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Sewerage infrastructure, including wastewater treatment facilities and conveyance pipes, is reaching the end of its useful life throughout the United States. Aging infrastructure may be more susceptible to fracturing and collapses due to deterioration. Further, sewerage infrastructure is usually designed to discharge untreated wastewater or stormwater into nearby waterways during intense wet-weather events, potentially contributing to environmental and public health concerns. Upgrading or replacing sewerage infrastructure often requires major construction projects that can be burdensome for municipalities. This study examines municipal sewerage infrastructure as part of a system with technical, administrative, social, economic, and environmental dimensions. Important disturbances and management strategies affecting municipal sewerage systems in Cook County, Illinois were identified through semi-structured interviews with Public Works and Engineering department professionals. Interviews were then analyzed using resilience theory, attending to system robustness, redundancy, resourcefulness, and rapidity. As the vast majority of literature indicates, findings suggest that managers of municipal sewer systems in Cook County are most concerned with maintenance of technical infrastructure, which is largely limited by economic constraints: unpredictable and decreasing financial resources, coupled with the high cost of repair projects. Interviewees from wealthier communities generally demonstrated less concern about current funding for sewerage infrastructure projects, although many expressed concern that they will not be able to sustain their current level of investment. Most interviewees also suggested concern with the lack of residents' knowledge about sewerage systems and engagement in the management process, often leading to widespread basement flooding and consternation among residents. Interviews

highlighted relationships between the robustness, redundancy, resourcefulness, and rapidity of many technical, administrative, social, economic, and environmental dimensions; that is, attempts to manage for specific system attributes can have direct and, often, predictable effects on other attributes within the sewerage system.

Municipal Sewerage System Resilience:
Disturbances and Management Strategies in Cook County, Illinois

by
Timothy J. Oravec

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APPROVED:

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Major Professor, representing Water Resources Policy and Management

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Director of Water Resources Graduate Program

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Timothy J. Oravec, Author

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Attempting to recognize all those who made this thesis possible is akin to declaring which stars make the night sky beautiful. So, unable to conceive of meeting such a challenge, allow me to focus on the brightest few from my current vantage point.

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> *The notion that Civil Engineers build objects intended to remain invariant with time is widely held: '[I]f it is meant to move, it is mechanical engineering, if it is meant to stay put, it is civil engineering.' Perhaps we all covet the steady state, because its analysis is easier and because, in some anthropocentric fashion, we are more comfortable with the idea of equilibrium in our lives.*
>
> — M.B. Beck and R.G. Cummings (1996): 413

Infrastructure of all types throughout the United States are reaching the end of their useful lives, creating situations that can pose threats to human and environmental health. These challenges are compounded by the fact that major infrastructure upgrades are often expensive and difficult to coordinate around other types of existing infrastructure. Moreover, infrastructure often reflects the knowledge and abilities of the times in which they were constructed. In the case of sewerage infrastructure, that means some sewerage pipes are intentionally designed to send untreated wastewater and stormwater into local lakes, rivers, and streams when pipes are filled beyond their capacity. These overflows can incite inhospitable conditions for aquatic organisms, hinder public health, and require costly clean up procedures.

Challenges surrounding upgrades to national sewerage infrastructure are well-known, although new policies to rectify these challenges remain scarce. Discussion of sewerage infrastructure systems often focus on wastewater treatment plants or systems in large cities, where larger populations depend on reliable sewerage infrastructure and where disturbances such as sewerage overflows or pipe collapses can often have much larger effects. Few studies specifically examine challenges faced by sewerage system managers in municipalities near, but outside of, major metropolitan cities. This study seeks to understand which threats are most relevant to municipal sewerage system managers and what strategies are underway to improve the system in municipalities in Cook County, Illinois.

It is important to note that sewerage systems are explored in this study as social systems. A social system can be understood simply as an arrangement of inputs—information, physical characteristics, environmental variables—which interact to produce specific outputs, or policy and management decisions about what to do or not do (Birkland, 2011). Inputs of particular concern in this study were factors that threaten municipal sewerage system, whereas outputs were primarily concerned with strategies for abating those disturbances and improving the overall system. Resilience theory was applied to better refine the analysis and build off previous studies examining infrastructure as social systems.

Subsequently, this study sought to answer three guiding questions. First, "What disturbances are relevant for understanding challenges to sewerage system resilience in municipalities in Cook County, Illinois?" Second, "What management strategies do municipalities in Cook County, Illinois pursue to manage sewerage system resilience?" And third, "How do key actors organize to manage municipal sewerage systems in Cook County, Illinois?" Municipalities in Cook County, Illinois manage either combined sewer systems (CSSs), which convey sewage and stormwater in a single pipe, sanitary sewer systems (SSSs), which convey sewage and stormwater in separate pipes, or some combination of the two systems. Therefore, municipalities were specifically selected to represent different types of sewerage systems. Municipalities were also selected to represent a range of community wealth since economic factors are often associated with the abilities of governmental agencies to pursue infrastructure projects. Thus, this study also sought to understand how different types of sewerage systems and community wealth affect managers' concerns about disturbances or management strategies.

Several terms and phrases are used throughout this paper to describe specific aspects of the sewerage system or theoretical concepts. Most terms are defined or described throughout, although a glossary of key terms is also available in Appendix B. To clarify the usage of similar words and phrases, the following definitions will be applied throughout this study:

- *Sewerage System* refers to the technical, administrative, social, economic, and environmental attributes that affect, determine, or comprise system inputs and outputs affecting the management of sewage, wastewater, and stormwater.
- *Sewerage Infrastructure* refers to all technical infrastructure used to convey, treat, pump, discharge, and otherwise manage sewage, wastewater, and stormwater. To remain consistent with common phrasing, the phrase "sewerage infrastructure" is sometimes replaced with the phrase "sewer system."
- *Sewage* refers to sanitary waste managed by the sewerage system. "Sanitary flow" is occasionally used synonymously with "sewage."
- *Stormwater* refers to runoff from wet weather events managed by the sewerage system.
- *Wastewater* refers to any combination of sewage and stormwater managed by the sewerage system.

Chapter 2: Conceptual Framework

> *…to a large extent, we live in 'yesterday's cities' in the sense that many of the urban patterns we see today—roads, buildings, land ownership, etc.—reflect decision making periods of the past. As the prevailing ideology changes so does the planning of our cities. Understanding the role of time and the way it conditions future urban options is a crucial part of urban resilience.*
>
> — Resilience Alliance (2007): 17

The following literature review examines theoretical, historical, scientific, and legal issues relevant to the study of sewerage systems in Cook County, Illinois. Resilience theory will be traced from its origins through its contemporary application to social systems, including urban community and infrastructure systems. Then, the evolution of sewerage systems in the United States will be explored, nesting sewerage systems within a distinctly social context. Last, an overview of site-specific information regarding Cook County sewerage and wastewater management will be provided.

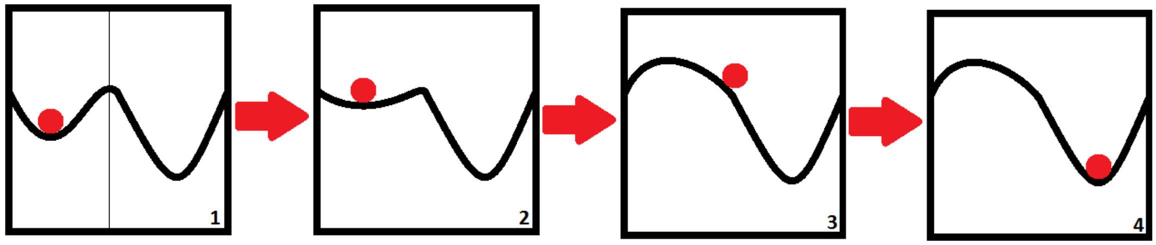
2.1: Theorizing the Resilience of Urban Social Systems

Holling (1973) established two forms of system resilience—engineering and ecological—which require separate analytical approaches and management strategies. Engineering resilience, which is generally analyzed quantitatively, measures the ability of a system to resist disturbance and the rapidity with which a system returns to its presumed single steady state following a disturbance (Holling, 1973; Pimm, 1984; Wu & Wu, 2013). Conversely, ecological resilience presumes that any given system has multiple potential steady states; however, none of these states are ever fully attained as outside forces continually push the system toward or away from each state (Holling, 1973). As such, it requires—at least in part—a qualitative approach to understand how variables and disturbances affects systems (Holling, 1973). Consequently, the ecological resilience framework proves to be far more applicable to fundamentally social systems (Liao, 2012).

Both engineering and ecological resilience can be visualized with the ball-in-the-basin model (Figure 1), which metaphorically represents a given system of analysis as a basin and the state of that system as a ball within the basin (Walker *et al.*, 2004; Walker & Salt, 2006; Liao, 2012). Engineering resilience hypothesizes that the entire system exists within a single basin, the base of which represents that system's steady state (Liao, 2012). Resilience theory contends that a system never exists entirely at equilibrium and, therefore, the ball continually moves toward the bottom of the basin without ever reaching it due to disturbances or imperfections in the system (Walker

& Salt, 2006). Nevertheless, under the framework of engineering resilience, all systems continually move toward one specific steady state. In contrast, ecological resilience (Figure 1) imagines the system of analysis not as a single basin with one steady state, but as a series of interconnected basins divided by thresholds, each of which contains a unique steady state at its base (Walker *et al.*, 2004; Walker & Salt, 2006; Liao, 2012). This series of interconnected basins is referred to as a "stability landscape" (Walker *et al.*, 2004: 3). As the ball moves toward equilibrium within its individual basin, exogenous drivers and endogenous processes continually alter the stability landscape which in turn determines the aggregate number of individual basins, the proximity of thresholds between basins, and the depth of each basin (Walker *et al.*, 2004). These changes can relate to the overall complexity of the system by respectively affecting the potential number of steady states, the relationship between different basins, and the relative effort required to move a system's state from one basin to another (Walker *et al.*, 2004). When the stability landscape alters to the point that the ball crosses a threshold and transfers from one basin to another, it is said to have entered a new regime (Walker *et al.*, 2004; Walker & Salt, 2006; Liao, 2012). Engineering resilience does not consider thresholds and focuses entirely on the state of a system in relation to that system's equilibrium (Walker & Salt, 2006). Conversely, ecological resilience is principally concerned with understanding the thresholds between basins and determining how a disturbance or suite of disturbances alter the stability landscape and, ultimately, induce a change in regime (Walker & Salt, 2006). Understanding key disturbances and thresholds within a system is important because regime shifts can have enormous implications, particularly for social-ecological systems (Peterson, 1998). For example, ongoing overfishing and climatic changes have catalyzed eutrophication in the Baltic Sea, changing the environment over time from one dominated by seals, to one dominated by cod and, eventually, to clupeid, each transition marking changes within systems or entire regime shifts (Österblom *et al.*, 2007).

Figure 1. Ball-in-the-Basin Illustration of Ecological Resilience[1]



[1]The ball-in-the-basin diagram illustration depicts key concepts of ecological resilience. (1) A system exists at a particular steady state and is separated from other steady states by a threshold. (2) As the system changes, the relationship between the steady state, the threshold, and other steady states also changes. (3) Regime shift: some system change, usually induced by disturbances, causes the system to cross a threshold. (4) The system begins to exist at a new steady state. Adapted from Wu and Wu (2013).

The ball-in-the-basin model provides a useful metaphor for understanding how systems change regimes, but it accounts insufficiently for how individual systems exhibit resilience within their regime. Holling (1986) described ecosystems as continually moving through a four-phase process later referred to as the adaptive cycle. The cycle's four phases—exploitation (r-phase), conservation (K-phase), release (Ω-phase), and reorganization (α-phase)—reflect the natural rhythms Holling (1986) identified in ecosystems (Wu & Wu, 2013). During the exploitation phase, people or species exploit new opportunities and available resources which prompts a long period of rapid growth, but also creates a system with weak interconnections and regulations of system components (Walker & Salt, 2006). The system eventually moves to the conservation phase, which is marked by slower growth but stronger connections within the system, producing longer-lasting and more efficient system components (Walker & Salt, 2006). A system that has reached the conservation phase is not, however, necessarily more resilient than systems in other phases (Wu & Wu, 2013). Indeed, slowed growth and increased connectedness elicit a dependence on a decreasingly flexible system, which "renders the system increasingly vulnerable to disturbance. Such a system is increasingly stable—but over a decreasing range of conditions" (Walker & Salt, 2006: 77). The longer the conservation phase continues, the more vulnerable the system becomes to disturbance and the more likely it is to move onto the release phase (Walker & Salt, 2006). During the release phase, the strong interconnections and regulations formed during the two preceding phases come undone, enormous amounts of previously accrued resources are lost, the system is briefly characterized by chaos, and the system is less resilient than at any other point (Walker & Salt, 2006; Wu & Wu, 2013). Holling (1986) describes the release phase as a period of "creative destruction" because the capital lost during this phase provide the building blocks for the final reorganization phase. A system is most resilient in the reorganization phase (Wu & Wu, 2013). The system begins to reorganize around a steady state, which may be identical to the previous cycle's steady state or entirely new, constituting a regime shift (Walker & Salt, 2006). Because resources are plentiful and the system is not yet interconnected, minor perturbations can have long-lasting reverberations and have an enormous effect on determining how the system moves through future phases of the adaptive cycle (Walker & Salt, 2006). A completed reorganization phase successfully sets the path for the rapid growth that follows during the r-phase (Walker & Salt, 2006).

