2). The same also goes for perspectives related to the need for new institutions and rules, with the Institutional Interventionist favoring this perspective while the Infrastructural Interventionist remains noncommittal (37: 0, +2). These differences continue to reveal the uneasy discords related to the preferred types of management approaches.

Moreover, it is notable to distinguish the points the Infrastructural Interventionist agrees with but the Institutional Interventionist views more neutrally. Two statements, in particular, stand out. The first is the creation of mitigation banking for stormwater management (#16: +2, 0). This divide is largely attributed to the way in which mitigation banking is perceived, either as enabling market participants to develop the most cost-effective means for mitigating stormwater or as enabling some actors to avoid implementing on-site mitigation measures. The second is on the development of stricter laws and regulations to address stormwater (#9: +3, 0). While the Infrastructural Interventionist strongly holds that there is a need for stricter laws and regulations and the Institutional Interventionist views this statement with less confidence, this difference is likely more attributable to the Institutional Interventionist desiring better enforcement and more integration among the institutions involved in stormwater management.

Finally, it is also worth noting the areas of disagreement where one factor interpreted a statement negatively whereas the other factor perceived the statement neutrally. The diverging statements center primarily on two statements. The first is on the role of private interests in developing stormwater controls. The Infrastructural Interventionist strongly disagrees with the statement that corporations and private interests should have a chance to participate in forming stormwater abatement targets, however the Institutional Interventionist is more impartial to the statement (#15: -3, 0). The impartiality presented by Institutional Interventionists should not be read as an ambivalence towards private actors participating in the development of targets they need to be held accountable for, but instead as a preference for market oriented approaches that involve the private sector. The second focuses on the perceived financial advantage centralized stormwater projects may offer. The Institutional Interventionist disagrees with the assertion that centralized stormwater projects make more financial sense than distributed and decentralized stormwater projects, but the Infrastructural Interventionist maintains a more unattached positions. The differences reflected in these two statements signal one of most confrontational points that may present barriers to further improving stormwater management. The statements reflect differences in perceptions of financing infrastructure to meet stormwater abatement targets and the type of infrastructure to put in place, which remains a contentious issue—one that may impede inter-stakeholder cooperation. In terms of policy implications, it would be worthwhile for those organizations vested in stormwater controls to better communicate the social and economic impact of improved stormwater infrastructure (whether centralized or distributed) and place them under different implementation scenarios as a means to talk in between these potentially disruptive differences.

5.6. Conclusion

This article examined the ways stakeholder preferences and perspectives of stormwater management converge and diverge. As environmental governance and decision-making comes to embrace the participation of a wider range of professions and stakeholders, understanding how the often multiple and fragmented perspectives of people are connected and disconnected to each other is important for shaping more sustainable transitions of urban landscapes, ones that align with social and ecological values. Scholars such as Hajer and Fischer (1999) have suggested that vague expressions of sustainable development introduced into policy frameworks produce generative metaphors capable of bringing these multiple and potentially conflicting parties together.

As planners continue to interact and engage with new forms of governing environmental resources in the city, such as stormwater, new perspectives assemble around existing and emerging institutional and policy frameworks (Ward, 2013). This study revealed two diverse and multi-dimensional conceptual framings of stormwater management options in Chicago. The Infrastructural Interventionist prefers stricter laws and regulations, coupled with more scientific and data-driven approaches, as the best route towards achieving more sustainable forms of urban stormwater infrastructure and management. The Institutional Interventionist perceives new institutions and rules to foster integrated management approaches, as well as economic instruments capable of assigning a value to stormwater, as critical to resolving stormwater problems. Conflicting points of perspective arise around the preferred type of infrastructure to be implemented to deal with stormwater and its development and implementation. Further research into how grey and green approaches may complement each other may help resolve some of these differences. The different framings come together around actors' perspectives and preferences towards developing approaches that are integrated and capable of utilizing market, economic, or financial principles. Finally, the combination of Q-method with semi-structured interviews permits a way of examining the converging and diverging patterns in the way people structure their understandings of stormwater management options in Chicago. As this study revealed, in planning environments where local officials share many of same broad goals of developing more sustainable cities but may disagree on the means to achieve them, Q-method provides a means to understand the sometimes contradictory and complicated interactions between decision-makers.

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Chapter 6: Framing the relationship between stormwater and the city

Abstract

This paper concentrates on how people engaged within diverse and multiple networks of institutional and bureaucratic practice come to different understandings of stormwater governance in Chicago and Los Angeles. By characterizing expert attitudes toward stormwater in cities with different political, technological, and climatic regimes this research accounts for geographical and institutional variations in environmental knowledge and the ways people understand stormwater governance. Drawing on Q-methodology and semi-structured interviews the results indicate four contrasting domains of knowledge: Science-driven Market Skeptic, Hydro-managerial, Market Technocrat, and Stormwater Pragmatist. Each of these represents a particular and contingent set of subjective positions about how stormwater governance should proceed. Subject positions align around shared framings of integrated water resource management and the utilization of the best available science and technology to drive decision-making. These framings nonetheless exist along a spectrum among those involved in stormwater management but formulate a set of cohesive stances towards how stormwater should be managed to improve water quality and quantity problems. Divergence centers on differences in the perceived effectiveness of different types of infrastructural interventions, of market and economic incentives, and how new institutions and rules to govern stormwater should be crafted.

6.1. Stormwater and the City

Cities are complex ecosystems where plants, water, animals, and other elements of the material world come face-to-face with the politics, social norms, and rules of humans to create novel forms of urbanization. Stormwater, however, is an often overlooked but integral part of these urban ecological relationships. From flood risk to water quality, and from water supply to notions of urban sustainability and resilience, stormwater presents a particularly unique management challenge for cities. Overcoming and negotiating the challenges presented by water's multiple roles and functions requires particular modes of social, political, and economic control to enable transformations of how society and water interrelate (Bakker, 2014; Linton and Budds, 2014).

Traditionally, approaches to stormwater management in the United States sought to reduce the impacts of urban flooding or to mitigate public health concerns (Karvonen, 2011; Melosi, 2000). Progressive Era reforms, in particular, profoundly influenced the relationship between stormwater and the city. During this time, social and environmental problems came to the fore of policy-making as ever more complex, necessitating the need for improved organizational structures to address them. Usually this meant an expansion of bureaucratic institutions meant to deal with societal problems and policy-making through objective expert management. This new structure placed engineers in government bureaucracies to craft management systems and public policy that would run systematically and efficiently. The emergent form of technocratic decision-making sought to impose order on the urban landscape through rational planning (Scott, 1998). Engineers and technical experts focused on channeling large volumes of stormwater away from the city through conveyance systems, and emphasized centralized structural approaches, such as storm drains, sewers, basins, and treatment facilities

(Porse, 2013). The legacies of these interventions to direct the flows of stormwater and craft a systematic and efficient urban metabolism are reflected in the infrastructural forms and bureaucratic functions of the modern city.

While the increased efficiency of urban stormwater metabolisms improved sanitary conditions and flood control in most cases, the approaches advocated during the Progressive Era conflicted with concerns over water quality. This came to fruition in the United States with the 1972 passage of the Clean Water Act (CWA) that initiated a basic regulatory structure for managing aquatic discharges of pollutants. The legislation set national policy to develop programs to control point and nonpoint sources of pollution. The diffuse character of nonpoint sources and urban runoff, however, created enormous challenges for municipalities and led to little progress in addressing stormwater through the 1970s and 1980s (Karvonen, 2011). Amendments to the CWA in 1987 helped resolve this by establishing a permitting program—the National Pollutant Discharge Elimination System (NPDES)—to establish minimum standards for stormwater treatment. The introduction of this legislation marked a break from many of the traditional approaches to stormwater management, which favored centralized "end-of-pipe" solutions.

Recent approaches to stormwater management incorporate decentralized and distributed methods that focus on local source control through on-site retention and recharge. Influenced by Phase II of the CWA to implement "minimum control measures", cities are beginning to experiment with ways to increase public education and outreach, public involvement, illicit discharge detection and elimination, construction and post-construction site runoff control, and pollution prevention (EPA, 2005). These efforts typically center on developing structural and non-structural Best Management Practices (BMPs). Non-structural BMPs focus on developing ordinances and education initiatives to improve water quality, while structural BMPs entail physical changes to infrastructure or the landscape to reduce the environmental impact of stormwater, often through green infrastructure (GI) or low-impact development (LID). GI is one type infrastructural intervention that is intentionally designed to utilize ecological processes to retain and treat stormwater. The decentralized and distributed character of these infrastructural interventions to manipulate the flows of stormwater, however, enroll a wide range of stakeholders into the governance process, including landowners, businesses, community groups, non-governmental organizations (NGOs), and a range of government agencies. In the United States, this creates a multilevel governance system where connections between vertical tiers of government create a hierarchical structure (local, regional, state, national) and horizontally (non-hierarchical) organized forms of governance that link together multiple city departments, environmental advocacy groups, and civic organizations through inter-agency working groups, task forces, public participation, and informal networks (Betsill and Bulkeley, 2006; Dhakal and Chevalier, 2016; Porse, 2013). These efforts entail changes to physical, bureaucratic, and institutional infrastructures to reorient stormwater flows.

While more recent shifts in urban stormwater management signal a pronounced shift from the Progressive Era logic of urban drainage, technical experts continue to dominate the realm of urban environmental governance. In many cases stormwater remains a fluid object, embodying different social, political, and bureaucratic lives as it flows across the landscape. It is at once a nuisance, a hazard, a commodity, and a resource. This multiplicity reflects the ways stormwater is a social and political construct, embodying a plurality of individual and institutionally based subject positions, and competing interests in how to best manage, control, and capture stormwater. This is despite new rules and regulations to facilitate integration and reduce “vertical fragmentation” between levels of government and “horizontal fragmentation” across levels of government. How then do we account for the variations in the ways rules and regulations shape thought and actions in and between institutions, as well as those tasked with managing stormwater, and to what effect on urban stormwater governance?

To answer this question, I engage with scholarship taking critical approaches to urban water governance to understand the relationship between urban stormwater flows and subject formation (Linton and Budds 2014; Cousins and Newell 2015; Finewood and Holifield 2015). I empirically focus on how technical experts situated within diverse networks of institutional and bureaucratic practice come to different understandings of stormwater governance in Chicago and Los Angeles. By characterizing expert attitudes toward stormwater in cities with different political, technological, and climatic regimes this research allows for a broader analysis of subject formation that accounts for variations in environmental practices and geographical differences, but also how diverse forms of expertise are negotiated and come to shape urban political ecologies. The paper argues that perspectives are forged through geographically and institutionally based practices that seek to control the flow of stormwater, albeit in often apolitical strategies that bifurcate social and hydrological systems in order to achieve water quality and quantity goals.

The following section outlines the theoretical framework, which draws on recent scholarship in urban political ecology at the interface of urban metabolism and the hydrosocial cycle. Specifically, I use this literature to draw attention to how different modes of expertise and environmental practice structure different ways of claiming authority to hydro-social relations. I then review stormwater challenges in Los Angeles and Chicago before outlining the methods.

The results and discussion focus on how different ways of knowing urban water systems interact and to what consequence on more equitable forms of urban environmental governance.

6.2. Urban metabolisms and the hydrosocial relations

Urban political ecologists frequently draw on notions of metabolism to characterize the socio-natural relations that transform urban ecosystems through the exchange and circulation of resources, capital, humans, and non-humans into and out of the spaces of global urbanization (Newell and Cousins, 2015; Swyngedouw, 2006b). Similarly, the hydrological processes, social practices, infrastructures, technologies, and landscapes that comprise the hydrosocial cycle influence how water circulates as a resource through nature and society (Bakker, 2003a). Urban water metabolisms thus reflect a range of social and technical systems, as well as the hydrological cycle in a "socio-natural process by which water and society make and remake each other over space and time" (Linton and Budds, 2014, p. 6). Bringing a socio-material focus to stormwater, where on the one hand it is a material flow that unevenly circulates through the city, and on the other, an object of social and political action, allows for an investigation into the ways power/knowledges, subjectivities, and institutions interact to influence environmental governance.

Research at the interface of urban political ecology and hydrosociality drawing on the metabolism metaphor excel at showcasing the complex networks of power that entangle nature, society, and technology (Domènech et al., 2013; March, 2013). Meehan (2013, 333), for example, takes a biopolitical approach to water theft where "the monitoring and tracking [of] infrastructure and bodies" maintains hydrosocial order and disciplines informal development. Anand's (2011, 545) theoretical development of "pressure" also works as a useful analytic to understand the formations of hydraulic citizenship: “a form of belonging to the city enabled by social and material claims made to the city’s water infrastructure.” Other work has examined the water-energy nexus (Delgado-Ramos, 2014; McDonnell, 2014), the ways hydrological science and social order become co-produced through the categorization of the environment (Bouleau, 2014), and the modernization of water systems and hydraulic control (Banister and Widdifield, 2014; Kaika, 2005; Swyngedouw, 2015). Although these studies take diverse analytical and methodological approaches, they succeed in revealing the power dynamics shaping urban metabolisms and hydrosocial relationships and highlight the co-production of human and non-human networks (Banister, 2013; Latour, 2005).

Nonetheless, many gaps remain in the ways scholars approach the relationship between metabolic urbanization and subject formation. As Arboleda (2015, 36) notes, “the extent to which these urban metabolisms can also translate into the production of urban subjectivities has not yet been fully developed.” Arboleda addresses this shortcoming by engaging with Hardt and Negri's (2009, 2001) theorizations of immaterial labor and biopolitical production, which argue that the dominant form of labor under the current political economic paradigm is immaterial; meaning labor produces “immaterial products, such as knowledge, information, communication, a relationship or emotional response” (Hardt and Negri, 2004, p. 108). This framework is then applied to a case centered on struggles over water threatened by large-scale mining projects to show how collaborative engagement from below, rather than top-down, produces new forms of community and social subjects. Other scholars address the perceived lack of subject-forming dimensions within urban environmental governance by engaging with post-structural and feminist political ecology to understand the forms of urban metabolic interaction that produce novel forms of urbanization (Grove, 2009). Kooy and Bakker (2008), for example, draw on

Foucaultian theories of governmentality to explore the interrelated formations of subjectivities, urban spaces, and urban infrastructure that influence water access in Jakarta. Loftus (2012) also accomplishes this by centering everyday subjectivity at the heart of environmental politics.

I use these studies as a departure point to ask: how does an urban metabolism structure subjectivity and to what effect on hydrosocial relations? I argue that in order to understand how stormwater circulates through the hydrosocial cycle, one needs to interpret the politics of urban metabolism as conditioned by the material flow of resources into and out of cities, as well as a domain of subject formation fostered through differently situated practices that unevenly bring humans into relation with resources. I suggest, that the conditions influencing the emergence of a particular subjectivity formulate out of the institutional and regulatory mandates that task water resource managers with addressing problems related to the material flow and circulation of stormwater. Government interventions to resolve water quality and quantity issues, for example, impose management systems that organize the flow of stormwater by restructuring social and natural processes. These systems, however, are not uniform. Instead, drawing on Foucault's notion of a *dispositif*, they are:

> A thoroughly heterogeneous set consisting of discourses, institutions, architectural forms, regulatory decisions, laws, administrative measures, scientific statements, philosophical, moral, and philanthropic propositions—in short, the said as much as the unsaid. Such are the elements of the apparatus [*dispositif*]. The apparatus itself is the network that can be established between these elements. (Foucault, 1980, p. 194)

The goal of the study is to understand how the elements of the *dispositif* relate to one another and structure the subjectivities of stormwater experts. This investigation into governmentality encompasses the "ensemble formed by institutions, procedures, analyses and reflections, calculations, and tactics that allow the exercise of this very specific, albeit very complex, power" (Foucault, 2007, p. 108). However, many variations exist—both geographically and across institutions and organizations—in terms of the type of social and political power relations that shape how one comes to interact and understand the environment (Agrawal, 2005). My analysis teases apart the particular ways these variations come to structure different forms of knowing and regulating the environment, and how different modes of expertise differentially claim authority over how hydro-social relations should occur.

6.3. Stormwater Challenges in Chicago and Los Angeles

Managing stormwater in cities like Chicago and Los Angeles is an enormous task that fosters many different types of governmental and infrastructural interventions to control and manipulate it. Both cities are recognized leaders in addressing stormwater challenges in the United States (Chen and Hobbs, 2013), but their unique concerns stem from their particular legacies of urban development and climate and precipitation patterns. The transformation of permeable natural areas into impervious surfaces such as roads, parking lots, and rooftops has frustrated city planners and engineers in both cities. Chicago and Los Angeles, however, took different paths in their attempts to intervene and improve the circulation of stormwater into and out of the city.

In the 1850s, Chicago was among the first cities in the United States to construct a stormwater conveyance system that combined wastewater and stormwater to direct the flows of water away from people and urban development towards treatment plants (Burian et al., 2000). The construction of combined sewers became the predominant sewerage system through the late 19th century for most American cities and was based on scientific understandings of the time that proposed that running water purified itself—this was used to justify the deposition of sewage into nearby waterways (Tarr, 1979). In Illinois, stormwater management is devolved to the county level. In Chicago, the Metropolitan Water Reclamation District is in charge of developing a countywide stormwater management program for Cook County and maintaining compliance with the federal and state NPDES Phase II requirements. The Illinois Department of Natural Resources is also involved as the regulatory agency involved with construction occurring in floodways and waterways and providing floodplain management.

In contrast, Los Angeles developed a municipal separate storm sewer system (MS4). Unlike the combined sewers found in Chicago, the MS4 in Los Angeles only contains untreated stormwater, which can include suspended metals, trash, pesticides, and fertilizer. This water is discharged to the Los Angeles and San Gabriel Rivers, eventually arriving in the Pacific Ocean. The MS4 system is a legacy of governmentalized efforts to improve flood control and protect and encourage urban development. While 1914 marked the establishment of the Los Angeles County Flood Control District (LACFCD), the passage of the Flood Control Acts of 1936 and 1938 would bring them into partnership with the Army Corps of Engineers. Together they would develop a comprehensive flood control plan known as the Los Angeles County Drainage Area (LACDA). The LACDA consists of over 500 miles of open channels, including portions of the Los Angeles River, 2,800 miles of storm drains, and numerous flood control and debris basins (LA County DPW, 2015).The California State Water Resources Control Board is in charge of issuing the NPDES permits for Los Angeles County, with the LACFCD designated as the Principal Permittee to coordinate and facilitate activities directed towards improving water quality and maintaining compliance with regulatory requirements. This creates a complicated network of stakeholders that emerge in relation to addressing problems of water quality and quantity in Los Angeles.

Despite important differences in infrastructural form and governance, both cities face similar challenges in meeting their water quality targets established in NPDES permits and in establishing financial mechanisms to fund stormwater infrastructure projects. Many uncertainties also remain in knowledge around actual costs and benefits to manage stormwater, the effectiveness of decentralized and distributed systems like GI and LID, maintenance, and finding space within the city. Strategies in both cities include market based approaches like mitigation banking to citywide ordinances and rebates to incentivize stormwater capture projects, GI and LID, and regulatory structure reform. These are all technical approaches, however, that partially look to value stormwater as resource through the utilization of GI and new forms of participatory and market-based governance. While the expert logic is based on finding solutions that advance economic growth and environmental conservation, it consequently depoliticizes the power-laden social relationships under which different forms of knowledge are debated and become normalized among communities and individuals. With many forms of expertise existing at multiple scales of governance, from the national level to the neighborhood and community, it is important to ask how different forms of environmental practice influence different ways of understanding how stormwater governance should proceed.