Given the complexity of resiliency theory, different definitions beyond the engineering-ecological dichotomy have been assigned to the term "resilience" depending on the particular contexts and systems of analysis. Holling (1973) originally defined resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (14). Carpenter e*t al*. (2001: 766) borrow from the definition by Gunderson & Holling (2001), by emphasizing resilience as the ability of a system to "persist" through disturbances. These definitions, which reject the engineering-oriented definition of resilience by Pimm (1984) as the rate at which a system returns to its singular steady state following a disturbance—cast resilience as neither an inherently positive nor negative attribute, but rather as an ability that can have positive or negative implications depending entirely on context. For example, eutrophic lakes, contaminated rivers, or depleted aquifers may all represent ecological systems that are exemplars of resilience despite their deleterious socio-ecological effects due to their persistence in the face of "disturbances" or efforts to manage the system toward a more productive state.

These definitions were crafted specifically for ecological or social-ecological systems, but they do not sufficiently apply resilience theory to the context of urban built environments. Liao (2012) contrasts definitions of community resilience that operate under the framework of engineering resilience against those that operate under the framework of ecological resilience. Many of the definitions (Tobin, 1999:13; Buckle *et al*., 2000: 13; Godschalk, 2003: 136; Bosher, 2008: 13; Lamond & Proverbs, 2009: 63) that Liao (2012) identifies emphasize a community's ability to resist disturbance and the rate at which communities can reorganize following a disturbance, both attributes being foundations of the engineering resilience. Liao (2012) deems these definitions inappropriate for measuring community resilience for much the same reason that Holling (1973,

1986) rejects engineering resilience: communities and their internal subsystems are constantly in flux and do not operate at a predetermined steady state. Instead, “they operate like evolving ecosystems rather than engineering systems and are characterized by complex behaviors associated with nonlinearity, emergence, uncertainty, and surprise” (Liao, 2012: 48). Definitions of community resilience that operate under the ecological framework may be far more effective at accounting for the characteristic unsteadiness of urban built environments (Liao, 2012).

Nevertheless, many definitions of community or social resilience—including Liao’s (2012)—limit their scope to only large-scale, often discrete and irregular, disasters such as earthquakes, tornadoes, hurricanes, or floods (Mileti, 1999: 32-33; Tobin, 1999:13; Godschalk, 2003: 136; Adger *et al.,* 2005: 1036; Bosher, 2008: 13; Lamond & Proverbs, 2009: 63; López-Marrero & Tschakert, 2011: 230). A more appropriate definition of resilience for communities could be “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks” (Walker *et al.*, 2004: 2). Authors who focus on natural disasters or severe shocks to communities laudably attempt to tailor the definition more closely to the needs of communities but, in so doing, ignore other factors that may prompt communities to move from the conservation phase to the release phase. While Walker *et al.*’s (2004) definition benefits from the breadth it grants to potential disturbances, it was not specifically ascribed to community resilience. Liao (2012) conversely adopts a definition almost identical to Walker *et al.*’s (2004: 4), with the substitution of “function” for “processes”. “Function” suggests separate and discernable services provided by the community as a whole, whereas “processes” better articulates the multifarious operations within and between communities. Thus, community resilience will be defined henceforth as the capacity of a community system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same processes, structure, identity, and feedbacks.

Beyond matters of definition exist matters of measurement. Resilience theory posits that all systems move throughout the adaptive cycle, but requires quantitative and qualitative research to better understand where a system resides in the cycle, the system’s proximity to thresholds, the types of disturbances most likely to cause a regime shift within the system, and other questions relevant to understanding the particularities of community infrastructure resilience (Holling, 1973). Indeed, “there is a much higher likelihood of crossing a threshold into a new regime if you are unaware of its existence” (Walker & Salt, 2006: 74). Bruneau *et al.* (2003)

conceptualized community resilience to earthquake hazards as comprising of two separate four-pronged suites of attributes. One suite addresses technical, organizational, social, and economic dimensions, where technical dimensions relate to the functionality of physical systems within a community (e.g., buildings, bridges, water mains), organizational dimensions relate to the capacity of organizations to sufficiently increase community resilience (e.g., efficacy of government administration), social dimensions relate to community access to critical services (e.g., access to electricity and running water), and economic dimensions relate to the capacity to reduce direct and indirect economic losses resulting from disruptions (Bruneau *et al.*, 2003). These indicators echo those proposed by Cutter *et al.* (2008), with some important differences. Cutter *et al.* (2008) identify six dimensions of community resilience: ecological, social, economic, institutional, infrastructure, and community competence. Economic, institutional, and infrastructure dimensions are essentially analogous to Bruneau *et al.*'s (2003) economic, organizational, and technical dimensions, respectively. Cutter *et al.* (2008) choose, perhaps redundantly, to separate demographics, community values, and social networks (social dimension) from the local understanding of risks, quality of life, and available services (community competence dimension); however, these factors are integral to community systems and rectify deficiencies in Bruneau *et al.*'s (2003) less holistic understanding of social community dimensions. The addition of the ecological dimension as part of community resilience aligns more closely with the argument that community resilience should be couched within Holling's (1973) broader ecological resilience framework (Liao, 2012). The absence of any ecological dimension from Bruneau *et al.*'s (2003) framework supports the contention it may too closely align with concepts of engineering resilience (Liao, 2012). Both the terms "organizational" and "institutional" refer predominantly to actions undertaken by entities responsible for community resilience, and so may be better understood as "administration," which Frederickson *et al.* (2012: 1) define as "organization and management practices in collective or public settings". Moving forward, both Bruneau *et al.*'s (2003) and Cutter *et al.*'s (2008) dimensions will be integrated and described as technical, administrative, social, economic, and ecological.

Bruneau *et al.*'s (2003) second suite of intersecting attributes addresses four system properties: robustness, redundancy, resourcefulness, and rapidity. Robustness references the ability of strong systems to withstand disturbances without degrading or losing functionality; redundancy references the substitutability of aspects within the system in the event that disruptions diminish the functionality of critical components; resourcefulness references the ability to apply resources to meet established priorities and achieve goals; and rapidity references the ability to meet established priorities and achieve goals quickly in order to minimize losses. Liao (2012) argues that these properties are indicative of engineering resilience, which encompass "both resistance to and recovery from disturbances, although the measurement is focused exclusively on recovery—the faster the full functionality is restored, the greater the resilience" (2). While Bruneau *et al.* (2003: 735) do, in fact, define resilience as "the ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes," the properties of robustness, redundancy, resourcefulness, and rapidity are not inherently engineering-oriented and are capable of being understood through Liao's (2012) ecologically-oriented lens of community resilience. Liao (2012) identifies five key attributes in communities resilient to floods: localized flood-response capacity (e.g., community agency and self-sufficiency), timely adjustments after every flood (e.g., rapidity), redundancy in subsystems, diversity (e.g., multiple management strategies to choose from, or resourcefulness), and flexibility (e.g., capacity to quickly adapt, or resourcefulness). These key attributes are analogous to each of Bruneau *et al.*'s (2003) with the exception of robustness. Yet robustness describes the ability of critical community systems to maintain functionality, not necessarily to resist disturbances, and is therefore a valid property of community resilience (Bruneau *et al.*, 2003; McDaniels *et al.*, 2007). Henceforward, properties of robustness, redundancy, resourcefulness, and rapidity should be interpreted as hybrids of Bruneau *et al.*'s (2003) and Liao's (2012) definitions. These properties will be used in conjunction with the former suite of dimensions derived from Bruneau *et al.* (2003) and Cutter *et al.* (2008) to measure system resilience. Further, the term "dimension" will be used to discuss technical, administrative, social, economic, and environmental attributes, while "property" will refer to the robustness, redundancy, resourcefulness, and rapidity of each dimension. These properties and dimensions will be referred to as "attributes" when being discussed generally or collectively. Table 1, adapted from O'Rourke's (2007) matrix, depicts the intersections of these nine attributes in the context of resilient urban community systems.

Table 1. Matrix of Intersecting Resiliency Attributes in Urban Community Systems[1]

Attribute	Technical	Administrative	Social	Economic	Environmental
Robustness	Technical strength or endurance; level of deterioration	Active decision making, planning, and execution of management strategies	Public safety, health, and general wellbeing	Financial stability; sufficient revenue	Environmental health and functionality of ecosystems
Redundancy	Substitutive, alternative, complementary, or supplemental technology	Decentralized autonomous management; institutional checks and balances	Availability of relief for victims following disruption	Diverse sources of revenue	Substitutive, alternative, complementary, or supplemental environmental services and processes
Resourcefulness	Availability of and ability to use materials and equipment for repairs and rehabilitation	Capacity to improvise, innovate, and modify policy and management	Public competence, preparedness, and engagement	Capacity to maximize funds; management costs	Capacity to access or use environment for community goals
Rapidity	Time required to use technology; time required for technology to resolve issue	Time required to make decisions and move policy through administrative processes	Time required to restore normal community services and operations	Rate of revenue losses and gains; rate of return on investments	Rate of environmental deterioration, services, or recovery

[1]Adapted from O'Rourke (2007).

2.2: Sewerage Infrastructure as an Urban Social System

Efficient and functional sewerage systems have become a cornerstone of many communities in developed nations, including the United States. Urban development "can hardly be imagined in the absence of sewerage, i.e. a water-based system of waste removal, and the biotechnical processes generally believed to be indispensable to contemporary wastewater treatment" (Beck and Cummings, 1996: 407). This technocentric definition of sewerage systems is qualified by the admission that "economic, social, or cultural dimensions" are "likely to be decisive considerations" as well (Beck & Cummings, 1996: 405). The significance of sewerage infrastructure to urban communities warrants its exploration as a full social system—one that is characterized by technical, administrative, social, economic, and environmental dimensions.

Beck & Cummings (1996) describe the broad strokes of community wastewater development in six stages: (1) migration of populations to communities, (2) installation of a centrally organized water supply system to communities, (3) installation of sewerage system for the purpose of avoiding flooding, (4) extension and adaptation of sewerage to use water to flush waste out of cities, (5) establishment of wastewater treatment at a regional facility, and (6) continual evolution of wastewater treatment to become successively more effective. This description, while most applicable to contemporary trends in developed nations, provides a useful framework for understanding how sewerage systems developed in the United States. This section will summarize knowledge of sewerage systems to date, beginning with a brief history of sewerage infrastructure followed by an overview of the more recent technical, environmental, social, economic, and administrative dimensions of sewerage systems.

2.2.a: Sewerage Systems in the United States: 1790 - 1972

Wastewater management in the Colonial America was decentralized, meaning waste was treated and disposed near the source (Burian *et al.*, 2000). Urban environments were not densely populated, and there was little concern about the effects of contemporaneous wastewater management practices on public or environmental health; consequently, the extent of wastewater infrastructure often entailed use of a privy with an outlet leading to the street, yard, or an open-channel sewer (Burian *et al.*, 2000). The 1790 federal census documented 24 cities in the United States, the combined population of which constituted only 5.1% of the population (Louis, 2004). Some rudimentary sewer systems existed primarily for the purposes of channeling stormwater to nearby waterways (Burian *et al.*, 2000). Yet as the industrial revolution progressed cities became industrial centers, attracting larger, mostly immigrant, populations (Louis, 2004). Subsequent influxes in the volume of waste produced a series of public health epidemics throughout the nation provoked "massive public hysteria, and created an impetus to understand the etiology of disease, and develop organized systems for administering public health and municipal sanitation" (Louis, 2004: 308). Decentralized sewer systems were insufficient in the rapidly changing urban environments, and managers began considering opportunities to shift toward a centralized system where wastewater is collected regionally and disposed at a central location (Burian *et al.*, 2000).

Cities began forming public agencies charged with managing sanitary and public health concerns, and by 1855 Brooklyn constructed a combined sewer system (CSS); by 1856 Chicago became the first city to rely on a CSS (Burian *et al.*, 2000; Louis, 2004). The CSS conveys stormwater, as well as household and industrial wastewater, in a combined network of pipes toward a centralized location for disposal. Meanwhile, some managers began advocating for a different approach to wastewater management by utilizing a separate-sewer system (SSS) (Burian *et al.*, 2000). Where the CSS conveys stormwater and wastewater together, the SSS consists of a storm pipe and a separate sanitary pipe for the respective conveyance of stormwater and wastewater. The sanitary pipe would lead toward a centralized location for disposal while the storm pipe would discharge stormwater into nearby waterways. Policymakers and managers in the United States were concerned about the lack of a European precedent to the SSS—whereas the CSS originated and was widely used in Europe—as well as agricultural usage of waterways downstream of a storm pipe outlet and, above all, the presumed surplus expense of constructing two sewerage pipes (Burian *et al.*, 2000). Despite arguments that SSSs were, in fact, cheaper than CSSs, and that neither system was superior for sanitation, most policymakers, managers, and engineers accepted the argument that CSSs were best suited for urban and rapidly growing communities (Burian *et al.*, 2000). By the early 1900s, CSS pipe mileage far outnumbered SSS pipe mileage, particularly in large urban communities (Burian *et al.*, 2000).

Notwithstanding the early predominance of CSSs in the United States, changing technical, social, administrative, economic, and ecological contexts during the first quarter of the twentieth century fomented a newfound interest in the potential of SSSs (Burian *et al.*, 2000). Between 1850 and 1920, the total percentage of United States residents living in urban areas moved from 12.5% to 51%, and 19th century sewerage infrastructure was not fully equipped to handle the influx in waste volume (Burian *et al.*, 2000; Louis, 2004). CSSs previously disposed of untreated waste into waterways at a centralized location, but as development expanded concerns grew that sewage was contaminating drinking water sources and diminishing public health (Burian *et al.*, 2000). The sheer volume of wastewater now discharged into waterways undermined the assumption that dilution sanitized sewage, spurring urban managers to explore wastewater treatment as a necessary prerequisite to disposal (Burian *et al.*, 2000). A progressive push for greater protection of natural resources, emerging laws requiring the protection of waterways from nuisance conditions, stricter judicial enforcement of waterway protection laws, and advocacy on the part of businesses, public health organization, and media combined to push urban managers toward an acceptance of wastewater treatment (Burian *et al.*, 2000). However, wastewater treatment was, at the time, considered incongruous with CSSs because they did not provide consistent and manageable flows to treatment facilities, particularly during wet weather events when the volume of flows would exceed the facilities’ capacity for treatment (Burian *et al.*, 2000). SSSs, which provided adequate flows for treatment facilities, became the new norm, and by the 1930s some urban communities began replacing CSSs with SSSs (Burian *et al.*, 2000).