6.4. Methods

This paper uses Q-Methodology to understand how different actors relate to one another and posit relationships between knowledge, power, and subjectivity (Watts and Stenner, 2012). The method provides a quantitative and qualitative technique that bridges the divide between more traditional and post-positivist approaches to policy research (Ellis et al., 2007). The approach developed as a way to render different subjective framings available to statistical analysis with the goal of revealing different arrangements of shared viewpoints about a topic (Brown, 1980).

The research proceeded in multiple phases between May 2014 and June 2015. During the initial phase a concourse of statements was assembled from academic articles, newspapers, policy documents, NGO publications and semi-structured interviews with key actors involved with stormwater management in Chicago and Los Angeles. The selection of these two cities was based on a desire to potentially increase the heterogeneity in actor responses and to understand how geographical and institutional context may shape one's perspective. Common in Q-methodology, the subjects were purposively chosen to represent the heterogeneity of expert opinion on stormwater management, which included NGO leaders, as well as city, county, state, and federal officials (Brown, 1980; Cotton and Devine-Wright, 2011). Statement collection continued until the addition of new statements no longer provided new elements to the concourse (Eden et al., 2005; Glaser and Strauss, 1967). Following recommendations in the literature, the concourse was reduced to 40 representative statements, which captured perceptions of how stormwater should be managed (Webler et al., 2009).

In phase two, purposively selected participants sorted the statements into a quasi-normal distribution. Purposively choosing participants is typical of Q-methodology, which is concerned about connections between respondent viewpoints rather than the distribution of beliefs across a population or sample (Robbins 2006; Brannstrom 2011). The 42 respondents include a subset of the original interviewees plus additional participants from a snowball sample. The Q-sorts were administered in April 2015 through Q-Assessor software (http://q-assessor.com). The online platform allowed for the administration of Q-sorts in-person with an iPad or remotely at the convenience of the respondent. This approach was preferable for some respondents who favored conducting the survey online by themselves and then having a follow-up interview. This is in contrast to traditional applications of Q-methodology, which are typically conducted in-person.

Utilizing both in-person and online Q-sorts is supported in the literature and reveals no significant difference in the validity of in-person sorts versus those carried out remotely by mail or online (Cairns and Stirling, 2014; Gruber, 2011; Reber et al., 2000; Tubergen and Olins, 1978). Once participants agreed to the study, an online interface presented respondents with a grid organized in a quasi-normal distribution and asked them to sort statements along a scale from +3 (most agree) to -3 (most disagree).

The final phase utilizes factor analysis to mathematically create new variables, or factors, that explain variation among the Q-sorts. Using PQMethod software, this study used centroid analysis to find the common orderings of statements among the different Q-sorts. Using the Kaiser-Guttman criterion (eigenvalue >1.00) as a guide, four factors were extracted (Guttman, 1954; Kaiser, 1960; Watts and Stenner, 2012). These factors were then rotated with varimax rotation. This widespread procedure extracts all of the significant factors and produces a solution that maximizes the percentage of explained variance and the number of individuals associated with a single factor or grouping (Setiawan and Cuppen, 2013; Webler et al., 2009). The output produces an idealized sort for each factor, which represents a distinct viewpoint or domain of subjectivity (Barry and Proops, 1999).

6.5. Results: Four domains of hydro-social relations

Four factors, or knowledge groups, emerged from the analysis. For ease of readability I define them as: (1) Hydro-reformist, (2) Hydro-managerialist, (3) Hydro-rationalist, and (4) Hydro-pragmatist (Table 10). Each group captures a domain of subjectivity, which collectively accounts for 53% of total variance (Table 11). Subject formation converges around shared framings of integrated water resource management (IWRM) and the utilization of science and technology to drive decision-making. While this cohesive set of framings exists along a spectrum of those involved in stormwater governance, consensus on how to proceed may mask fundamental differences among varying groups of expertise. Contrasting perspectives center on the effectiveness of different types of infrastructural interventions, of economic incentives, and how new institutions and rules should be crafted. Aside from the Hydro-managerial perspective, all other perspectives share stakeholders from each city.

Table 10. Factor array of Chicago and Los Angeles perspectives of stormwater governance.

	Statement	Group			
		1	2	3	4
1.	One of our biggest barriers is increased regulation.	-2	**1**	-2	-2
2.	Implementation is a barrier in large part due to NIMBY type of concerns. People do not want to be liable.	-1	1	0	0
3.	We lack the data needed for the adoption green infrastructure and to accurately quantify its performance.	**0**	**2**	-2	-1
4.	The trouble within the city is that we're so congested and built up we don't have the space for many types of green infrastructure; space is a significant limitation.	-1	2	1	-1
5.	Climate uncertainty is the most difficult challenge for proactive adaptation planning for stormwater management.	-1	0	**-3**	**1**
6.	Land-use change presents the most difficult challenge to stormwater management.	-1	-1	-1	**0**
7.	I think there is a cultural problem. Stormwater engineers see only engineering solutions and green infrastructure is not part of that.	1	**-2**	0	**0**
8.	Getting people to apply to incentive programs is problematic because people don't care about stormwater management and lack knowledge of water issues.	0	**-3**	0	-1
9.	We need stricter laws and regulations to address stormwater because change is not going to happen voluntarily.	1	0	**3**	1
10.	Failure to address stormwater, like climate change, is a fault of political leaders; they are the ones who need to be educated and incentivized to innovate.	0	**-1**	0	1
11.	Science and data should direct decisions on stormwater and infrastructure. We need data driven and fact-based approaches drawing on the best available science and engineering.	3	**2**	2	2
12.	Development of a tradable credit system, with appropriate regulatory safeguards, will encourage investment in green infrastructure and help deliver stormwater mitigation at the lowest possible cost.	**-1**	1	1	1
13.	We need market based approaches and fewer government interventions and regulations to finance stormwater management.	-2	**0**	-2	**-1**
14.	Stormwater management needs economic instruments to put a value on stormwater and make it a resource rather than a hazard.	**0**	1	2	2
15.	Corporations and private interests should have the chance to develop their own targets for stormwater abatement.	**-3**	**0**	**-2**	**-1**
16.	A mitigation bank for stormwater will help foster public-private partnerships to address stormwater by allowing developers to meet LID requirements by paying into that bank.	**0**	1	**2**	0
17.	Stormwater, or water more generally, should not be guided by market, economic, or financial principles.	**1**	**-2**	-1	-1
18.	Waste water, water supply, flood water, water quality and all of that stuff is just water. If you just think of it as one water then you can manage it much more efficiently.	**2**	**-1**	1	0
19.	We don't need more integrated approaches. We need better enforcement of existing regulations and improvement of local codes and ordinances; integrated water resource planning is not the answer	-2	**-2**	**0**	-3
20.	An integrated management approach is critical. There needs to be a shift towards more	3	3	**2**	3

	integrated approaches across all of the institutions and sectors concerned with the management of water.				
21.	We need stormwater fees. Municipalities need fees and cost sharing plans.	2	1	**3**	1
22.	Stormwater fees are not feasible, nor are they enough for successful implementation in the long term. Stormwater fees are problematic.	-1	-1	-3	-2
23.	Stormwater needs to be held and used on-site; there are too many concerns about unregulated off-site mitigation.	1	-1	0	0
24.	Stormwater mitigation should be able to occur off-site; it offers more flexible opportunities. Off-site approaches lead to better outcomes than on-site.	**-1**	0	0	0
25.	We need to maintain the narrative of engagement by redefining city services and bringing the expertise to the neighborhoods. We need a grass roots community driven approach to create better outcomes.	1	0	0	1
26.	Homeowners need to be educated and they need to educate each other about the benefits of improved stormwater management. They need to be the targets of interventions because community driven approaches tend to be more effective than data driven approaches.	1	0	1	1
27	Local residents' contributions to decision-making usually show a lack of expertise, are not factual, or biased.	**0**	0	-1	-1
28.	Big systems and dams or reservoirs are important for floods and stormwater mitigation, but after the rain, how you handle that water is important for water quality and/or supply.	2	**2**	2	**0**
29	Centralized urban water systems are maladapted to address climate change impacts and environmental stressors.	1	-1	-1	2
30.	Larger centralized projects for handling and capturing stormwater are typically more cost-efficient than trying to treat it at thousands of small sources. Centralized stormwater projects make more financial sense than distributed and decentralized stormwater projects.	-1	**3**	0	**-3**
31.	LID offers economic benefits, such as deferring or even replacing costly large grey stormwater infrastructure projects. LID is more cost effective than gray infrastructure.	2	**0**	1	2
32.	Resilience of urban water systems will be improved by moving away from the centralized model and using more distributed solutions like green infrastructure.	1	**-2**	1	**2**
33.	Distributed projects are not effective; they don't scale up across the city or to other sites and will never meet the level of stormwater abatement and/or capture needed.	-2	-1	-1	-2
34.	As we build green infrastructure we are going to change the nature of neighborhoods. We are going to push working class people out as we build more economic development around green space.	-2	-1	-2	-1
35.	For every dollar we spend on a water quality project that's one less emergency service dollar, recreation dollar, or funds for other services. It's hard to justify money for stormwater management.	**-3**	-2	-1	-2
36.	I'm really opposed to creating new institutions or rules to manage stormwater. There are too many agencies and there is too much diversity already.	0	**2**	0	**-2**
37.	I think there definitely will be a need for new institutions and rules to manage stormwater.	**0**	**-3**	**-1**	**3**
38.	With many community groups and NGOs there are issues with them maintaining the infrastructure or with them focusing too narrowly on certain issues.	0	1	1	0
39.	I think there's enough NGO capacity within the city to have a better coordinated and more strategic approach to green infrastructure.	0	0	1	0
40.	Rather than focusing on new development, we need to focus on the existing development and encourage retrofitting. Only looking at new developments hurts us.	2	1	**-1**	1

Bold underlined are distinguishing statements (significant at $p<0.05$).

Table 11. Factor Characteristics

Factor Characteristics	Group			
	1	2	3	4
Eigenvalue	6.88	3.67	4.87	5.79
No. of defining variables	10	5	7	7
Composite reliability	0.976	0.952	0.966	0.966
SE of factor scores	0.156	0.218	0.186	0.186
% total variance	36.35	8.43	3.94	4.32

6.5.1. Hydro-reformist

Ten respondents comprise the “Hydro-reformist”, including two from academic institutions in Los Angeles, five non-governmental organization professionals (four from Los Angeles, one from Chicago), one county official (Los Angeles), and two city planners from Chicago. The Hydro-reformist is defined by an articulated skepticism of market-oriented approaches and a progressive vision that looks to reform current regulations and codes to alter urban environmental governance arrangements. This group reflects a strong commitment towards integrated strategies that are “data-driven” and facilitate transformation of the existing environment rather than on new development (# 20, +3; #11, +3; # 40, +2). The perspective is unique, however, in its skepticism of market-oriented approaches and the involvement of private interests in stormwater governance (#12, -1; #15, -3; #17, 1). This group also supports more regulations and more stringent code enforcement to drive reform (#9, +1). Respondents also acknowledged the value of both distributed and centralized facilities to manage stormwater and agree that GI is a cost-effective solution to stormwater management that offers economic benefits (#31, +2).

The resulting picture of stormwater is that it is much more than simply a matter of conveyance, but a matter of better science, stricter requirements, and better enforcement. Under this perspective science needs to guide the formulation of improved stormwater governance (#11, +3). A common concern, however, is the lack of data to foster science-driven approaches. Without data or models sophisticated enough to identify the type of projects needed, where they need to go, or the volumes of water captured, implementing GI and attaining water quality and supply benefits may remain elusive for the Hydro-reformist. While it is perceived that this lack of standards and quantifiable aspects of water supply and water quality benefits impedes the implementation of GI, it is also understood that redevelopment will not occur fast enough or at a large enough scale for LID and GI to have a significant impact without focusing on the existing environment (#40, +2).

For the Hydro-reformist, not only does the science have to improve but the regulations have to get better. One respondent noted:

> Current regulations continue to allow pollution at levels that endanger the environment and human health, we need stricter requirements and enforcement, not looser regulations. The current approaches are full of loopholes and opportunities for regulated parties to escape responsibility, a path unfortunately too many cities or other entities have taken. (Respondent 33, April 2015)

This is a common discourse for Hydro-reformists who perceive regulations as the primary driver fostering transitions in the ways cities relate to water.

The preference for increased regulations can be found in their skepticism of market-oriented approaches. This group does not want private interests to have an opportunity to develop their own targets for stormwater abatement (#15, -3). Here, involving private actors would allow them to evade accountability by creating loopholes. For the Hydro-reformist, government interventions and regulations need to respond to societal needs and involving the market or private actors is less likely to accomplish desired outcomes.

Respondents also strongly disagree with the statement "For every dollar we spend on a water quality project that's one less emergency service dollar, recreation dollar, or funds for other services. It's hard to justify money for stormwater management" (#35, -3). A common sentiment among the group was that the statement simply showed "a lack of appreciation for the value of water" (Respondent 38, April 2015). This group acknowledges the difficulty of justifying money for stormwater management, but as one respondent noted, it stems from "the lack of expertise and pervasive apathy demonstrated by the general public and elected officials [towards stormwater]" (Respondent 18, April 2015).

6.5.2. Hydro-managerial

The "Hydro-managerial" perspective consists of five officials from Los Angeles. The name derives from Worster's (1985, 5) framings of water resource development in the American West as "dependent on, a sharply alienating, intensely managerial relationship with nature." Three work for large municipal water agencies. Another has a background working for a large municipal water utility but now works for a NGO. The final respondent is an official from the Army Corps of Engineers. What distinguishes the Hydro-managerialist is that stormwater is considered an unharnessed resource and management needs to be altered to maximize economic gain and resource capture. Power for this group derives from their ability to exert technological control over large volumes of water. Their emphasis on quantity leads respondents towards preferring volumetric solutions that translate stormwater into market calculations of how many acre-feet captured and stored. This reflects part of an inherited paradigm of water resource management in the American West and concerns over the increasing uncertainty and instability of imported water supply sources.

Stormwater problems, in this view, are about getting the cost-benefit ratio correct. The Hydro-managerialist agrees that integrated approaches are critical (#20, +3), but views large centralized facilities as more cost-efficient than distributed solutions when considering the amount of water captured and infiltrated for flood control and water supply (#30, +3; #28 +2). This aligns with cost-benefit analyses in Los Angeles Department of Water and Power's Stormwater Capture Plan, which calculate centralized projects as offering the lowest cost per unit volume captured and distributed stormwater capture remaining in excess of the cost of imported water. As one official noted, “distributed capture is problematic in that no one ever wants to be responsible for maintenance. In a centralized facility, the [costs of] operation and maintenance is also centralized (Respondent 11, April 2015). The respondent goes on to explain their disagreement over the statement that “resilience of urban water systems will be improved by moving away from the centralized model and using more distributed solutions like green infrastructure” (#32, -2) is rooted in the data, which shows that centralized approaches are cost effective. The perspective centers on utilizing economic calculations capable of forging stormwater into a supply source.

While the Hydro-managerialist may prefer centralized solutions, they disagree that stormwater engineers do not see green infrastructure as part of the solution to the stormwater problem (# 7, -2). As one participant answered, “Engineers greatly see the social benefits of green infrastructure; however, when it comes to decision-making, particularly of public funds, measureable and tangible benefits are much easier to argue for” (Respondent 12, April 2015). This is also reflected in the sentiment among this group that space for implementing GI is a significant limitation (#4, +2). While these respondents value the function of GI, their role as public officials compels them to prefer centralized solutions which can hold up to a business case scenario.

Hydro-managerialists oppose the creation of new institutions and see increased regulation as a major barrier (#1, +1; #36, +2; #37, -3). As one official noted, “better enforcement of existing rules and development of new policy is a better option” (Respondent 22, April 2015). Nonetheless, this group prefers policies capable of allowing stormwater to be guided by market, economic, and financial principles. Another respondent noted, “I disagree with the idea that stormwater should not be guided economically. This creates a major burden on taxpayers without much benefit" (Respondent 12, April 2015). As a matter of preference, economic and market principles should be utilized to create incentive programs that encourage integration "at all levels with all stakeholders, including commercial, household, and NGOs," one respondent noted, because "the federal, state, and local governments cannot do this alone" (Respondent 22, April 2015).

Moreover, a common attitude among Hydro-managerialists is that if stormwater is economically valued as a resource, more people will become interested in its management. They disagree that incentive programs are problematic because people do not care about stormwater or lack knowledge of water issues (#8, -3), but instead see the problem as creating incentive programs that effectively encourage residents to participate. A shared sentiment among the group is that people respond to incentive programs, albeit as long as the "price is right". Beyond price, however, distributed projects and GI are seen as a mechanism to engage people about water resource issues at the neighborhood and household scale and influence their relationship with water. Distributed projects, however, are not viewed as a tangible way of securing adequate volumes of water supply.

6.5.3. Hydro-rationalist

The "Hydro-rationalist" describes seven individuals. Two are water resource engineers for the City of Los Angeles, one is an official with the US EPA, another is a water resource engineer for the City of Chicago, two are representatives for non-governmental agencies based in Chicago, and one is a member of the California State Water Resource Control Board. I define the Hydro-rationalist based on a shared emphasis on expert problem solving that seeks to establish better linkages between science, technology, and the market to foster social change and direct decisions on water and infrastructure governance (#14, +2; #11, +2).

A perception that stormwater fees, stricter laws and regulations, and market mechanisms need to all work in accordance to address stormwater is most common among the group (#9, +3; #21, +3; #22, -3). While respondents disagreed with the statement that we need market based approaches and fewer government interventions and regulation to finance stormwater (#13,-2), it is not because they do not desire market based approaches. Rather stormwater needs more government interventions *and* market mechanisms. As one respondent noted,

> A combination of environmental requirements and stormwater performance standards, along with economic incentives and flexibility to select tailored solutions for meeting performance standards based on site specific conditions will be most effective and most cost-effective for meeting stormwater goals. (Respondent 8, April 2015).

A distinguishing perspective of this group, however, is their strong disagreement with the statement that climate uncertainty is the most difficult challenge for proactive adaptation planning for stormwater management (#5, -3). These respondents understand that climate change is going to present many challenges in the future, but it is perceived at longer time-scale. As one respondent noted:

> Climate uncertainty is not important to me at this time as it potentially may become a problem, but only in the very long term. The real challenge is to figure out what to do over the next 10-20 years, and, in short, make sure that it will work. From a water quality perspective, stormwater needs regulations otherwise chances are that it doesn't happen. Market-based approaches have more chance of success for stormwater management for the purpose of using stormwater as a water resource. (Respondent 27, April 2015)

Similarities exist with other groups, in that stormwater needs mechanisms to attribute an economic value to it, but the Economic and Scientific Rationalist sees a broadened role for public-private partnerships and a role for NGOs (#39, +1). Part of this, one respondent explains, is rooted in "a kind of logic… looking for ways to share costs" (Respondent 34, June 2014). A distinguishing statement for the group was that a mitigation bank for stormwater would help foster public-private partnerships to address stormwater by allowing developers to meet LID requirements by paying into a bank (#16, +2). Here the perspective views market based approaches, like mitigation banking, as a mechanism to integrate actors across sectors and scales of environmental governance. Science and engineering, however, becomes the means and the ends of this process by providing credibility and by legitimizing the effectiveness of market-based approaches in achieving water quality/quantity goals.