Following this transition, urban managers focused primarily on expanding current systems rather than developing new technology, and federal funding for sanitation infrastructure diminished between the periods of 1902 and 1970 (Cain, 1997; Burain *et al.,* 2000). Nevertheless, echoing earlier trends during the industrial revolution of the late eighteenth and early nineteenth centuries, the twentieth century bore witness to economic prosperity and a higher quality of life, which came with a higher consumption of water and production of wastewater via a larger overall population and innovative plumbing fixtures such as showers, dishwashers, clothes washing machines, and food waste disposals (Burian *et al.*, 2000). The federal government reacted to the growing urban wastewater challenge by enacting the Water Pollution Control Act of 1948, which set out to provide "comprehensive planning, technical services, research, financial assistance, and enforcement" (Burian *et al.*, 2000: 53). Through extensions in 1952 and amendments in 1965, the Water Pollution Control Act not only set uniform water-quality standards, it also established the protection of waterway aesthetics and aquatic life as legislative goals (Burian *et al.*, 2000). Finally, the passage of the 1972 Clean Water Act (CWA) set a goal of nationwide water pollution elimination by 1985 and established new regulations for polluters (Burian *et al.*, 2000; Copeland, 2010a). The CWA also promoted the construction of treatment facilities by allocating billions of dollars toward research and construction costs, further increasing the proliferation of urban communities with SSSs throughout the United States (Burian *et al.*, 2000; Copeland, 2010a; Ferrey, 2010).

2.2.b: Technical Dimensions of Sewerage Systems in the United States: 1972 - 2014

The American Society of Civil Engineers (ASCE) gave sewerage infrastructure a grade of D on its 2013 Report Card for American Infrastructure (ASCE, 2013). The ASCE (2013) estimated that there were between 700,000 and 800,000 miles of public sewer mains in the United States as of 2013 and 14,780 wastewater treatment facilities in 2008. The vast majority of these facilities (98%) are publically owned, and serve nearly three-quarters of the population (EPA, 2002). Of this infrastructure, much is reaching the end of its useful life—if it has not already—and is unable to meet current flow capacity demands required (EPA, 2002; Koo, 2009; ASCE, 2013). Assessments for gathering data on the condition of water and sewerage infrastructure conditions generally reinforce the need for renewal engineering, entailing a broad spectrum of infrastructure repairs, replacements, and rehabilitative practices to bring infrastructure to acceptable performance levels (Jung, 2014).

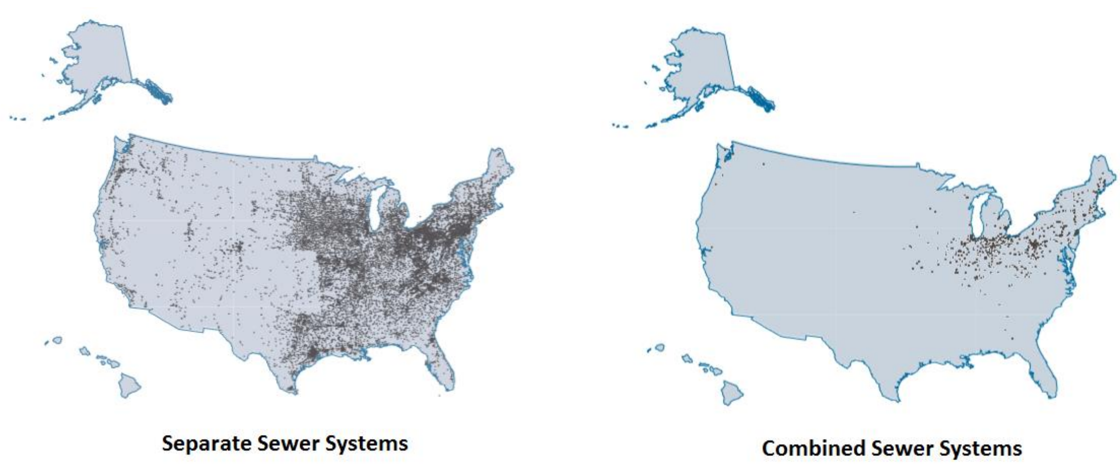
The vast majority of technical sewerage infrastructure needs are related to pipe conditions, as opposed to wastewater treatment facilities themselves. Consequently, most individual municipalities face the most pressing technical challenges, even if there is no treatment facility within municipal lines. Numerous factors are relevant to the technical stability of sewerage infrastructure, including pipe age, diameter, length, material, depth, and gradient, environmental factors such as soil conditions, frost damage, groundwater infiltration, and urban development (Chughtai, 2008). The industry standard useful life for most sewerage conveyance pipes can be as low as 15 years, but is generally between 50 and 100 years for vitrified clay, reinforced concrete, and cement lined ductile iron pipes; however, as of 2001, the average age of sewerage pipes was 42 years, with half of the nation relying on pipes older than 50 years, and many older communities using systems that are 100—and sometimes nearly 200—years old (EPA, 2002; WWE, 2010; Wirahadikusumah, 2001). Figure 2 depicts estimated deterioration trends of sewerage pipes through 2020 assuming pipe systems extend to accommodate growth and development, but no efforts are taken to replace or rehabilitate existing pipe (EPA, 2002). Although treatment facilities generally have a useful life of 20 to 50 years and will likely need rehabilitation within the next two decades, their general condition is less impaired because most facilities were built later than sewerage pipes, they are above ground and easier to see, and they tend to undergo more regular inspections (EPA, 2002).

Figure 2. Estimated Sewerage Infrastructure Deterioration Trends through 2020[1]

[1]Assuming pipe networks continue to expand, but no efforts are taken to replace or rehabilitate old pipes, approximately 45% of the nation's sewerage pipes are estimated to be classified as "poor," "very poor," or "life elapsed" by the EPA. From EPA (2002).

SSSs remain far more widespread than CSSs. Approximately 20,000 municipalities use separate systems in the United States, versus the 772 communities—mostly located in the northeast and around the Great Lakes—that rely on combined systems (Figure 3) (EPA, 2001, 2012). An additional 20% of the United States population relies on decentralized septic tanks for on-site treatment of wastewater (EPA, 2013). Besides their distinct approaches to transporting waste and stormwater, CSSs and SSSs are noteworthy for their response to intense wet weather events. Under dry and moderate wet weather conditions, CSSs transport both waste and stormwater to a wastewater treatment facility, where the aggregate flows are treated and discharged as effluent into a receiving waterway. If wet weather conditions are particularly severe and the sewerage infrastructure is unable to convey and treat the additional flows, CSSs are designed to discharge untreated waste and stormwater into a receiving waterway to increase the available capacity. Alternatively, SSSs are designed to always discharge untreated stormwater into receiving waterways, while wastewater is sent to a treatment facility during dry and moderate wet weather condition. During severe wet weather conditions, however, SSSs can also reach capacity and surcharge untreated wastewater and stormwater into waterways, public spaces, or subterranean environments. Untreated discharges from CSSs are known as combined sewer overflows (CSOs) and untreated sanitary pipe discharges from SSSs are known as sanitary sewer overflows (SSOs).

Figure 3. Partial Distribution of Separate and Combined Sewer Systems in the United States[1]



[1]Maps depicting distribution of most separate sewer systems (left) and combined sewer systems (right) throughout the United States. Adapted from EPA (2004a).

2.2.c: Environmental Dimensions of Sewerage Systems in the United States: 1972 – 2014

The 2004 National Water Quality Inventory report to Congress surveyed 16% of streams and rivers in the United States and found 44% to be "impaired," defined as unable to support one or more of their designated uses as determined by the CWA (EPA, 2004b). Water pollution comes from several sources, though CSOs, SSOs, and stormwater discharges from SSSs represent a considerable adverse input. Indeed, CSOs discharge 850 billion gallons each year, while SSOs contribute 10 billion gallons annually—not including normal discharges of stormwater or wastewater that surcharges into subterranean environments (EPA, 2004a). These discharges can have serious deleterious effects on water quality and aquatic ecosystems by introducing oxygen-demanding substances, sediments, pathogens, toxics, metals, pesticides, microbes, nutrients, floatables and other pollutants into the natural environment (Paul & Meyer, 2001; EPA, 2004a).

The negative impacts of CSOs and SSOs on aquatic ecosystems are well documented. Phillips *et al.* (2012) compared treated wastewater effluent from a treatment facility in Vermont to CSO discharges into Lake Champlain and found that, on average, CSO discharges contained ten times the levels of estrogens, androgens, and micropollutants. Iannuzzi *et al.* (1997) determined that sediments in New Jersey's Passaic River adjacent to CSO outfalls showed traces of several contaminants, including metals, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls (PCBs). Street dust contaminated with PCBs was found to wash into sewer systems and enter the Buffalo River in New York through CSO discharges (Loganathan *et al.*, 1997). SSOs have been associated with the deaths of over 10,000 fish in North Carolina between 1997 and 2002, as well as the deaths of 320 fish, 67 shrimp, 169 clams, 1 snail, and 1 bird after a single SSO event at Camp Pendleton in California (EPA, 2004a).

Sewerage systems undoubtedly affect surrounding community ecosystems, but environmental processes—heightened by climate change—are widely expected to also have a disruptive effect on sewerage infrastructure. The Intergovernmental Panel on Climate Change (2013) asserts with "medium" confidence that heavy precipitation events and increases in the frequency, intensity, and/or amount of heavy precipitation are due in part to anthropogenic activities, and that it is "very likely" these observed conditions will increase into the late 21st century over most mid-latitude lands and wet tropical regions (7).[1] Several assessments conclude that increased precipitation may strain wastewater infrastructure globally and nationally by increasing the frequency that wet weather events exceed system capacity, leading to more urban flooding, CSOs and SSOs, more sewage surcharging into subterranean environments like

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[1] The International Panel on Climate Change associates a "likely" forecast with a 66-100% range of confidence, and a "very likely" forecast with a 90-100% range of confidence.

residential basements, and insufficiently treated effluent discharging from wastewater treatment facilities (e.g., Niemczynowicz, 1989; Patz *et al.*, 2006; NACWA & AMWA, 2009; Mailhot & Duchesne, 2010; Kessler, 2011; Wilbanks & Fernandez, 2012).

2.2.d: Social Dimensions of Sewerage Systems in the United States: 1972 – 2014

A large body of research documents persistent urban population growth (e.g., DeFries *et al.*, 2010; McDonald *et al.*, 2010; Wu *et al*, 2010; Günerlap & Seto, 2013), and while the United Nations (2011) notes slowing growth of urban populations worldwide, it still predicts a doubling of the current 3.6 billion people living in urban areas within the next 63 years. Statistics from the most recent United States Census confirmed these global trends are also playing out nationally: urban areas account for 80.7% of the national population, and the urban population growth increase of 12.1% between 2000 and 2010 surpassed the nationwide population growth increase during the same ten-year period (DOC, 2012a). Urban population growth in the United States has been correlated previously with increased consumption of water resources and, consequently, increased production of wastewater (Burian *et al*., 2000; Louis, 2004). Assuming wastewater production goes unchecked by water efficiency policies and innovative technology, urban population growth may continue to strain sewerage systems by increasing inputs or requiring extensions to the existing sewerage network.

No matter the contribution climate change or urban population growth may have on flows in sewerage infrastructure, flooding, sewer surcharging and overflows already present a social challenge. When CSSs and SSSs are filled beyond capacity—usually during intense wet weather events—wastewater and stormwater will move to less pressurized areas, often being into buildings and residences (EPA, 2004a). Information about property damage due to sewer overflows is lacking and difficult to quantify because of case-specific circumstances, and many instances go unreported or are difficult to track (Papa *et al.*, 2013); however, it is estimated basement backups caused by CSOs and SSOs cost between $305 million and $654 million annually (Dorfman, 2004).

Sewer overflows into buildings and basements, as well as those that discharge into open waters, can deleteriously effect public health. One of the most famous national public health calamities connected to sewage overflows occurred when a massive wave of cryptosporidiosis—a severe gastrointestinal illness caused by the parasite, cryptosporidium—broke out in Milwaukee during the spring of 1993, affecting approximately 400,000 people and attributing to 725,000 absentee work and school days over a six-week period (MacKenzie *et al.*, 1994; Dorfman, 2004). The outbreak factored into at least 54 deaths, mostly amongst immunocompromised populations such as individuals infected with HIV (Vakil *et al.*, 1996; Hoxie *et al.*, 1997), and cost $96.2 million in costs associated with medical expenses and productivity losses (Corso *et al.*, 2003). Deficiencies in water treatment processes allowed the parasite to pass into drinking water and, though a source of the cryptosporidium itself was never definitively established, it is widely believed to have originated entirely or in part due to insufficiently treated sewage discharges and raw sewage overflows near one of the city's main drinking water inlets (e.g., MacKenzie *et al.*, 1994; Hoxie *et al.*, 1997; Rose, 1997; Dorfman, 2004; Eisenberg, 2004). Since 1999, annual nationwide medical costs associated with consuming shellfish obtained from waters contaminated by sewage overflows is between $2.5 million and $22 million, and costs associated with illness spurred by recreation in fresh and marine waters contaminated by sewage overflows is in the range of $591 million to $4.1 billion (Dorfman, 2004).

Recreation and tourism are impacted by sewer overflows. Swimmers at polluted beaches tend to have more gastrointestinal illnesses than non-swimmers, inducing communities to often close beaches suspected of being contaminated by sewer overflows (Dorfman, 2004). In 2012, there were 443 days of beach closings at coastal United States beaches due to known pollutant events such as sewage discharges and overflows, but 16,662 days of beach closings due to detected bacteria from unknown sources, which may include sewage (Dorfman & Haren, 2013). The value of a single beach trip is estimated to be between $15 and $50 per person per day (Pendleton & Kidlow, 2006), making beach closings a large source of lost community revenue; two months of beach closures following sewer overflows in Los Angeles were estimated to cost the city $2.4 million, while economic losses from beach closings due to all forms of pollution in Lake Michigan may exceed $37,000 each day (Dorfman, 2004; Rabinovici *et al.*, 2004).

2.2.e: Economic Dimensions of Sewerage Systems in the United States: 1972 – 2014

The ASCE justifies its grade of D for sewerage infrastructure in the United States not only by citing the deteriorating conditions of pipes and treatment facilities, but also by detailing the prohibitive cost of repair and rehabilitation (ASCE, 2013). Despite a significant jump in investments from $2.3 billion in 1956 to $93.6 billion in 2008, "local government is on a spending treadmill where ever-growing annual investments may not be sufficient to guarantee safe, affordable and adequate supplies and services in the 21st century" (Anderson, 2010: 4). Over the next twenty years, capital improvements to repair, replace, rehabilitate, and upgrade wastewater infrastructure—including wastewater treatment facilities, pipes, CSO corrections, stormwater management programs, and recycled water distribution—will carry a price tag on the order of $298 billion, twice the current investment by all levels of government (EPA, 2008; ASCE, 2013). Small communities with populations of fewer than 10,000 people will require $22.7 billion in capital improvements, or 8% of the total estimated nationwide cost (EPA, 2008).

The 1972 CWA authorized Congress to assist in funding sewerage infrastructure and wastewater treatment construction and rehabilitation. States receive grants according to state population and infrastructure needs as assessed by EPA surveys (Copeland, 2010a). Between 1972 and 1989, federal grants covered 55 to 75% of infrastructure improvement costs, with more funding allocated to construction of priority or innovative technology (Copeland, 2010a). The 1987 Water Quality Act established the Clean Water State Revolving Fund (CWSRF), which officially went online in 1989, as an alternative state-by-state revolving loan funding source for sewerage infrastructure (Copeland, 2010a). For every dollar the federal government donates to a state's CWSRF, the state will match that donation with 20 cents (EPA, 2014a). Individual communities can borrow money from the CWSRF for a range of wastewater infrastructure needs and repay loans at low or no interest over 20 years, allowing other communities to tap into funds for infrastructure projects (EPA, 2014a). While the EPA (2014) insists the CWSRF program is more flexible than previous federal grant programs, some cities and smaller communities struggle to pay back loans (Copeland, 2010a). Moreover, federal investments in wastewater infrastructure declined between 2008 and 2012 to an average $2.1 billion annually, or $42 billion over two decades (ASCE, 2013).

Local government expenditures constitute 97% of all investments into public water and wastewater infrastructure, yet "limited resources prevent them from acquiring and implementing technologies as quickly as they and regulatory agencies would prefer" (EPA, 2004a; Anderson, 2010). Local governments primarily rely on municipal obligation bonds, revenue bonds, and user rates to fund water and wastewater infrastructure needs (Anderson, 2010). The difficulty local governments have in financing major capital improvements may be exacerbated by their failure to charge appropriate user rates for water and sewerage services (Anderson, 2010). An estimated 70 to 80% of utilities set user rates high enough to cover the costs of operations and maintenance, but not high enough to sufficiently finance repair, replacement, and rehabilitation projects (Anderson, 2010).

2.2.f: Administrative Dimensions of Sewerage Systems in the United States: 1972 – 2014

The 1972 CWA established two goals: the elimination of all pollution discharges into waterways by 1985 and, wherever possible, the establishment of waterways that are both "fishable" and "swimmable" by 1983. Nearly three decades later, the Environmental Protection Agency (EPA)—the federal agency with primary authority over implementing the CWA—has been unable to meet the first ambitious goal, and continues working toward achieving the second goal.

The CWA is a regulatory, technology-forcing statute to help make reaching those goals feasible (Copeland, 2010a). The CWA required industrial dischargers to install the "best practicable technology," understood as the best available technology for limiting polluted effluent discharges at the most appropriate cost as determined by the EPA no later than July 1, 1977; industries unable to comply were shut down (Copeland, 2010a; Ferrey, 2010). Industries specifically discharging toxic and nonconventional pollutants into waterways were given until March 31, 1989 to install the "best available technology," which did not include a cost-benefit analysis (Copeland, 2010a; Ferrey, 2010). Municipalities did not have to achieve industry standards for effluent treatment and, instead, were required to install "secondary treatment" technology at wastewater treatment facilities by July 1, 1988 (Copeland, 2010a). Primary treatment of wastewater is entirely physical, removing large suspended solids, heavy solids, or excessive amounts of fat, oil, and grease (Ferrey, 2010). Secondary treatment is entirely biological, which uses microbial oxidation processes as wastewater filters through a gravel bed to mimic purification processes of streams (Ferrey, 2010). The Municipal Wastewater Treatment Construction Grants Amendments of 1981 established that municipalities are not required to install tertiary treatment (i.e., chemical treatment) of wastewater as well (Copeland, 2010a; Ferrey, 2010). By 1988, 86% of all municipalities met the deadline for secondary treatment technology installation, with the remaining municipalities being required to comply as quickly as possible (Copeland, 2010a).

Another major amendment to the regulatory provisions of the CWA took the form of the 1987 Water Quality Act, which expanded the scope of the CWA from combatting only point-source pollution to also requiring National Pollution Discharge Elimination System (NPDES) permits for some forms of nonpoint source pollution (Copeland, 2010a). The amendment encouraged states to develop and implement nonpoint pollution management initiatives to protect waterways from contaminated stormwater runoff, which accounts for an estimated half of all national water quality impairment (Copeland, 2010a). The EPA employed NPDES permitting for nonpoint source pollution in urban areas issued in two phases. Phase I was issued in 1990 and targeted "medium and large municipal separate storm systems…located in incorporated areas and counties with populations of more than 100,000, certain industrial activities, and construction activities disturbing five acres or more" (EPA, 2005: 27). Phase II was issued in 1999 and required NPDES permitting for "operators of small [municipal separate storm systems] in "urbanized areas" (as defined by the Bureau of the Census) and small construction activities disturbing between one and five acres of land" (EPA, 2005: 27-28).[2]

The EPA was able to launch the 1994 CSO Control Policy, which sought to provide "guidance to communities and permitting authorities on options for CSO control that will meet [CWA] requirements in a flexible, cost-effective manner" (EPA, 1998: 1). The policy sought to make effective CSO management, in accordance with nine minimum controls,[3] simpler for municipalities and, four years after its inception, the EPA (1998) reported more than half of CSO communities were implementing the nine controls. Each state with CSS communities completed long-term CSO control plans by 2001 (EPA, 2001). There has been little additional major federal legislation or policy guiding sewerage system administration beyond the publication of the 1994 CSO Control Policy, and most recommendations for new laws—typically regarding funding of sewerage infrastructure and control of CSOs and SSOs—remains contentious and politically immobile (Copeland, 2010b).

State and local governments have considerable agency in setting policy for water pollution and sewerage systems. The CWA and many other federal environmental laws embody "a philosophy of federal-state partnership in which the federal government sets the agenda and standards for pollution abatement, while states carry out day-to-day activities of implementation

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[2] The Department of Commerce, through the Bureau of the Census, classifies "urbanized areas" as densely settled territories that contain 50,000 or more people (DOC, 2010).

[3] The nine controls are: (1) Proper operation and maintenance of the combined sewer system, (2) Maximum use of the collection system for storage, (3) Review and modification of pretreatment requirements, (4) Maximization of flow to the publicly owned treatment works (POTW) for treatment, (5) Prohibition of CSOs during dry weather, (6) Control of solid and floatable materials in CSOs (7) Pollution prevention, (8) Public notification of CSO occurrences and impacts, (9) Monitoring of CSO impacts and the effectiveness of CSO controls (EPA, 1998).

and enforcement" (Copeland, 2010a: 4). Many agencies and associations are involved with state and local-level management of water resources, including regional special-purpose districts, public utility or service commissions, state, county, and municipal governments, as well as citizens' groups and non-profits, such as the American Water Resources Association (Louis, 2004; Marques, 2010).

2.3: Sewerage System Management in Cook County, Illinois

This section will provide an overview of Cook County relevant to its sewerage system management practices. The government of Cook County, Illinois (2011)—established in 1831—describes the county as:

> …an urban county in the upper northeastern section of the State of Illinois that contains more than 800 local governmental units within its boundaries. With a population of approximately 5.3 million people, it is the second most populous county in the nation and the 19th largest government in the United States (2005 census statistics)…Cook County contains 128 municipalities in its region, the most well known being the City of Chicago - which is the County seat where the central offices of Cook County are located. The City of Chicago and the suburban municipalities account for approximately 85% of the County's 946 square miles, while unincorporated areas make up the remaining 15%.

Cook County is a home rule county, defined by the Illinois Constitution as a county with an elected chief executive officer or any municipality with more than 25,000 residents and, thereby, granted powers to protect "the public health, safety, morals and welfare; to license; to tax; and to incur debt" (Article VII, section 6a). Municipalities with populations of less than 25,000 may elect to become home rule communities by referendum (Article VII, section 6a). Home rule municipalities in Cook County rely on property taxes for 18% of their overall revenue, less than the statewide home rule average of 23%, and despite widespread concern over the abuse of home rule taxing authority, there have been few instances of abuse of home rule taxes in Illinois since 1970 (Banovetz, 2002).

A number of waterways border or run through Cook County, including but not limited to Lake Michigan, the Chicago River, the Des Plaines River, the Calumet River, the Little Calumet River, Salt Creek, the Chicago Sanitary and Ship Canal, and the Cal-Sag Channel. Cook County also exists within seven watersheds, including the Little Calumet-Galien Watershed, the Pike-Root Watershed, the Lake Michigan Watershed, the Chicago Watershed, the Des Plaines Watershed, the Upper Fox Watershed, and the Lower Fox Watershed (EPA, 2014b). Communities in Cook

County rely on water from Lake Michigan or local aquifers, which is generally sent to one of seven water reclamation facilities operated by the Metropolitan Water Reclamation District of Greater Chicago (MWRD), before being released as effluent into local waterways that ultimately travel the Des Plaines River, which feeds into the Illinois River and, from there, the Mississippi River, before its final release into the Gulf of Mexico.

The MWRD is an independent government and taxing body run by a nine-member Board of Commissioners. The agency's stated mission is to:

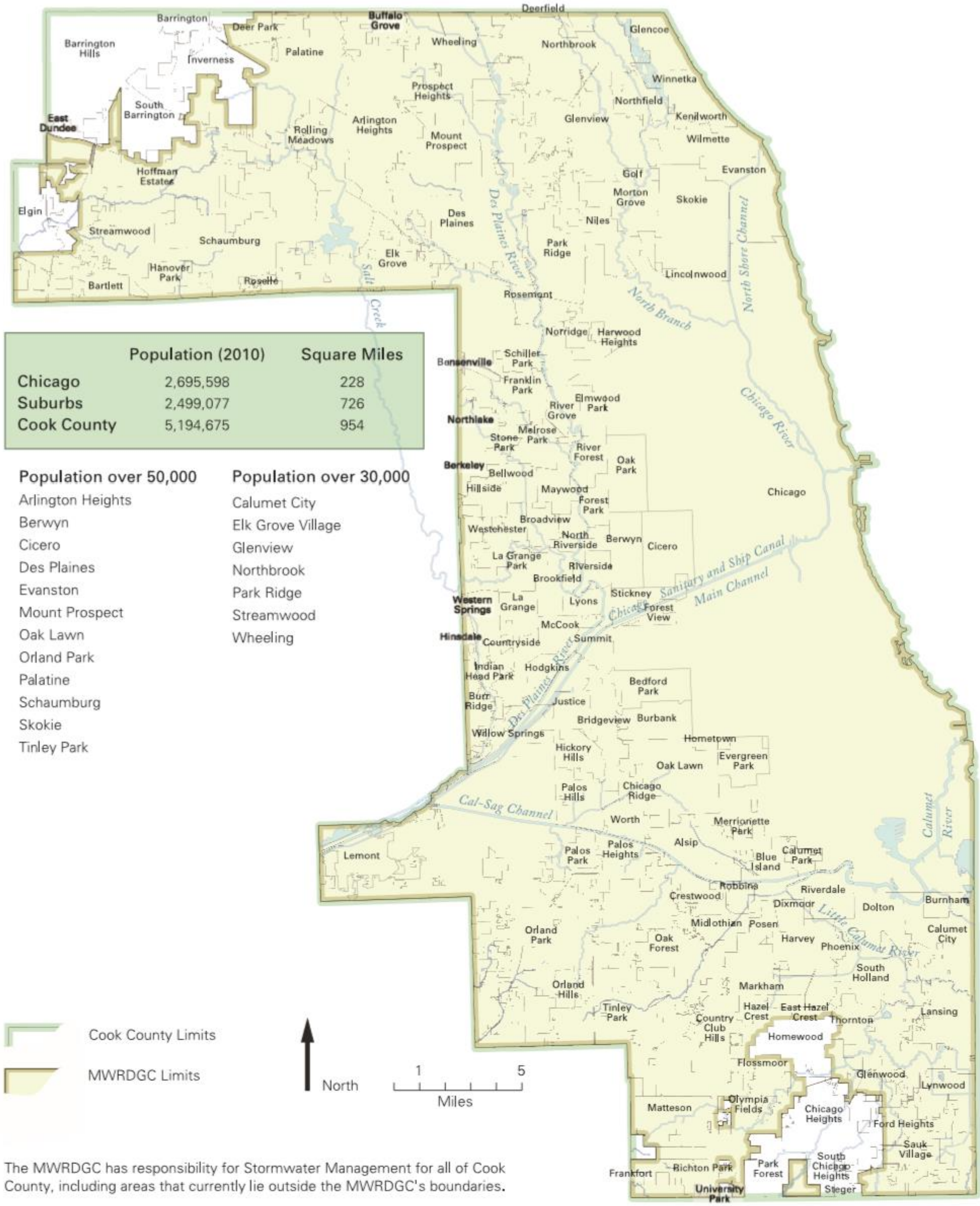
> protect the health and safety of the public in its service area, protect the quality of [Lake Michigan], improve the quality of water in watercourses in its service area, protect businesses and homes from flood damages, and manage water as a vital resource for its service area (MWRD, 2014).