While an economic and scientific rationality is important for this perspective (#11, +2), they still see other gaps to fill. The Economic and Scientific Rationalist may disagree that there is a lack of data for the adoption of GI and to accurately quantify its benefits (#3, -2), but post-sort interviews suggest that this disagreement is not entirely due to having quality data. As one respondent noted,

> The technology is working. But specific technological investments. A permeable parking lot is working, but what is not working are our planning and decision-making processes on where is the optimal location for that thing. Like if I only had $500,000 and I want to invest it in GI, how do I know I'm investing it where I'll get the biggest bang for my buck? That's not happening. So we end up with something that looks like GI but actually isn't infrastructure because it's not part of a network or system designed to solve the problem. (Respondent 10, April 2015)

The problem is not a lack of data or how well a piece of technology works, but one of how to strategically utilize the resources at hand and connect GI into a broader system of water conveyance. They do not see the development of new institutions as a way to accomplish more efficient uses of resources either (#37, -1). Rather they see enough governmental and non-governmental capacity within the city to have a better-coordinated approach to GI (#39, +1). Final decisions, however, should be guided by proper scientific and economic calculations.

6.5.4. Hydro-pragmatist

This position is based on the understanding that new rules and institutions will be needed to improve urban resilience by fostering integration and distributed stormwater capture. Three of the respondents work for major environmental NGOs based in the US. Another respondent includes a director of a NGO working solely within the Chicago region. The remaining respondents include a representative from the State of Illinois Department of Natural Resources, a director of an NGO based in Los Angeles, and an engineer for the City of Los Angeles. Drawing on Dryzek (1997, 99–100), this view reflects 'democratic pragmatism' in that they believe in "interactive problem solving in a world full of uncertainty but situated within the basic institutional structure of the current political economic system."

The Hydro-pragmatist strongly supports the development of new institutions and rules to manage stormwater (#37, +3) and strongly disagrees with the perspective that large centralized facilities are more cost-efficient (#30, -3). This is the exact inverse of the Hydro-managerial perspective. Here, new institutions and rules are key for fostering sustainability transitions and the diversity of opinions is seen as an asset rather than a barrier to better stormwater management. As one respondent noted after conducting the sort: "I disagreed with the statement that there is too much diversity and not enough room for new stormwater institutions, because to manage stormwater sustainably and efficiently, there needs to be some changes in management sources" (Respondent 16, April 2015). As another respondent also noted, "I think there definitely will be a need for new institutions and rules. Among those will be some permission or maybe a creation of mechanisms for stormwater agencies to collaborate and cooperate with water agencies (Respondent 20, June 2015). Furthermore, a different respondent noted,

> The MS4 permit is really the Big Kahuna [in driving changes in stormwater management]. And making sure municipalities fully integrate green infrastructure into

> their requirements, because otherwise, it's a good idea. It's an aesthetic preference. It's not changing the way a city makes its investments or manages their stormwater. (Respondent 37, April 2015).

Unlike some of the other perspectives, however, climate change is perceived as an important dimension influencing integrated approaches to stormwater governance. As one respondent noted, "there needs to be an integrated approach to stormwater management. With climate change becoming a big reason in the shift of stormwater management, there needs to be different perspectives in decision-making" (Respondent 16, April 2015). Here a plurality of perspectives is embraced as a way to find novel approaches to stormwater management and foster more sustainable and cost-efficient approaches through more distributed solutions (#32, +2). This perspective, more generally, embraces distributed GI projects as necessary due to a perception that centralized urban water systems are maladapted to address climate change impacts and environmental stressors (#29, +2). Hydro-pragmatists do not perceive centralized facilities as more cost-effective and efficient than distributed, integrated, green approaches due to their inability to provide co-benefits. As one respondent noted:

> Centralized projects may have worked in the past when rain events were less frequent and intense, and when less of the land was covered with impervious surfaces. The outdated infrastructure of centralized systems is crumbling in many cities, and this is forcing people to re-evaluate the logic behind these systems and their effectiveness. The need to repair this infrastructure or find alternate ways to deal with stormwater has opened the opportunity for the use of distributed solutions like green infrastructure. With increasing knowledge and awareness of these methods and the efforts of organizations and progressive leaders to encourage their use, as well as their proven success (and revealed challenges), I believe now is the time to re-envision urban water systems. (Respondent 1, April 2015)

Stormwater problems, in this view, are a product of too much emphasis on traditional engineering approaches and not scientific advances drawing the latest developments in green infrastructural design. Hydro-pragmatists tended to be the most vocal about the role of GI in mitigating the impacts of climate change and fostering more sustainable cities. Climate uncertainty is certainly considered a challenge for planning (#5, +1), but proper planning can only move forward if the available data is used to its full potential. As one respondent from Chicago noted, "We also need to take advantage of the vast amount of data available and new technologies that can be utilized to manager stormwater and use it as a resource" (Respondent 1, April 2015).

6.5.5. Converging and diverging perspectives

How do competing views of stormwater governance interact with one another? Results indicate a number of shared perspectives across groups. First, actors strongly agree that integrated approaches that connect all of the institutions and sectors concerned with the management of water are critical in meeting stormwater regulations. As one actor noted,

> Taking an integrated watershed perspective in attempting to address stormwater management is paramount. Within the existing agencies tasked to manage different forms of water within a jurisdiction, too often agency management strategies do not consider impacts outside their mandates. In other words, often the right hand does not know what the left hand is doing. (Respondent 18, April 2015)

Without a more coordinated approach across all sectors of water management, actors do not see appropriate change happening or successfully reaching regulatory requirements.

Coordinating across all sectors of water governance is also related to costs. The issue for many of those involved in stormwater management is not that it is hard to justify the money needed for stormwater management, but instead that municipalities need fees and cost sharing plans. As one respondent noted, "without local and regional stormwater fees, there will never be enough funding to make a meaningful difference in stormwater capture and re-use" (Respondent 39, April 2015).

The second major unifying point centers on utilizing science-based approaches. On the surface, this point may seem insignificant. In theory, decision-making and regulations should rely on the best available science and engineering. The significance of the alignment, however, lies in the production and utilization of knowledge. With a preference for science-driven approaches over community-driven approaches, the concern becomes one of whose knowledge counts and for what type of outcomes. This is further revealed in a shared disagreement with the statement that GI has the ability to change the nature of neighborhoods and push working class people out of their neighborhoods as more economic development revolves around green space. With evidence suggesting that urban greening can have unintended consequences such as gentrification (Dooling, 2009; Wolch et al., 2014), it raises concerns about how the implementation of GI may proceed across cities. This is particularly important as actors tend to converge around the idea that distributed and decentralized projects reflective of GI can scale-up across cities and meet federal and state stormwater regulations. As Finewood (2016, 6) notes, this may be less of a convergence around alternative approaches, such as GI, than a reframing of "grey epistemological" strategies that continue to serve powerful and elite interests, albeit under a greener guise. In other words, the preference for science and data-driven approaches may only work to reinforce dominant planning paradigms and maintain the interests of more powerful parties.

Convergence on integration and science-driven approaches, however, may only mask the real differences between expert viewpoints. Actors across groups, for example, disagree over the role of centralized and distributed infrastructure, market and economic incentives, and the role of new institutions and rules. The Hydro-managerialist, with a focus on water supply, and the Hydro-pragmatist, with a water quality focus, are the two domains of knowledge with the most dissimilar perspectives. First, they hold opposing views of centralized and distributed infrastructure. They disagree over the costs of centralized urban water systems as well as their role in addressing climate change impacts and environmental stressors. This is further reflected in their diverging stances toward the statement that the resilience of urban water systems will be improved by moving away from the centralized model and using more distributed solutions like GI. These differences stem from different ways of knowing the urban environment, but also different visions of urban hydro-social relations. In sites like Los Angeles, where water suppliers derive much of their power through their ability to exercise technological control over the flows of water, alternative visions of hydro-social relations may be subverted for the sake of water supply.

The Hydro-managerialist also conflicts with the Hydro-reformist over the role of institutions, but also how they view the culture and engineering of stormwater infrastructure. While Hydro-managerialists maintain that engineers see the social value of GI, it appears that actors within other knowledge groups do not see this being translated into practice, and is reflected in differences regarding limitations of urban space. Furthermore, the Hydro-managerialist is at odds with both the Hydro-rationalist and Hydro-reformist over the role of incentive programs to incite behavior that aligns with stormwater quality and conservation goals. More fundamental, however, is the disagreement over data. The Hydro-managerialist sees a lack of data for the adoption of GI, whereas the other perspectives, especially the Hydro-rationalist, do not share this vision. This discord, however, is rooted in the different volumetric approaches applied by actors. Volume control for the Hydro-managerialist is based on estimating the range of water supply costs and benefits per acre-foot of stormwater capture, which typically leads to large centralized approaches capable of capturing large volumes of stormwater. In contrast, the other perspectives primarily seek volume control as means to ensure a specified volume of runoff is retained on-site. This outlook favors more distributed and decentralized forms of volume control that reduces runoff and provides water quality benefits.

6.6. Stormwater and the Politics of Urban Metabolism

While it is clear that some discourses align actors while others are divisive, it is shown that different forms of involvement in stormwater management and regulation matter in shaping how environmental actors conduct themselves in relation to the hydro-social cycle. Variations in subject positions are closely tied to their environmental practices, but are also based on contingent and idiosyncratic expressions of broader knowledge claims that lead them to accept or resist different efforts (Birkenholtz, 2009; Brannstrom, 2011). In conclusion, I want to stress four points about hydro-social relations and the implications this has for more sustainable forms urban metabolic relationships.