The MWRD oversees seven water reclamation facilities, each ranging in capacity from 2.3 million gallons per day to 1.2 billion gallons per day at the Stickney plant, the largest water reclamation plant in the world (MWRD, n.d.a). The MWRD oversees most sewage and wastewater management and all stormwater and flooding management in Cook County (Figure 4). Yet the MWRD's authority is separate from that of individual municipalities:

> While exercising no direct control over wastewater collection systems owned and maintained by cities, villages, sewer districts, and utilities, the District does control municipal sewer construction by permits outside the City of Chicago. It also owns a network of intercepting sewers to convey wastewater from the local collection systems to the water reclamation plants (MWRD, 2014).

Thus, while the MWRD is a regional agency responsible for treating wastewater and issuing permits for sewerage infrastructure construction, municipalities maintain control over public sewerage infrastructure within their jurisdiction, while private citizens are responsible for private laterals that feed into the municipal system.

Figure 4. Jurisdiction of the Metropolitan Water Reclamation District of Greater Chicago[1]



	Population (2010)	Square Miles
Chicago	2,695,598	228
Suburbs	2,499,077	726
Cook County	5,194,675	954

The MWRDGC has responsibility for Stormwater Management for all of Cook County, including areas that currently lie outside the MWRDGC's boundaries.

[1]From MWRD (2014).

The MWRD originally formed as a response to public health concerns over drinking water contamination (Cain, 1978; Hill, 2000; MWRD, 2014). Despite natural drainage from local rivers, Chicago's landscape was so flat that rainwater would not run off, creating swampy conditions until the water would evaporate or percolate through the soil (Cain, 1978). In 1848, with a population of approximately 30,000, there was no sewer system; the primary drainage system consisted of roadside ditches into which citizens would dump refuse and waste until rainwater washed it into the Chicago River (Cain, 1978). At the time, the Chicago River naturally flowed into Lake Michigan, Chicago's source of drinking water. Waterborne diseases were regular occurrences, including an outbreak of cholera in 1854 that killed nearly six percent of the population (Cain, 1978; Hill, 2000). Desperate to solve their wastewater woes, Chicago's Board of Sewerage Commissioners hired Ellis Sylvester Chesbrough, then the city engineer for Boston, to improve the city's health (Cain, 1978; Hill, 2000). Chesbrough set out to establish one of the country's first comprehensive combined sewerage systems, which required wastewater to drain into the Chicago River thereby effectively condemning it as an open sewer (Cain, 1978; Hill, 2000). Nevertheless, while Chesbrough's efforts relieved much of the city's drainage problems, the Chicago River not only became entirely polluted, but the pollution continued to stretch through Lake Michigan and to the city's water supply intake (Cain, 1978; Hill, 2000).

Polluted drinking water stymied public health improvements, so, in the 1860s, the city took the drastic step of engineering the Chicago River to intermittently reverse its flow as a means of flushing pollutants downstream (Cain, 1978). Yet over the next four decades, water quality was still so poor that even temporary reversals of the Chicago River were not enough to protect public health (Cain, 1978). Inadequate sewerage infrastructure to control odors, flooding, contamination, and illness prompted vocal responses from citizens in the 1880s (Hill, 2000). In 1886, Chicago created a governmental Drainage and Water Supply Commission charged with developing a plan that would rectify the ongoing public health challenges and flooding (Hill, 2000). Chicago's Drainage and Water Supply Commission ultimately determined that the best means of ameliorating the city's wastewater problems was to permanently reverse the Chicago River by creating a new canal to alter the hydrologic flow (Hill, 2000). However, building the canal would cost an estimated $7 million, and so it was determined that a separate county-wide governmental body must be created with taxing authority to increase available funds at the city's disposal for embarking on such an ambitious engineering project (Hill, 2000). Further, local industries demonstrated interest in the proposed canal when it became known that, if the canal were made wide enough, it could be determined a navigable waterway and allow for increased financial gains by connecting the Mississippi River to Lake Michigan (Hill, 2000).

After significant lobbying efforts by Chicago to convince other communities, especially those downstream of the Mississippi River where Chicago's wastewater would flow after the construction of a canal, the "Act to Create Sanitary Districts and to Remove Obstructions in the Des Plaines and Illinois Rivers" passed through the Illinois House and Senate (Hill, 2000). The act authorized the creation of county-wide sanitary districts intended to protect public health by managing wastewater. The Sanitary District of Chicago was formed shortly thereafter in 1889 with enormous public support (Hill 2000; MWRD, 2014). Immediately after formation of the Sanitary District of Chicago, the board of commissioners began planning for the creation of the Sanitary and Ship Canal, named in order to reflect its dual functions for protecting public health and enhancing economic development. Construction began in 1892 and concluded in 1900. Once completed, the canal successfully and permanently carried the flow of the Chicago River into the Des Plaines River and away from Lake Michigan (Cain 1978; Hill 2000). Reversing the flow of the river yielded significant benefits for public health within Chicago, and allowed the city to maintain its rapid rate of growth (Lee, 2001). The long-term success of Chicago's wastewater system earned it recognition amongst the ASCE's (2014) ten "Monuments of the Millennium" that "had the greatest positive impact on life in the 20^{th} century."

The Sanitary District of Chicago continued taking bold and progressive action into the twentieth century, including construction of the North Shore Channel in 1910 and the Cal-Sag Channel in 1922 to further reduce wastewater contamination of Lake Michigan, as well as the installation of its first wastewater treatment plant in 1922 and six additional plants in following years (Cain, 1978). Today, most wastewater travels south of Chicago to the Stickney Water Reclamation Plant (Stickney), which became fully operational in 1939 (MWRD, n.d.a). Stickney is the world's largest wastewater treatment facility, and uses a four-step treatment process to mimic processes of a natural river (COC, 2009). Wastewater first moves through rotating screens to catch large debris, before being pumped and transported by gravity through the remainder of the plant. At the first tank, heavy inorganic particles like sediment naturally filter toward the bottom, and oxygen is injected to break down remaining organic materials. The second tank allows organic materials to settle, oils to move to the surface, and water to continue on to the third tank, where water is again injected with oxygen, but this time with microbes that breakdown remaining waste materials. Finally, water enters pools with diameters of 30 feet where sediments settle and the treated effluent moves through channels to the Sanitary and Ship Canal.

While reversing the Chicago River and establishing the world largest wastewater treatment facility were critical for cleaning up local waterways, more work was needed. Many municipalities in Cook County rely on CSSs, so intense wet weather events often cause sewers to exceed their capacity and overflow into waterways, streets, or basements. As the region grew, so did the amount of impervious surfaces, causing more stormwater to enter sewerage infrastructure and significantly increasing the number of overflows into Lake Michigan, exposing the public to untreated wastewater (MWRD, n.d.b).

The MWRD addressed the issue in 1972 by adopting the Tunnel and Reservoir Plan (TARP), a multi-billion dollar project to protect Lake Michigan, other local waterways, streets, and basements from raw sewage and stormwater flooding (MWRD, n.d.b). TARP—often referred to as Deep Tunnel—is a two-phase project. Phase I - the primary pollution control component - involved the creation of four major tunnels systems throughout Cook County with pipes that automatically remove water from the system after a storm event in order to maximize capacity before the next event. In total, there are over 109 miles of enormous pipes currently capable of capturing 2.3 billion gallons of combined flows. The captured combined flows undergo treatment, and then discharge into local waterways. Over the years, this system became gradually operational, with full completion of Phase I in 2006. The second phase is still ongoing, focusing primarily on flood control and abatement of polluted waterways. This phase involves building three massive reservoirs throughout the county, which will increase the storage capacity of TARP to 17.5 billion gallons.

Chapter 3: Methodology

> *That quantitative procedures remain predominant in the social sciences is not in itself a problem or a question. What must be questioned, however, is the preoccupation of so many quantitative social scientists with methods, often at the expense of both theory and substance. Qualitative strategies, on the other hand, are intricately intertwined with both the substance of the issues they explore and theories grounded in these substantive issues. If social science is to sort the noodles from the soup, it must to do in a substantively meaningful manner.*
>
> — Bruce L. Berg & Howard Lune (2012): 419

Despite extensive literature on emerging challenges associated with management of sewerage infrastructure internationally, no previous studies examining challenges to the resilience of municipal sewerage systems and strategies for managing for resilience in Cook County, Illinois were identified prior to this study. Further, no identified studies associated with sewerage system management specifically analyzed for technical, administrative, social, economic, and environmental criteria at the municipal scale. This section details how qualitative research methodology was selected and constructed to fill the identified knowledge gap.

3.1: Approaches to Qualitative Research

Whereas quantitative analysis tends to count and measure, qualitative research has been described as a method of answering the "what, how, when, where, and why of a thing—its essence and ambience," in order to understand "meanings, concepts, definitions, characteristics, metaphors, symbols, and descriptions" (Berg & Lune, 2012: 4). Social constructionism suggests that social relationships are constructed and highly interpretive phenomena that cannot be fully or sometimes even partially understood through quantitative approaches alone (Robson, 2011). Yet social constructionism and qualitative research are not entirely divorced from an understanding of physical, tangible, and otherwise quantifiable objects, events, or phenomena. Indeed, "the meaning that people attach to their experiences and the objects and events that make up these experiences is not accidental or unconnected. Both the experiences and the events surrounding them are essential to the construction of meaning" (Berg & Lune, 2012: 14). Social construction can provide meaningful insights into how these things are identified and perceived (Robson, 2011). Qualitative researchers have several research methodological approaches at their disposal to better understand the social environment, including case studies, participant observation, unobtrusive measures, focus groups, and interviews. Methodological choices should be made with respect to the type of information sought by the research, and the circumstances under which research is taking place (Robson, 2011).

Interviews are conversations with the purpose of obtaining information from an informant (Berg & Lune, 2012). Interviews can be fully structured, semi-structured, or unstructured. Fully structured interviews are similar to surveys in that they rely on precisely phrased and ordered questions, and do not allow the interviewer to deviate from a predetermined script (Robson, 2011; Berg & Lune, 2012). Oppositely, unstructured interviews are generally impromptu or improvisational, allowing the interviewee to explore areas of interest without concern for consistency across interviews (Robson, 2011; Berg & Lune, 2012). Between the two are semi-structured interviews, which allow adjustments to the phrasing and order of questions, as well as the addition of probes or the exploration of interesting topics; however, all interviews cover the same general topics (Robson, 2011; Berg & Lune, 2012).

3.2: Site Selection

Cook County, Illinois is relatively flat topographically, reducing the effects of topographic variance on county-wide sewer system functionality. Further, while Cook County is subject to severe weather—including floods, heavy snowfall, and tornadoes—these events seldom damage subterranean infrastructure as thoroughly as hurricanes or earthquakes in large urban coastal areas of the United States. The 128 municipalities vary in terms of sewer system type utilized (CSO, SSO, or both), relative economic affluence, age, proximity to Chicago, governmental structure, and several other factors. Two such factors—sewer system type and relative economic affluence—were targeted specifically to explore differences and similarities among municipalities with different infrastructure and economic resources within the community. Most municipalities in Cook County fall under the jurisdiction of the MWRD and are subject to its rules and regulations concerning wastewater management. To maintain consistency with regard to external management organization, only municipalities within the MWRD's jurisdiction were included in this study.

Municipalities were chosen according to sewer system type and an economic profile. Municipal sewer system type was determined by consulting the MWRD's website (www.mwrd.org) and confirmed with municipal professionals in person or over the phone. Economic profiles were created by consulting the most recent information available on the website for the United States Census Bureau (DOC, 2012b). Three economic indicators are available directly relating to the wealth of individuals within each municipality: per capita money income in the past 12 months (2012 dollars), median household income, and percentage of persons below the poverty level. Values for each indicator were compared with the averages for all of Cook County ($30,048, $54,648, and 16.4%, respectively). Municipalities were first categorized according to sewer system type (combined, separated, or both combined and separated), and then categorized according to their economic profiles. Municipalities above or below the county average for all three indicators were selected as candidate sites, while municipalities with only one or two indicators above or below the county average were excluded. Municipalities became candidate sites if they fell above or below the county average for at least median household income, a metric often used as a partial proxy of community wealth (e.g., Rives & Heaney, 1995; Imperial, 1999; Saxton & Benson, 2004). Thus, municipal sites were initially chosen according to six potential categories (Table 2). Three additional municipalities were selected based on their status as a non-home rule community, a concept that emerged during the initial interviews and was further explored. Limited availability and access to non-home rule communities resulted in an additional two municipalities with separate systems and economic profiles above the county average, and one additional municipality with combined and separate systems and an economic profile below the county average.