First, like cities across the globe, Chicago and Los Angeles face considerable fiscal constraints. New ways to govern stormwater through market-oriented approaches are about trying to respond to environmental issues through profitable ventures. The position is that the current political-economy needs reconfigured in order to show that ecological modernization can be profitable. This discourse of ecological modernization, nonetheless, constitutes a particular view of how governance should proceed. While the uptake of this discourse is not universally taken up, it does show how new methods and technologies of governing stormwater are the result of changing perceptions about stormwater's use. In other words, stormwater needs to be governed as a resource rather than a nuisance. For both cities, this way of seeking environmental regulation through profitable enterprise is linked to funding gaps created at the state and federal level. The motivations driving this transition, however, vary between municipalities. In Chicago actors are utilizing stormwater as a resource to mitigate flood risks and pollution, while Los Angeles is seeking to garner more water supply benefits in addition to flood and pollution control (Garcetti, 2015). Consequently, stormwater is framed as an apolitical problem, requiring expertise for its proper management, and divorcing stormwater problems from its social context.

Second, hydrosocial relations in Los Angeles and Chicago reflect regulatory structures that incent integration and collaboration through horizontal relationships and hybrid governance arrangements that bring together state and non-state actors (Sletto and Nygren, 2016). Part of the appeal of integrated plans and approaches is that it can work as a boundary object allowing different actors, in different domains of water governance, to engage in a collaborative setting without necessarily having to compromise differences of opinion or their structural position (Star and Griesemer, 1989; Ward, 2013). Integrated approaches also devolve decision-making powers while shifting the scale of analysis to the entire watershed, which most actors view as the optimal scale to coordinate efforts across bureaucratic and jurisdictional boundaries and reduce fragmentation. This is evident with respondents in both Chicago and Los Angeles.

While integrated approaches are perceived as a way to reduce bureaucratic, jurisdictional, and institutional fragmentation, the more participatory and inclusive approach to decision-making remains uneven. Some actors question the credibility and legitimacy of public participation and the participatory process is fraught with disagreements about the specific aspects of water management that need integrated (Bakker, 2014; Hughes and Pincetl, 2013). These challenges also lead to other questions about who should be involved in decision-making and in what type of capacity. The persistence of technocratic viewpoints espoused by the actors in this study, even among those not typically considered technocrats, confronts the broader impact of the so-called paradigm shift in water governance from a centralized approach to a distributed and participatory approach (Cohen, 2012; Pahl-Wostl, 2007). It also questions the effectiveness of rules that encourage participation, especially when final decision-making is at the discretion of agency leadership (Dhakal and Chevalier, 2016).

Third, and related to participation, is the scientization of urban environmental governance, where science frames the issues and problems are identified and resolved through the application of scientific techniques and reasoning (Blue, 2015; Eden, 1998; Habermas, 1970). A broad appeal to scientism permeates the subjectivities of actors across all knowledge groups and is reflected in their desires for more science-based rules and methods. While it is not surprising that the scientization of urban stormwater politics appears among technocratic decision-makers tasked to make credible and objective decisions about resource management, the scientization of stormwater governance highlights the ways science can bound decision-making (Cohen, 2012; Robards et al., 2011). Rather than fostering open debate and discussion among the competing values, preferences, or perspectives inherent among the different knowledge groups, the scientization of politics suppresses these conversations that explore the variable subjectivities and constructions within each knowledge group. This is problematic, as Blue (2015, 71) notes because this runs the risk of “disenfranchising legitimate dissent on the grounds that alternative perspectives are not perceived as sufficiently reasonable or rational, but it can also engender a reciprocal process whereby scientific expertise and information becomes politicized.” In other words, those unable to use science to support their claims may be marginalized and unable to participate in the decision-making process.

Finally, the conceptual frames utilized by water resource managers to manipulate the flows of stormwater reflect shifts in the metabolic relationship between nature and human knowledges, politics, institutions, and subjectivities. The work of water resource managers to transform urban stormwater metabolisms has relied on the development of a series of knowledges directed towards achieving goals in water quality and quantity. How particular strategies play out to achieve desired aims, however, is rooted in the geometries of power that influence socio-environmental change. With a shared framing of science to direct changes in the way humans relate to and manage stormwater, power is rationalized through different forms of expertise. The diverse sets of calculations and measurements produced through the application of science come to influence the ways stormwater circulates as a metabolism through cities as well as one's subjective domain. Each of these sets come to create a series of differentiated subjective frames that at times enable actors to direct decision-making toward their own goals and desires. While subject formation depends on the ability of an actor to exercise power in the pursuit of a goal (Agrawal, 2005), the uneven ways environmental governance is achieved produces fragmented and differentiated subjectivities. It is within these gaps, however, where the creativity within the processes of metabolism lies and the potential for new socio-spatial formations exist (Heynen, 2014; Smith, 1984).

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Chapter 7: Conclusion

7.1. Summary and Contributions

This dissertation research stemmed from a desire to make contributions in theory, method, and practice to urban political ecology and environmental governance. In part, this was driven by an interest in the relationships between the changing nature of water resource governance and the role of resource flows in shaping the ways cities are transitioning to adapt to climate change and ongoing demographic, political, and economic changes. Through a multi-method approach, the preceding chapters illustrated how water's multiple social and ecological functions generate a range of competing visions on how to best manage and control urban hydrologic flows. From developing stormwater as a "new" resource to contrasting perspectives on management approaches, I highlighted the social and material elements of resource governance. The aim was to provide an empirical examination of the ways stormwater enables and constrains different types of governmental interventions. In this section, I review the major finding and contributions of the research and conclude by outlining the broader themes of the dissertation and future research directions.

Chapter 2, published in *Geoforum*, considered the embodied energy and emissions of Los Angeles's water supply metabolism, as well as the historical and political processes that have shaped it. The chapter sought to take an approach that integrated political ecology and industrial ecology approaches to understand the energy and material flow of Los Angeles's water metabolism, yet also sought to remain critical. To do this, the approach took the typical urban political ecology approach to explore the "interwoven knots of social process, material metabolism and spatial form" (Swyngedouw and Heynen, 2003, p. 906). Rather than rely on conventional urban political ecology insights, however, the approach looked to industrial ecology to explore the relationship between spatial form and material metabolism, but remained attentive urban political ecology's focus on the social and political processes shaping the way goods and resources flow through cities.

With this chapter, we made a modest contribution towards bridging political ecology and industrial ecology. One way this was accomplished was by broadening considerations of social metabolisms by being attentive to the inputs and outputs of resource flows and how they are shaped by politics, history, and social power. Combining theory and method from these two fields of study have led to two major outcomes. First, it unveiled how aspatial assumptions about the system boundary, activity data, and emissions factors embedded in conventional urban water metabolism modeling can fundamentally shape the end result. Second, the chapter argued that the approach has the ability to make life cycle assessment more politically and socially relevant by revealing the uneven spatiality of water supply burdens (and carbon emissions) across demographics, along supply chains, and among resource users. The results also indicate broader socio-economic and political factors that shape how geographic complexity is scoped in the production and application of industrial ecology approaches and how Los Angeles's various water supply infrastructures came to be. The outcome helps illustrate how sustainability transitions based narrowly on indicators such as the carbon calculus (e.g. GHG emissions) are problematized by historical circumstances and strategic new paradigms to secure water resources.

Chapter 3 examined the relationship between the volume and material flow of stormwater and the social, political, and technical practices involved in identifying stormwater as a “new” and underutilized water resource in Los Angeles. In the chapter I traced the ways technology and technological expertise has been deployed to define and redefine government interventions to control stormwater. The chapter argued that current approaches to achieve water conservation, security, and reliability goals, has relied on overcoming historical barriers that rendered stormwater multiple things to multiple institutions, as well as technopolitical interventions organized around overcoming problems related to the volumetric variability of stormwater flowing and circulating through Los Angeles. The chapter identified how experts calculate the metabolic inflows and outflows stormwater as well as the legal and bureaucratic mechanisms and household incentives enrolled to help water resource managers achieve their goals. It is shown that establishing stormwater as a resource has relied on its ability to fit many existing technological and political arrangements, while also solving problems of water quality and quantity. In this way, transitions have not necessarily presented an alternative but rather a re-articulation of existing forms of governance.

The chapter makes a number of contributions to scholarship working at the interface of political ecology, industrial ecology, and ecological economics. First, the chapter expanded on the development of political-industrial ecology outlined in Chapter 2. Rather than looking to integrate approaches from political and industrial ecology, the chapter was at once critical and complementary of the varied approaches. The chapter looked at the actual volume and composition of material flows, typical of industrial ecology and ecological economics, but also the social and political contexts in which urban metabolisms are calculated and implemented in order to attain political goals. Second, by attending to the actual volume and composition of material flows, the chapter provides a new way for political ecological analysis to engage with the materiality of resources, but by attending to the social and political dynamics of urban metabolisms it also provides new insights for industrial ecologists interested in resource flows. In this way, the chapter offered political-industrial ecology as a way to examine social and material flows simultaneously.

Chapter 4 focuses on the politics of stormwater in Los Angeles and how different stakeholders come to understand stormwater problems and their solutions individually. The results reveal four perspectives on stormwater governance in Los Angeles. The first is labeled the Market Skeptic. This view favors integrated approaches, in combination with stronger rules and regulations, over market-based approaches as the preferred mode of managing stormwater. The second is characterized as a Hydro-managerialist perspective, which shows a preference for large centralized projects for stormwater capture and market and data driven approaches. The third is defined as a Market Technocrat, which presents a view that is centered on utilizing market mechanisms in tandem with environmental regulations to manage stormwater. The fourth perspective is labeled as a Regulatory and Administrative Technocrat and perceives stormwater problems as a product of too few regulations and approaches to alter land-use. Actors across all of these perspectives tend to agree that more integrated approaches are needed across all of the institutions and sectors concerned with the management of water and that science and data driven approaches should guide the process. Disagreement across perspectives stems from competing infrastructural visions (centralized v. decentralized), the role of market and economic incentives, and how stakeholders understand the role of new institutions and rules to govern stormwater.