Table 2. Initial Categories of Municipal Selection Criteria

CATEGORY 1	**CATEGORY 2**	**CATEGORY 3**
COMBINED SYSTEM & ECONOMIC PROFILE ABOVE COUNTY AVERAGE	COMBINED & SEPARATED SYSTEMS & ECONOMIC PROFILE ABOVE COUNTY AVERAGE	SEPARATE SYSTEM & ECONOMIC PROFILE ABOVE COUNTY AVERAGE
CATEGORY 4	**CATEGORY 5**	**CATEGORY 6**
COMBNED SYSTEM & ECONOMIC PROFILE BELOW COUNTY AVERAGE	COMBINED & SEPARATED SYSTEMS & ECONOMIC PROFILE BELOW COUNTY AVERAGE	SEPARATE SYSTEM & ECONOMIC PROFILE BELOW COUNTY AVERAGE

Once candidate municipalities were identified, professionals from Public Works and Engineering departments were contacted via phone, email, letters, or in person with requests for interviews. Requests included the name of the study, the purpose of the study, and the researcher’s affiliation with Oregon State University. Professionals were contacted using information available on municipal websites, and while the highest ranking departmental officials were targeted, all requests asked for interviews with the highest ranking official best able to speak on behalf of the municipality concerning management of the municipal sewerage system. Many contacts did not respond to the interview requests, while others directly declined, usually contending that the business of their schedules precluded them from the time necessary to participate in the interview. The researcher then decreased the requested time for interviews from 60 minutes to 30 minutes; subsequently, contacted professional generally demonstrated greater willingness to participate in the study. One professional agreed to be interviewed, but canceled the morning of the interview to work on emergency repairs.

3.3: Municipality Descriptions

To preserve the confidentiality of all municipalities and study participants, information that may directly identify individuals or municipalities involved in this study has been omitted or substituted with codes. Table 3 provides information about the number of interviews and interviewees from each municipality included in this study, as well as the form of government and generalized population for each municipality. Population data are generalized in clusters of 10,000 residents and taken from census estimates (DOC, 2012b). Below is a description of information included within each municipality code:

- M#: "Municipality," followed by an arbitrarily assigned number.
- C / S / CS: The municipality has a "combined" sewer system, "separate" sewer system, or a "combined and separate" sewer system, respectively.
- A / B: The municipality is "above" or "below" the Cook County average for community wealth, respectively, defined as mean household income and, in most cases, mean per capita income and percentage of persons below the poverty line as well.
- HR / NHR: "Home rule" or "non-home rule," respectively.

Overall, nine municipalities were included in the study. Three municipalities had a separate sewer system, two municipalities had a combined sewer system, and four municipalities had both separate and combined sewer systems. Five municipalities were above the Cook County average for community wealth, while four municipalities were below the average. Six of the municipalities were home rule communities, whereas the remaining three were non-home rule communities. Six of the municipalities operated under council-manager forms of government, one municipality operated under a strong mayor form of government, one municipality used an aldermanic-city form of government, and one municipality used a village-trustee form of government.

Municipality populations ranged from less than 10,000 residents to between 50,000 and 60,000 residents.

Table 3. Municipality Codes, Interview Data, Government Form, and Population

Municipality[1]	Interviews / Municipality[2]	Interviewees / Municipality[3]	Interviewee Department	Municipal Government[4]	Municipal Population[5]
M1(S-A-HR)	1	2	Public Works; Engineering	Council-Manager	<60,000
M2(C-A-HR)	2	2	Public Works; Engineering	Council-Manager	<50,000
M3(CS-A-HR)	1	1	Public Works	Council-Manager	<30,000
M4(S-B-HR)	1	1	Public Works	Strong Mayor	<20,000
M5(C-B-HR)	1	1	Public Works	Council-Manager	<30,000
M6(CS-B-HR)	1	1	Public Works	Aldermanic-City	<30,000
M7(S-A-NHR)	1	1	Public Works	Council-Manager	<10,000
M8(CS-A-NHR)	1	2	Public Works	Council-Manager	<20,000
M9(CS-B-NHR)	1	1	Public Works	Trustee-Village	<20,000

[1] Municipality codes should be interpreted as follows: M# (“Municipality,” followed by an arbitrary number); S (“separate” sewer system); C (“combined” sewer system); CS (“combined and separate” sewer system); A (“above” average community wealth in Cook County); B (“below” average community wealth in Cook County); HR (“home rule”); NHR (“non-home rule).

[2] Total number of interviews: n = 10.

[3] Total number of interviewees: n = 12.

[4] Municipal form of government was determined by checking the municipality’s website.

[5] Populations are clustered in groups of 10,000, ranging from 0-9,999 (<10,000), 10,000-19,999 (<20,000), 20,000-29,999 (<30,000), 30,000-39,999 (<40,000), 40,000-49,000 (<50,000), and 50,000-59,999 (<60,000).

3.4: Semi-Structured Interviews

A total of ten semi-structured interviews were conducted with twelve interviewees during the months of June, July, August, and December 2013. The majority of interviewees were professionals in the municipality’s Public Works department, although two interviewees represented the Engineering department (Table 3). All interviews took place at the interviewee’s office during their normal working hours. Most interviewees lasted approximately 30 minutes. Interviewees were reminded about the purpose and intent of the interviews, and consented to be audio recorded and have their contributions included in the study and any final publications. All interviews were audio recorded using a Sony digital flash recorder.

The researcher prepared an interview guide (see Appendix C) with key topics for discussion. Primary questions were put to all interviewees, and additional prompts, clarification, or unpremeditated questions were used to obtain additional information or explore emerging topics of interest and potentially relevant to the study aims. All interviews were concluded by asking if the interviewee had any final questions or comments.

3.5: Coding and Analysis

All interviews were transcribed onto a Microsoft Word document within one week after conducting the interview. Interviews were edited for extraneous or unnecessary words and phrases (e.g., “uh” and “um), but were otherwise transcribed verbatim.

Following interview transcription, the researcher combed through interviews to separate text according to codes (see Appendix D) based on Table 1. Due to the strong theoretical basis of most codes, the researcher chose to conduct all coding by hand to ensure consistency, accuracy, and relevance. Codes were categorized as primary (i.e., challenges or projects), secondary (i.e., technical, administrative, social, economic, environmental), and tertiary (i.e., robustness, redundancy, resourcefulness, rapidity). During coding, it became apparent that interviewees were also emphasizing organizational components of the municipal sewerage system not directly applicable to codes for challenges and projects; thus, the research created an additional set of codes with primary (i.e., organization), secondary (i.e, internal or external), and tertiary (i.e., public, private, or collaborative) themes related to organizational issues.

All data were associated with individual interviews, not individual interviewees. During interviews conducted with two interviews, one interviewee generally acted as the primary informant. While interviewees occasionally emphasized different issues, in no instances did either disagree with or contradict the other. Thus, for coding purposes, it was assumed that both interviewees collectively provided the same information. In the case of one municipality, M2(C-A-HR), responses from both interviewee were coded and categorized separately because interviews were conducted independent of one another; therefore, interviewees were unable to influence each other’s responses.

Thus, study results and analysis operate with the understanding that data come from ten interviews, not necessarily from twelve interviewees. For example, if results report that all interviewees mentioned a particular topic, it indicates that during each of the ten interviews, at least one of the interviewees mentioned that topic.

3.6: Limitations

One potential limitation in this study is the relatively small sample size and short duration of interviews. This limitation particularly constrains the conclusiveness of data analyzed to answer the fourth and fifth research questions—the effect of sewer system type and community wealth on concerns about disruptions and management strategies, respectively—because these questions further reduce the sizes of sample populations. Nevertheless, many qualitative researchers argue that the number of interviews does not have a direct bearing on the substantive quality of interviews (e.g., Baker & Edwards, 2012). Further, while each interview had unique characteristics and emphases, major topics and themes relevant to the study were generally repeated throughout, such that the final interviews contributed insights already expressed during previous interviews. Thus, saturation appears to have been achieved (Guest *et al*., 2006).

Another limitation is that all interviewees represented either the municipality's Public Works or Engineering departments. None of the interviewees represented other actors in the system, particularly municipal leaders (e.g., mayors, village managers, or trustees) or residents, all of whom affect municipal management and may answer interview questions very differently. Nevertheless, interviews were requested with the individual or individuals best able to speak on behalf of the municipality as a whole; therefore, intentionally pursuing different categories of interviewees could have potentially undermined the study's attempt to arrive at a broad understanding of municipal sewerage system management.

Finally, all qualitative research, coding, and analysis is affected by some level of subjectivity. Consequently, researcher bias may affect study results, discussion, and recommendations. While efforts were taken to minimize bias, there is no way to fully eliminate subjectivity from the research process.

Chapter 4: Results

> *For much of U.S. history, particularly since the Progressive Era, we have attempted to divorce engineering and politics; but no longer. Engineering brilliance, which now carries a cost in the billions, no longer gathers the public support it once did.*
>
> — Louis P. Cain (1995): 131

The following section details results obtained from all interviews according to the established coding schemes. Each interview stressed issues differently than the others, but there was a general consensus on major themes. Some topics were directly addressed by a minority of interviewees but, due to contextual evidence from other interviewees, would likely correspond with the views of others had interviewees been asked to comment directly. Outliers that are likely not representative of most municipalities were usually excluded; however, given the relatively small number of interviews, some outlier topics were included for their contribution to the overall discussion of municipal sewerage system resilience. These outliers are identified as not being likely to represent the views of other interviewees.

Both challenges and projects were coded using the matrix in Table 1 (section 2.1) and the code books in Appendix D. For further clarification while coding, the following definitions were applied:

- *Challenges* refer to factors that diminish sewerage system robustness, redundancy, resourcefulness, or rapidity, and the deleterious resulting consequences.
- *Projects* refer to strategies and efforts for preventing, mitigating, controlling, or rehabilitating diminished sewerage system robustness, redundancy, resourcefulness or rapidity.
- *Technical* refers to municipal sewerage infrastructure or technology requiring specialized knowledge or training to construct, operate, or maintain.
- *Administrative* refers to decision-making processes, policies, and practices affecting the management of municipal sewerage systems.
- *Social* refers to end-users of services provided by municipal sewerage systems.
- *Economic* refers to finances, budgeting, or revenue necessary to maintain or improve municipal sewerage systems.
- *Environmental* refers to natural processes that interact with municipal sewerage systems.
- *Robustness* refers to categorical strength or resistance to disruptions.

- *Redundancy* refers to the reliance on multiple supplemental or repeating services to sustain municipal sewerage system functionality, operations, and management in the event that some services become critically disrupted.
- *Resourcefulness* refers to the capacity to identify problems and priorities, mobilize and maximize available resources.
- *Rapidity* refers to the ability to achieve goals at a rate appropriate for minimizing losses and future disruptions.

Thus, robustness entails a notion of engineering resilience—which emphasizes resistance to disturbances—whereas redundancy, resourcefulness, and rapidity highlight the system's ability to persist, a notion central to ecological resilience.

Codes for municipal sewerage system organization emerged from the data, and were categorized in a code book (Appendix D). For further clarification while coding, the following definitions were applied:

- *Organization* refers to the way in which key actors assemble, interact, and influence one another concerning municipal sewerage system management.
- *Internal* refers to actors, assemblages, interactions, and influence strictly within individual municipalities.
- *External* refers to actors, assemblages, interactions, and influence exogenous to individual municipalities, but affecting internal management.
- *Public* refers to individuals, groups, or agencies responsible for acting on behalf of the public when managing municipal sewerage systems (e.g., elected officials and government agencies or departments).
- *Private* refers to individuals, groups, or organizations not responsible for acting on behalf of the public who influence management of municipal sewerage systems (e.g., individual citizens, community groups, or businesses).
- *Collaborative* refers to communication and project implementation between two groups. Internal collaboration may occur between public and private actors, or within public and private actors. External collaboration may occur between two external actors, or between external and internal actors.

4.1: Challenges

Challenges were categorized as either technical, administrative, social, economic, or environmental, and then further analyzed as addressing system robustness, redundancy, resourcefulness, or rapidity. Challenges were discussed in all categories, although most interviewees focused on technical, social, and economic issues that negatively impact the sewerage system. Challenges were typically discussed as either exogenous factors that affect the sewerage system, or as challenges resulting from some endogenous factor in the sewerage system.

4.1.a: Technical

Interviewees generally demonstrated a greater depth and breadth of knowledge concerning technical challenges than any other type of challenge. Consequently, interviewees generally discussed technical challenges earlier, more often, and in more detail during interviews. Nevertheless, interviewees also often discussed the close relationship between technical challenges and other administrative, social, economic, or environmental factors. Technical issues typically revolved around robustness—including general deterioration—although redundancy, resourcefulness, and rapidity were each referenced to a lesser extent.

Robustness

All interviewees discussed challenges to technical robustness more frequently and thoroughly than any other challenge. Discussion of these challenges took two forms: (1) challenges that *cause* diminished technical robustness, and (2) challenges *from* diminished technical robustness.

Among challenges that cause diminished technical robustness in the municipal sewerage system, the age of the infrastructure and concomitant deterioration received the most attention within and across interviews. Not all interviewees knew or stated the age of their municipality's sewerage infrastructure, though the range of ages mentioned was 50 to over 100 years old. Interviewees often described age as increasing the likelihood of "deterioration," "disintegration," or "collapse" of the sewerage infrastructure. Sewerage infrastructure age and deterioration can also contribute to the deterioration of other infrastructure, with one interviewee describing the municipality's situation by stating that:

> We've got a lot of collapses. This system is well over 100 years old. And a lot of the piping that was originally placed in was never replaced, so you've got steel and a lot of clay that's out there. So for the last few years, the pipes have just been falling in…the sewer along with the street itself is actually kind of disintegrating. In the other places, you've got the

> sewer which has collapsed, and it looks like a pothole, but the remainder of the street is solid. It might be a little rugged, but relatively solid. On the north side, you've got where the street is actually crumbling. Totally crumbling away.