Chapter 5 examined the politics of stormwater in Chicago. This added a comparative component to the dissertation to understand how disparate understandings of stormwater come to shape how it is managed. In contrast to Chapter 4, Chapter 5 revealed only two dominant perspectives towards stormwater management: the Infrastructural Interventionist and the Institutional Interventionist. These two competing visions represent the dominant discourses that shape how stormwater management is contested in the Chicago. As the names suggest, they indicate two opposing views on how to intervene in the system in order to come to more sustainable stormwater management approaches. One perspective is geared more towards reworking urban infrastructure while the other is more focused on crafting better institutions and rules to manage stormwater. Similar to the Los Angeles case, the different framings of how to intervene in stormwater management come together around a shared preference for integrated approaches that are capable of utilizing market, economic, or financial principles.

The findings from Chapter 4 and Chapter 5 highlight important areas of consensus and dissension among water resource managers in Chicago and Los Angeles. In doing so, the results provide practical and useful data for where decision-makers might begin to find compromise and focus their efforts. While it is unlikely that all stakeholders will agree on all aspects of something as complex was stormwater management, the utilization of Q-methodology allows participants to see where their viewpoints lie in relation to other viewpoints. This is important for allowing decision-makers to see and understand the real and perceived differences in stakeholder opinions on the best ways to manage stormwater. Given the challenges of water resource management, these two chapters together make important contributions that illustrate how different ways of seeing the world produce different types of perspectives and preferences for improving stormwater management. More, importantly, however, the chapters highlight the how these differences shape how different infrastructural and institutional choices come to shape urban ecologies and the material flow of water.

Chapter 6 presented a comparative study of stormwater politics in Chicago and Los Angeles. It followed recommendations in the literature to employ the results from both of the previous studies (Chapter 4 and Chapter 5) to produce a set of "super factors" that capture important associations and relevant differences between sites (Watts and Stenner, 2012). For example, by characterizing expert attitudes toward stormwater in cities with different political, technological, and climatic regimes, Chapter 6 brought attention to the ways geographical and institutional variations may shape one's understanding of stormwater governance. Between the two cities, four different perspectives emerged from the analysis, defined as: Hydro-reformist, Hydro-managerial, Hydro-rationalist, and Hydro-pragmatist. While some of these perspectives arose in previous Chapters, it is worth noting that the Hydro-managerial perspective only includes actors from Los Angeles. This is important as it indicates broader perspectives that may be shared at other sites, but also indicates perspectives that may only be unique to water stressed sites, such as Los Angeles. Across the indicated perspectives, subject positions come together come together around shared framings of integrated water resource management and the utilization of the best available science and technology to drive decision-making. While these framings exist along a spectrum among those involved in stormwater management, they indicate the establishment of certain discourses to shape stormwater management and improve water quality and quantity problems. Difference across the varied perspectives come from contrasting viewpoints on the effectiveness of different types of infrastructural interventions to achieve water resource goals, as well the role of market based approaches, and new institutions and rules to govern stormwater.

Through this chapter, I sought to engage with and contribute to critical scholarship on urban water governance in order to understand the relationship between urban stormwater flows and subject formation. As a way to bridge the work in the dissertation, Chapter 6 utilized a socio-material focus to stormwater. This allowed stormwater to be understood as a material flow that unevenly circulates within cities, but also an object of social and political action. I argued that this allowed for an investigation into the ways power/knowledges, subjectivities, and institutions interact to influence environmental governance, which in turn, shapes urban environments and ecologies through an altered urban hydrologic system. The chapter showed that despite new rules and regulations to facilitate integration and reduce vertical fragmentation between levels of government and horizontal fragmentation across levels of government, stormwater continues to embody different social, political, and bureaucratic lives as it flows across the landscape. This enables and constrains actors as they come to view stormwater and its role in urban environmental governance differently. The chapter makes a number of contributions to urban political ecology, not only by being among the first to apply Q-methodology to stormwater governance (the others being Chapters 4 and 5), but also by addressing the relationship between urban metabolisms and subjectivity in a quantitative form. From a practical perspective, however, the research allows decision-makers and researchers to see and understand broader trends in stormwater governance and the positive and negative relationships among and between the various perspectives vested in managing stormwater. While I cannot argue that these views indicate a broad consensus on how stormwater should be managed, they do indicate the importance of understanding the geographically specific and non-local ways preferences are shaped.

7.2. Broader Themes

Each of the dissertation chapters contributed to political ecology and environmental governance and decision-making in unique ways, but taken together they bring out a number of cross-cutting themes. I want to highlight a number of them. First, the works taken together, provide a number of examples of the ways various forms of expertise are central to the ways environmental governance is enacted and achieved. The chapters reveal how expertise not only comes from formal state actors, such as the EPA or California DNR, but also a range of non-state actors, such as NGOs and private firms. The interactions among these various forms of expertise come to shape how stormwater flows, as a metabolism, in and through cities—enabling some types of social-ecological relationships while constraining others. Furthermore, I showed that despite common goals and a shared technical language, the application of expertise in Chicago and Los Angeles produced differentiations in the ways stormwater is understood and controlled. In this way, I contributed to geographical scholarship investigating the role of expertise in shaping the relationship between nature and society and in legitimizing the political aims (Birkenholtz, 2008; Goldman and Turner, 2011; Lave, 2015).

A second theme that spans across the dissertation is that of urban metabolism. As this project unfolded, it always sought to remain attentive to the ways stormwater flows as a metabolism. In particular, I sought to utilize the metabolism metaphor in a dual sense, as both a material flow and a process of organizing and transforming social-ecological relationships. As Chapters 2 and 3 illustrated, the formulation of political-industrial ecology provided one means to simultaneously map out and account for the composition, volume, and metabolic density of material flows, as well as the social, political, and technical processes enrolled in transforming society's relationship with stormwater. Chapter 6 further expanded on this by demonstrating how urban stormwater metabolisms produce certain viewpoints, or subjectivities, that stem from their various roles in managing stormwater. Collectively, this contribution matters for political ecology, where the tendency all too often centers on singular aspects of metabolisms rather dual or multiple aspects (Moore, 2015). Given the need to understand multiple dimensions of global environmental change, the use of political-industrial ecology offers an approach that can balance the social and ecological dimensions of environmental change.

Interdisciplinary insights also span across the dissertation and are used to engage with both the social and material dimensions of environmental change. Chapters 2 and 3 developed PIE as an interdisciplinary approach to examine the volume and composition of material flows and how they are influenced by social and historical processes. This adds to both the field of political ecology and industrial ecology by offering complementary theoretical and methodological insights. The approach I take to socio-material flows also draws attention to the ways stormwater shapes socially-held positions that come to shape action towards its management. Actions taken to direct and control the flow of stormwater, however, are not predetermined. As I illustrated, the social dimensions of power, knowledge, subjectivity, and institutions unevenly interact with stormwater to shape environmental governance.

Finally, as a whole, this dissertation brings to light multiple dimensions of environmental governance. The application of Q-methodology, for example, worked as an applied approach to show how different forms of environmental governance come to embody different ways of understanding and acting towards the environment. The multiple perspectives I revealed in the dissertation, however, also allow policy makers to fully consider all points of agreement and disagreement and come to more acceptable outcomes. I also highlighted the different tools used to by government officials to control and direct volumes of water. Collectively, this brought new insights into the role of subjectivity in urban political ecology and environmental governance.

7.3. Future Research

Through the process of conducting the research for this dissertation a number of future research projects have emerged. The first is an obvious extension of this project that looks more broadly at the distribution of the social perspectives identified in this study across a larger population. A large national scale survey, for example, could examine the extent to which different stances towards how stormwater should be governed align with different actors, in different regions, and across different political viewpoints. This would produce a study that is more representative of the distribution of beliefs across the population of people concerned with managing the flow of stormwater.

The second deals with material collected over the course of the dissertation research and is directly relevant to the research presented here. It takes my research conducted as the Trent R. Dames Fellow in the History of Civil Engineering at The Huntington Library as a starting point to trace the multifaceted and contested histories of water resource development in California and the American West. This research will explore how technical experts have been tasked with addressing the intermittent threats and uncertainties associated with abundance and scarcity. This includes water transfers, the construction (and demolition) of dams and canals, and the creation of legislation to fit shifting and competing goals. The emphasis of the research is not meant to only be historical, but to use water infrastructure as a way to understand the evolving relationship between engineers, planners, government officials, institutions, and water users as they adapt to changing social, ecological, and climatic realities.

A third interest stems from a developing interest in how the interactions between surface and subsurface water flows are being negotiated and governed. This work will include utilizing and furthering the political-industrial ecology approach to explore how the measurement of water use generates new debates and solutions on water management and governance at the basin scale. Using examples from California on the impacts of groundwater pumping on surface water and ecosystems, I plan to analyze how efforts to measure water use and flows has been utilized as a metric-based tool to shape resource governance and legitimate certain types of water transfers and flows based on volume and containment. Such strategies have potential to cause significant conflict, however, and California's legal structure is not currently adequate to address conflicts that arise between surface and subsurface resource flows. With many experts suggesting that one of the biggest problems facing California, and other western states, has been the failure to accurately measure water use, this research will look at the barriers, opportunities, and potential consequences of how water is measured. In much of this preliminary work I am examining how metric-based tools of governance are being shaped by state and municipal governments and how they might be used to secure their environmental futures and legitimate certain claims over others. The goal of the research is to reveal the challenges associated with governing both surface and subsurface geographies of resource consumption and utilization. Other goals of this research are to understand how in the context of scarcity, different actors (e.g. the state, municipalities, farmers, private companies, etc.) are securing their supplies, how they interact and conflict, and how this shapes the development of new institutional, technological, and regulatory mechanisms introduced to resolve water resource challenges as they relate to climate change and natural resource development.