This quotation is important because it conveys (1) the extent to which age can diminish technical robustness, (2) the high degree of connectivity between municipal infrastructure, particularly sewerage and streets, (3) the general unpredictability of challenges arising from sewerage infrastructure deterioration due to differing contextual factors, and (4) the extent to which challenges that diminish technical robustness of sewerage infrastructure (e.g., age) can have direct and indirect effects on the larger community system (e.g., street deterioration).

Another factor relating to age was the material used to build the infrastructure. Some interviewees described older systems made of clay or pipe as being more susceptible to damage with age. While interviewees generally agreed that older age—due in part to older materials—negatively affected the robustness of sewerage infrastructure, some interviewees cautioned against the assumption that older sewerage infrastructure is always less robust than modern infrastructure. One interviewee, after stating that he was unsure "if [the infrastructure] can be worse, because it's 100 years old," qualified that comment by admitting that, "there are some parts about [the infrastructure] being old that are actually good, because there was more care taken in the construction at the time." Another interviewee found that the municipality's infrastructure, despite being over 100 years old, was "still holding up pretty well."

Other challenges that cause diminished technical robustness in the municipal sewerage system generally focused on environmental factors. Every interviewee mentioned, with varying degrees of emphasis, the deleterious effects of intense wet weather events on sewerage infrastructure, often noting a trend of increasingly intense rainfall. One interviewee summarized the challenges posed by intense wet weather events, stating that:

> When the pipes become full and they can't take any more, they also become pressurized. That puts a strain on the actual structure of the sewer. When you start pressurizing the pipe, any weaknesses you have there are going to become exposed. You can have some pipe failures that come out. And once you have a pipe failure, you start losing the soil structure around the pipe causing voids underneath the pavement…

This quotation reiterates several of the key concepts gleaned from discussions about the technical robustness of municipal sewerage systems. Phenomena that adversely impact sewerage infrastructure, such as pressurization, can result in negative consequences with broader impacts, such as the loss of soil structure under roads, sidewalks, and other paved areas. Thus, the condition of sewerage infrastructure can directly affect the condition of the surrounding environmental, at least related to soil properties. Other environmental challenges to technical sewerage system robustness were emphasized far less within and across interviews, and included root intrusion into sewerage infrastructure, and the tendency for infrastructure to reach capacity due to the region's flat topography.

Other challenges arising from diminished technical robustness were mentioned, including difficulties sufficiently rehabilitating infrastructure given the amount of pipe the municipality is responsible for; blockages from fats, oils, greases, or other items not intended for disposal in the sewerage system; cross contamination of stormwater and sanitary flows due to pipe leakages; and insufficient technology to abate flooding inside residents' homes.

Redundancy

Only one interviewee expressed concern about challenges emerging from diminished technical redundancy. The interviewee stated that the municipality was built prior to the construction of additional flood control technology to supplement the engineered ability of sewerage systems to mitigate flood impacts. Specifically, the interviewee stated that because of the large area of impervious surfaces, stormwater has nowhere to go aside from sewerage systems, basements, or it floods opens areas and public spaces.

Resourcefulness

Interviewees generally expressed that diminished technical resourcefulness results in diminished technical robustness and, therefore, any discussion of the challenges caused by insufficient resourcefulness reflected sentiments expressed in discussions of robustness.

Instead, discussion of challenges to technical resourcefulness focused primarily on factors limiting the municipality's ability to use technology, equipment, and materials to complete necessary and desired repair projects. The biggest limiting factor for technical resourcefulness was economic. One interviewee expressed the dilemma:

> …it all goes back to the almighty dollar. You can be as, you know, proactive as you could possibly be, but when there's not money to fund your projects, now what? You know? So, it's a double-edged sword. You can send somebody out inspecting every one of them, but if you don't have any money to fix them, what the hell is he inspecting for?

Many other interviewees expressed similar constraints on technical resourcefulness, emphasizing that they have the technical and administrative competence to complete necessary projects, but their access to the necessary equipment and materials is blocked by economic constraints. The majority of interviewees who cited economic constraints as a limit to their municipality's technical resourcefulness were already unable to complete all projects due to a lack of funding. The minority suggested they are currently able to complete all necessary projects, but fear they will have to be more selective in the future.

Other mentioned limits to technical resourcefulness were administrative. One interviewee commented that the inability to administer the sewerage system beyond municipal lines can severely limit municipal capabilities, stating that the municipality is "totally at the mercy of the MWRD with respect to sanitary flow," and is therefore limited in its ability to manage for flooding. Another interviewee focused internally, stating that the extreme complexity of municipal sewerage systems means all projects begin with a large degree of uncertainty.

> Everything collaboratively has an effect on the sewer system as well, because you really only go off of markings. You don't know where something is at until you actually start to excavate or drill. So as you try to go through things you will run across stuff that you yourself are damaging and it may not surface for many, many years…it's like trying to put a height on a baby. You don't know how tall that baby is going to be, you just know it's going to grow. It's kind of difficult.

Limited knowledge about not only where conduct to sewerage system projects, but also about how projects may adversely affect other parts of the system later on limit the municipality's ability to best use the proper equipment and materials.

Rapidity

The majority of interviewees mentioned challenges causing or resulting from diminished technical rapidity, focusing primarily on issues of limited capacity. Concerns about limited capacity often stemmed from recognition of a growing trend of intense wet weather events. One interviewee noted that "the recent 100-year storms…keep coming through every other year," while another observed that:

> Going forward in the future, it seems like we're getting a lot more heavy and intense rains than we have in the past, so one of the biggest issues that we have in [the municipality] is that our system is designed for about a five year rain event, to be able to handle. You know, anything over that is when it starts to overwhelm the system, and that's when we start to have problems with people getting basement backups and things like that,

> because the system isn't large enough to keep up with the intensity of the rainfall that's coming.

As the quotation implies, the limited capacity of sewerage pipes was often associated with discharges of wastewater into basements, as well as infrastructure deterioration and reduced rates of wastewater conveyance, leading to ponding of stormwater in open areas and streets. Municipal efforts to increase capacity are limited because all wastewater travels from the municipal infrastructure into the infrastructure owned and operated by the MWRD; therefore:

> …even if we changed your 8" pipe to 20" pipe, it still has to flow into a pipe that is smaller, and then you just have a natural restrictor, and even if you change that pipe, there's still all these other pipes down the road, and they all go to the Deep Tunnel system. When that gets full it does not matter how big your pipes are, they will surcharge, and you will get water in your street.

Another interviewee describes the relationship between municipal and MWRD sewerage pipe capacity as being "like a bathtub, but the bathtub is only going to drain as fast as it's going to drain."

Other interviewees concurred that while conditions would be worse without the MWRD and TARP, the regional infrastructure projects to help alleviate municipal flooding and sewerage challenges are insufficient. An interviewee stated that after an especially intense wet weather event in 2009:

> …the MWRD made it very plain that they want to build a ten-billion gallon reservoir. At the same time they said that it won't help if we get these kinds of storms again. Why? Well, because ten-billion gallons sounds like a lot; however, what they got countywide was 240 billion gallons. So where does the other 230 go?

Despite indications of frustrations with MWRD infrastructure robustness, the majority of interviewees spoke about the MWRD in positive terms.

Another heavily emphasized challenge to technical rapidity within and across interviews related to the slow rate at which stormwater can be conveyed away from municipalities, thereby diminishing the system's technical rapidity.

Echoing concerns about challenges to technical robustness and capacity caused by the relationship between municipalities and the MWRD, one interviewee said that:

> …we're kind of limited. We can build pipes like crazy, but it's like emptying a bathtub through a pinhole. We're restricted to the pinhole that the Water Reclamation District gives us. We can't get it out of here any quicker than that.

Consequently, municipalities often incur damages due to flooding and sewer overflows that cannot be alleviated quickly.

Another factor commonly emphasized as contributing to the diminishment of municipal rapidity is the protracted length of time required to complete sewerage infrastructure projects. One interviewee stated that, due to the complexity and large scale of projects, a single project “can tie you up three or four years.” Another interviewee focused on monitoring of extensive sewerage infrastructure systems which can take employees “a large chunk of the year” to complete. A third interviewee projected this challenge outward, arguing that MWRD projects take far too long to be useful in the short term.

The above challenges diminish technical rapidity; however, one interviewee asserted that the condition of municipal sewerage infrastructure is so poor and the consequences for inaction are so severe, that “if we can’t try to solve some of these issues now, then we won’t be around long enough to do any kind of long term planning. They’re going to kick us all out. You want to put in effect the plan. Something that you know will yield some type of tangible result.” Thus, according to this interviewee, diminished rapidity not only exacerbates damage and makes the municipality more vulnerable to flooding, it also threatens administrative continuity.

4.1.b: Administrative

Administrative challenges were among the least emphasized by almost all interviewees. Generally, administrative challenges resulted from two sources: (1) uncertainty about future budgets, technical needs, and policy decisions, and (2) administrative differences with other public agencies, typically the MWRD. Challenges associated with uncertainty emphasized the extreme difficulty of making plans and preparing for future needs. Regarding administrative differences, interviewees were uniformly positive about the MWRD and other agencies, and understood that their mission differs from the mission of individual municipalities, but still expressed occasional frustration about limits on their own administrative authority.

Robustness

Most of the interviewees mentioned challenges affecting administrative robustness due to significant amounts of uncertainty about future resources, administrative decisions, and project requirements. Many of the interviewees stated that future funding is a major uncertainty, and limits the ability for municipalities to make effective long term plans for sewerage system management. One interviewee summed up the general consensus regarding economic uncertainty and administrative robustness:

> The state of the state right now, if you will, with the economy, are they going to tap into the state shared revenues? If that goes away, some of these programs go away. Or, to a lesser extent, which is a very high risk right now, if they can't get the business [in the Illinois capital] taken care of that can affect all these communities and all these programs because they take away a lot of our state shared funding. We have to find the funds somewhere, and does it come from a sanitary or storm sewer tax, or does it come from your roadway projects, or your water main projects, or a little bit of all? Do you tap into each one of them and add it up to make up the difference? So there's a lot of uncertainty. We live that every day. 'Okay, we think we made it through this session, they're not going to touch our state shared funding for six months or a year,' a year from now we're sitting here again, 'Okay, here they are, they're back at the table, are they going to come after our state shared funding? And we're going to be losing out.' And we look at that, we keep that at the back of our mind that those things could go away…

This quotation reflects the notion that budgetary uncertainty keeps municipal planning short-term and relatively speculative. Interviewees generally described municipal planning for future projects as spanning one to five years, though most confessed that these plans are highly susceptible to change.

Other issues that challenged administrative robustness included uncertainty about how, according to one interviewee, "you don't know who's going to be in office four years from now, or what they're going to do with their power," which may positively or negatively affect the municipality's focus on sewerage infrastructure. The same interviewee, among others, mentioned that emergency repairs can disrupt even relatively short term planning and management strategies.

Redundancy

Most interviewees described challenges stemming from diminished administrative redundancy associated with their relationship with the MWRD. Challenges generally concerned two broad themes: (1) limits to municipal flood abatement projects due to infrastructure connections to the MWRD system, and (2) a lack of tangible, municipal-scale assistance due to the MWRD's regional purview. Interviewees who discussed flooding expressed frustration with their inability to hasten the rate at which stormwater exits their system because they are unable to increase the capacity of the MWRD interceptors and because they are competing with nearby communities to send water to the same MWRD system. One interviewee said the system is:

> …an inefficient way of doing business, but it's historically the way that the older communities had available. And as storm water runoff has become more of an issue, the limitations of that type of system has become more apparent.

Other interviewees found the centralized MWRD system a challenge to administrative redundancy because individual municipalities often struggled to benefit from MWRD funded projects and grants because the district serves so many different municipalities. An interviewee stated that having so many municipalities seek funding from the MWRD creates intense competition for grants. Another interviewee complained that the MWRD is not interested in rectifying local challenges, and that the relatively minor influence its projects have had on individual municipalities means that "the only thing the town itself can do is what we've already started," rather than relying on the MWRD for assistance.

Resourcefulness

Most interviewees did not mention challenges affecting administrative resourcefulness. Two interviewees, however, emphasized that their municipal department is understaffed. One said that, "in a perfect world, it would be nice to have two mechanics, ten water guys, ten sewer guys. But you have to pay for all this, and that's all on the backs of the residents…" Both interviewees stated that they rely heavily on contractors to assist with projects, and one interviewee specifically stated that the entire staff is trained to complete all required tasks to provide more flexibility.

One interviewee mentioned that the municipality attempts to couple sewerage infrastructure projects with other projects, such as road repairs, because construction on one system will inevitably affect the other. Consequently, the municipality must coordinate project management with other department and municipal infrastructure needs. While none of the other interviewees specifically mentioned coordinating construction efforts to meet other needs, comments about the interconnectedness of sewerage infrastructure with roads, buildings, and other infrastructure suggests that management of multiple projects simultaneously may not be limited to this particular municipality.

Rapidity

Only one interviewee mentioned challenges affecting administrative rapidity. The interviewee stated that:

> …the focus changes at times. Sometimes there's money for relief sewers, sometimes they want to put a lot of money into studies. And sometimes I've seen the same studies come through a couple of times, and we present them with the results and these things, and it's like we don't have the money to do that. What's suggested in these studies now, then 15 years later they'll do another study, and say, 'I kind of think we came to those conclusions 15 years ago, but we have money now.' They can't use 15 year old studies to justify a huge expenditure. So it kind of goes in cycles…

While this specific challenge was not mentioned by other interviewees, it again reflects the importance of financial security in expediting action to move forward with sewerage projects. This quotation is noteworthy because it also reflects the length of time—at least within this municipality—that some sewerage projects may be delayed (i.e., 15 years).

The same interviewee also expressed frustration with new legislation that comes through from administrative agencies outside the municipality. Regarding requirements to conduct regular inspection of the sewerage system, the interviewee said:

> …we provide a lot of paperwork with all that inspection, you have to have that on hand, be able to supply that. But it's kind of all that it is. We find stuff anyway that we maintain. But that has changed over the past 10 years: the amount of time that we spend on jumping—not jumping through hoops—complying with these mandates…

4.1.c: Social

Social challenges were some of the most frequently and thoroughly discussed by almost all interviewees. Interviewees generally focused on challenges to residents due to flooding, and challenges to the municipality due to residents' misunderstandings about how the sewerage system works and is managed. Most interviewees acknowledged an awareness of how social factors can shift policy decisions and have sizable effects on strategies for managing sewerage infrastructure. Despite the emphasis on social challenges, it was clear that they were of a different type than technical and economic challenges; that is, technical and economic challenges can affect whether or not the sewerage system works, whereas social challenges can affect how the sewerage system is managed and whether management strategies are considered successful.

Robustness

Every interviewee discussed challenges to social robustness, although only two interviews framed the challenges within a public health and safety context. One interviewee said:

> …if there's a problem in the main…and it's charged…you're going to have sanitary water in their front yard which is unhealthy. And kids play. Kids don't know what it is. They're walking to school, they're going to splash in it…if you don't stay on top of the condition of the pipe or the condition of the manholes they start to cave in, gravel starts to get in them, [there could be] vehicle accidents. A motorcycle will run over it and cave in, kids step into it and fall in the manhole. I mean, there could be some serious consequences for not being on top.

The second interviewee expressed concern that, due to pipe failures, "somebody could be driving along the street and their car gets swallowed up by the street because there's a sinkhole there." These quotations exemplify the range of public health and safety issues that may arise from deteriorated sewerage infrastructure, including illness and physical harm. The quotation also reflects the extent to which administrative management and technical solutions can have a direct bearing on social robustness.

Other interviewees, while not directly referencing public health or safety, discussed diminished social robustness caused by general inconveniences to residents, particularly homeowners whose basements flood and experience sewer backups, but also those who use public spaces like schools. These backups can cause serious damage to private property, especially since:

> …more people, of course, want finished lower levels of homes. It's not a basement of just cinderblock or concrete, it's a finished basement with all that goes with that—there's more that gets destroyed.

These inconveniences, along other mentioned challenges to social robustness, including flooding of streets that prevent residents from accessing roadways and damage to the natural environmental that can reduce property values, all constrain general social wellbeing.

Two interviewees framed challenges to social robustness within an economic context, explaining that they are sometimes reluctant to pursue additional expensive projects because they are aware that funding for those projects will be paid for, in large part, by the municipal residents.

Redundancy

None of the interviewees directly discussed challenges to social redundancy; however, one interviewee did say that, "in some areas you start seeing water bubbling in backups, you have houses that get flooded, you have a high school that gets overrun. You have people who are kind of displaced." The interviewee did not expand on the concept of resident displacement—stemming from a challenge nearly all interviewees identified—though it appears to reflect residents' limited use of their homes (e.g., inaccessible flooded basements) and their communities (e.g., inaccessible flooded streets), as well as temporary readjustments to the usage of public or commercial spaces.

Resourcefulness

Issues affecting and emerging from diminished social resourcefulness were among the most emphasized challenges within and across almost all interviews. The most frequently mentioned challenge was a lack of community competence about the sewerage system. One interviewee said:

> I think one of the biggest issues is helping them understand how the sewer system works. When they get backups they say, number one, I think that the leaves clogged it—and it wasn't flowing right—or they'll say there was a blockage, or something along those lines. And then you'll say to them, no, actually the pipes were completely full of water. They were backed up. And so they couldn't take any more water. And so the water was in the street, or it was in your front yard, or worse it was in your basement. And they don't like to hear that, so they say, 'why don't you just build bigger pipes?'…That's an education piece. So sometimes they don't understand that, no, the sewers are working, but they are only designed to hold so much water. And when you get these 2% storm events, multiple times in a decade, people get frustrated.

This quotation reflects a number of concepts that emerged in multiple interviews. First, residents are generally not only uninformed about how the sewerage system works, but also misinformed about why flooding and sewerage backups occur, typified by the residents' assumption that the sewers overflowed because they were clogged with leaves instead of correctly understanding that the infrastructure had reached its capacity.

Further, residents are often misinformed about strategies for managing the sewerage system to prevent flooding and backups, often erroneously assuming that adding larger pipes in the municipality will alleviate the issues. Several interviewees also described residents' misunderstanding about the separate roles and abilities of municipalities and the MWRD. One interviewee added that, "we'll get calls, if their sanitary is backed up, 'Call the village manager, have him push open the locks or push the button.' Well there's no magic button, there's no magic relief valve that we pull," while another interviewee reiterated this challenge:

> …someone's basement will start flooding up with water, and someone will call and say, 'Well, you guys have to open your valves and let the water out," and a lot of times people don't understand we don't have anything like that. Our sewer systems are all open pipes, it's all gravity, it just goes. And then they say, 'Tell MWRD to open up the tunnel,' well, it's not that simple. They have their whole system over there. They don't have some guy sitting at the switch who's going to say, 'Okay, I'll open it.' It's a lot more complex, it's all computer controlled depending on flow and everything else, it's a pretty complex system that they have over there.

These comments underscore what may be a lack of understanding that the individual municipality is simply one part of the MWRD's wider jurisdiction; therefore, the MWRD may not—and often cannot—take action to relieve the flooding of individual municipalities. The comments also reflect misunderstanding about the distinction between the MWRD's responsibilities over opening locks and the municipality's responsibility to manage the sewerage system only within municipal lines.

Misunderstandings about flood control management also revolve around municipal use of restrictors that keep stormwater on streets for a longer period of time, but help prevent water from entering residents' basements. One interviewee accounted for this issue, stating:

> …the public doesn't always understand--if we can contain stormwater on pavement and use it as a short-term detention, and it drains off in a reasonable time, it might be an hour or less, that's not a bad thing. Now everybody doesn't see it that way, because it means we have to throw our high water barricades out and people have to drive around that area for a short period.

Interviewees emphasized that the public is unaware that standing stormwater on streets may be a part of an intentional effort by municipalities to prevent stormwater from backing up into basements, and expressed frustration that the public not only does not understand, but faults the municipality for the slow rate of stormwater conveyance.

Finally, the first quotation also touched on another commonly frustration: regular criticism of municipal officials for their management of the sewerage system. One interviewee said that as basements flood, "everybody gets all up in arms," and that "when we get calls, it's not to give us a pat on the back. It's, 'My basement is flooded, everything has gone crazy, what are you doing?'" Another interviewee said that, "everybody at Public Works, they live somewhere. They have water in their basements. But they're out here working to help out the residents…and they catch a lot of flak. Not always; there are a lot of residents that are very grateful. But it's a universal problem." Thus, the consequences of diminished social resourcefulness are, according to the interviewees, misinformed belief that the public officials are insufficiently and ineffectively managing the sewerage system.

Interviewees generally agreed that public misunderstanding about the sewerage system was reflected in the lack of effort and resources invest in protecting their own home. Interviewees collectively identified three reasons why residents do not invest in protecting their homes from flooding. First, residents are unaware of how to protect their homes, or disregard information by the municipality and other agencies, including the Federal Emergency Management Agency (FEMA). Second, residents demonstrate concern about protecting their homes only during a short period following a flooding event. An interviewee explained the problem:

> …let's face it, when the water goes down and the sun goes up, things get put to the backburner, and they spend their money somewhere else on their home… 'Oh it wasn't that bad, and it doesn't happen that often.' Well, then it starts happening more often.

Third, many residents expect the municipality to rectify all sewerage and flooding problems. According to one interviewee, many residents:

> …don't realize why [the sewerage system is] not handling it, because the stormwater is getting into the sanitary sewer. And if they have so much money invested in their basement, they're going to have to at some point invest in—you know, they say they have $30,000 worth of stuff in their basement, then invest $10,000 in protecting it with flood control or plumbing. That's a hard sell, because people say they spend a lot on taxes here. They think that they should be immune from any kind of problems like that.

The unwillingness to invest money, according to this quotation, again reflects an assumption on the part of residents that municipalities are capable of rectifying the flooding problem but are simply failing to do so. Despite residents' insistence that the municipality solve their flooding problems, one interviewee insisted that, "sometimes the simplest answer is right on your own property." Another interviewee stated that public engagement with municipalities to solve sewerage problems is essential: "in order to have a great community, it has to be the residents and the government working together."

Similarly, some interviewees mentioned that residents are unaware or unconcerned about how their behaviors may contribute to sewerage flooding. Two residents mentioned that residents are increasingly developing on their private lots, creating more impervious surfaces, which not only increases the volume of stormwater entering the sewerage system but also increases the rate at which it enters the system. One interviewee mentioned that residents will occasionally send fats, oils, and grease down drains, or flush objects like diapers down toilets. Substances and objects that are not intended for the sewerage system can create blockages which reduce flow and contribute to more backups. Other interviewees added that residential downspout connections to the sewerage system add surplus stormwater to the system which can contribute to backups.

Aside from public misunderstanding and disengagement, some interviewees commented on the public's resistance or reluctance to fund sewerage infrastructure projects. Reluctance to fund projects typically stemmed from what interviewees described as an "out of sight, out of mind" mentality. Indeed, one interviewee claimed that "nobody wants to invest money in something you can't see." Two interviewees commented that the public is generally opposed to spending significant amounts of money on sewerage infrastructure, but is supportive of street repairs; nevertheless, according to an interviewee:

> …they don't see the sewer systems that we see, the 100 year old clay pipes, and the manholes that are brick and crumbling. So they see it can't be that much to redo the street, but we have to explain to them that it's what's underneath the streets. The more important thing—you don't like the potholes, but we don't like the collapsing sewers—you're really not going to like it when it collapses and we're out there in an emergency.

Visibility of the sewerage system was not the only factor that contributed to residents' resistance to funding expensive sewerage infrastructure projects. An interviewee believed that:

> …the issue is, if you've got somebody on one side of town where it doesn't flood, why do they need a storm tax? I've done everything to protect my property, I don't have a flooding issue, why should I have to pay for somebody on the south side of town's flood control, when it should be their problem…

Further, another interviewee expressed that many residents feel they should not be required to finance sewerage infrastructure projects because they already pay taxes. A perceived sense of inequity centered on municipal taxes is, according to some interviewees, a point of tension for some residents. Lastly, one interviewee supported the residents by arguing that some of the reluctance comes from the fact that they simply do not have money: "it's hard to justify something when somebody's been cut back on hours or they lost their job."

The general sentiments expressed by all interviewees regarding challenges associated with social resourcefulness can be summarized by a brief exchange between two interviewees during a joint interview. One interviewee said, "fixing the sewers is the easy part. That's something we know how to do," to which the second interviewee followed, "convincing the public what is a smart move on their part is hard."

Rapidity

None of the interviewees thoroughly discussed challenges affecting or arising from diminished social rapidity, although many interviewees discussed that flood management strategies to may require stormwater to remain in streets for "hours." There was no discussion of time required for residents to clean out flooded basements or otherwise return to their normal routines.

4.1.d: Economic

Economic challenges were clearly among the most pressing for all interviewees. Many interviewees did not discuss their municipality's economic situation and processes in depth, and some confessed that they are not in charge of economic considerations for infrastructure projects. Thus, while interviewees stressed that funding is essential for all infrastructure projects, the level of sophistication with which interviewees discussed economic challenges was not as high as conversations about technical or social challenges.

Robustness

Challenges from diminished economic robustness were some of the most commonly referenced across interviews. The general consensus was that the biggest challenge for managing municipal sewerage systems is "budgetary and funding, because everybody's strapped to the limit." Diminished economic robustness and a lack of available funds was almost always tied to insufficient revenue or the shifting priorities of budgetary personnel. One interviewee explained the latter situation: "sometimes there's money for relief sewers, sometimes they want to put a lot of money into studies…and we present [the studies] with the results and these things, and it's like, 'We don't have the money to do that.'"

Redundancy

Most interviewees discussed diminished economic redundancy as a challenge to management of municipal sewerage systems. None of the mentioned challenges reflected a complete or permanent loss of revenue from one of the municipality's traditional sources. Instead, interviewees focused on factors that limit or constrain revenue from diverse sources. The most common source interviewees discussed was taxes from residents and service users. An interviewee summarized this challenge as described by the interviewees, stating that "funding is clearly a challenge, and you can't overwhelm, oversaturate your community with the need for funding, so you've got to balance that out." Another interviewee focused on diminished revenue from property taxes:

> …we have a lot of foreclosures. If something's foreclosed, a piece of property, you're not receiving tax money and you're not getting your share…it all adds up. We're about a million and a half down from last year in what we received.

A third interviewee emphasized the importance of balance in applying water and sewerage service fees: "unfortunately we have to pass along the [rate] increases to our consumers, but it's just the nature of the beast. It's a very delicate balance."

Other interviewees addressed challenges to obtaining revenue from administrative personnel and agencies. An interviewee explained that administrators within the municipality are not always willing to invest money in sewerage projects, particularly if there