While many other possibilities for research exist, from decision-making under hydro-climatic uncertainty to the decentralization of water governance, my future research will maintain a focus on how the relationships between nature, society, and technology effect environmental change. In the meantime, development pressures on freshwater systems and increases in droughts and floods as well as less frequent and more intense storms associated with climate change continue to present challenges for maintaining human and ecological health. While prescriptions for overcoming these challenges may seem elusive, I am optimistic in our ability to find resilient and equitable ways to come to more sustainable interactions between the human and non-human world. This dissertation has provided only a modest contribution to this effort and towards ongoing efforts to understand the human dimensions of environmental change.

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Appendices

Appendix A: Supplemental material to Chapter 5

Appendix A shows an idealized sort for both of the factors (Infrastructural Interventionist and the Institutional Interventionist) from the Chicago study. The bold and underlined numbers are distinguishing statements, significant at $p<.05$.

Statement		Factor	
		1	2
1.	One of our biggest barriers is increased regulation.	-2	**-2**
2.	Implementation is a barrier in large part due to NIMBY type of concerns. People do not want to be liable.	-1	0
3.	We lack the data needed for the adoption green infrastructure and to accurately quantify its performance.	**-2**	-1
4.	The trouble within the city is that we're so congested and built up we don't have the space for many types of green infrastructure; space is a significant limitation.	**-1**	**1**
5.	Climate uncertainty is the most difficult challenge for proactive adaptation planning for stormwater management.	-1	0
6.	Land-use change presents the most difficult challenge to stormwater management.	-1	0
7.	I think there is a cultural problem. Stormwater engineers see only engineering solutions and green infrastructure is not part of that.	**1**	-1
8.	Getting people to apply to incentive programs is problematic because people don't care about stormwater management and lack knowledge of water issues.	1	0
9.	We need stricter laws and regulations to address stormwater because change is not going to happen voluntarily.	**3**	0
10.	Failure to address stormwater, like climate change, is a fault of political leaders; they are the ones who need to be educated and incentivized to innovate.	1	1
11.	Science and data should direct decisions on stormwater and infrastructure. We need data driven and fact-based approaches drawing on the best available science and engineering.	**3**	**2**
12.	Development of a tradable credit system, with appropriate regulatory safeguards, will encourage investment in green infrastructure and help deliver stormwater mitigation at the lowest possible cost.	1	1
13.	We need market based approaches and fewer government interventions and regulations to finance stormwater management.	-2	-1
14.	Stormwater management needs economic instruments to put a value on stormwater and make it a resource rather than a hazard.	**2**	**3**
15.	Corporations and private interests should have the chance to develop their own targets for stormwater abatement.	**-3**	0
16.	A mitigation bank for stormwater will help foster public-private partnerships to address stormwater by allowing developers to meet LID requirements by paying into that bank.	**2**	0
17.	Stormwater, or water more generally, should not be guided by market, economic, or financial principles.	-1	-1
18.	Waste water, water supply, flood water, water quality and all of that stuff is just water. If you just think of it as one water then you can manage it much more efficiently.	0	0
19.	We don't need more integrated approaches. We need better enforcement of existing regulations and improvement of local codes and ordinances; integrated water resource planning is not the answer	-1	-3
20.	An integrated management approach is critical. There needs to be a shift towards more	2	**3**

	integrated approaches across all of the institutions and sectors concerned with the management of water.		
21.	We need stormwater fees. Municipalities need fees and cost sharing plans.	**2**	1
22.	Stormwater fees are not feasible, nor are they enough for successful implementation in the long term. Stormwater fees are problematic.	**-2**	-2
23.	Stormwater needs to be held and used on-site; there are too many concerns about unregulated off-site mitigation.	1	0
24.	Stormwater mitigation should be able to occur off-site; it offers more flexible opportunities. Off-site approaches lead to better outcomes than on-site.	0	-1
25.	We need to maintain the narrative of engagement by redefining city services and bringing the expertise to the neighborhoods. We need a grass roots community driven approach to create better outcomes.	1	2
26.	Homeowners need to be educated and they need to educate each other about the benefits of improved stormwater management. They need to be the targets of interventions because community driven approaches tend to be more effective than data driven approaches.	0	1
27.	Local residents' contributions to decision-making usually show a lack of expertise, are not factual, or biased.	0	-1
28.	Big systems and dams or reservoirs are important for floods and stormwater mitigation, but after the rain, how you handle that water is important for water quality and/or supply.	**2**	-1
29	Centralized urban water systems are maladapted to address climate change impacts and environmental stressors.	**0**	-1
30.	Larger centralized projects for handling and capturing stormwater are typically more cost-efficient than trying to treat it at thousands of small sources. Centralized stormwater projects make more financial sense than distributed and decentralized stormwater projects.	0	**-2**
31.	LID offers economic benefits, such as deferring or even replacing costly large grey stormwater infrastructure projects. LID is more cost effective than gray infrastructure.	1	1
32.	Resilience of urban water systems will be improved by moving away from the centralized model and using more distributed solutions like green infrastructure.	**0**	**2**
33.	Distributed projects are not effective; they don't scale up across the city or to other sites and will never meet the level of stormwater abatement and/or capture needed.	-1	**-2**
34.	As we build green infrastructure we are going to change the nature of neighborhoods. We are going to push working class people out as we build more economic development around green space.	**-2**	-1
35.	For every dollar we spend on a water quality project that's one less emergency service dollar, recreation dollar, or funds for other services. It's hard to justify money for stormwater management.	-3	**-3**
36.	I'm really opposed to creating new institutions or rules to manage stormwater. There are too many agencies and there is too much diversity already.	-1	-2
37.	I think there definitely will be a need for new institutions and rules to manage stormwater.	0	**2**
38.	With many community groups and NGOs there are issues with them maintaining the infrastructure or with them focusing too narrowly on certain issues.	1	0
39.	I think there's enough NGO capacity within the city to have a better coordinated and more strategic approach to green infrastructure.	0	1
40.	Rather than focusing on new development, we need to focus on the existing development and encourage retrofitting. Only looking at new developments hurts us.	0	**2**

Bold underlined are distinguishing statements (significant at $p<0.05$).

Appendix B: Institutional Review Board Approval

UNIVERSITY OF MICHIGAN

Joshua Cousins <jojaco@umich.edu>

eResearch Notification: Notice of Exemption

eresearch@umich.edu <eresearch@umich.edu>
Reply-To: eresearch@umich.edu
To: jojaco@umich.edu

Fri, Mar 21, 2014 at 10:50 AM

UNIVERSITY OF MICHIGAN
eResearch.umich.edu

Health Sciences and Behavioral Sciences Institutional Review Board • 540 East Liberty Street, Suite 202, Ann Arbor, MI 48104-2210 • phone (734) 936-0933 • fax (734) 998-9171 • irbhsbs@umich.edu

To: Joshua Cousins

From:

Thad Polk

Cc:

Josh Newell
Joshua Cousins

Subject: Notice of Exemption for [HUM00086441]

SUBMISSION INFORMATION:
Title: Stormwater Politics and the Sustainable City: Understanding divergent perspectives among water experts in Chicago and Los Angeles
Full Study Title (if applicable):
Study eResearch ID: HUM00086441
Date of this Notification from IRB: 3/21/2014
Date of IRB Exempt Determination: 3/21/2014
UM Federalwide Assurance: FWA00004969 (For the current FWA expiration date, please visit the UM HRPP Webpage)
OHRP IRB Registration Number(s): IRB00000246

IRB EXEMPTION STATUS:
The IRB HSBS has reviewed the study referenced above and determined that, as currently described, it is

Appendix C: Institutional Review Board Amendment Approval

UNIVERSITY OF MICHIGAN

Joshua Cousins <jojaco@umich.edu>

eResearch Notice: Amendment (Ame00053484) for (HUM00086441) has been approved by the IRB.

eresearch@umich.edu <eresearch@umich.edu> Tue, Jun 2, 2015 at 9:14 AM
Reply-To: eresearch@umich.edu
To: jpnewell@umich.edu, jojaco@umich.edu

UNIVERSITY OF MICHIGAN
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Health Sciences and Behavioral Sciences Institutional Review Board (IRB-HSBS) • 2800 Plymouth Rd., Building 520, Room 1170, Ann Arbor, MI 48109-2800 • phone (734) 936-0933 • fax (734) 998-9171 • irbhsbs@umich.edu

To: Joshua Cousins

From:

Thad Polk

Cc:

Josh Newell
Joshua Cousins

Subject: Notice of Amendment Approval and New Exempt Status

SUBMISSION INFORMATION:
Study Title: Governing Stormwater: Perspectives of and Preferences Towards Stormwater Management
Full Study Title (if applicable):
Study eResearch ID: HUM00086441
Amendment eResearch ID: Ame00053484
Amendment Title: HUM00086441_Amendment - Thu May 28 15:18:36 EDT 2015 - Change study title to: Governing Stormwater: Perspectives of and Preferences Towards Stormwater Management
Date of this Notification from IRB: 6/2/2015
IRB Exemption Determination Date: 6/2/2015
UM Federalwide Assurance: FWA00004969 (For the current FWA expiration date, please visit the UM HRPP Webpage)
OHRP IRB Registration Number(s): IRB00000246

IRB EXEMPTION STATUS:
The IRB HSBS has reviewed and approved the amendment to the study referenced above. The committee has also determined that the study, as currently described, is now exempt from ongoing IRB review, per the following federal exemption category: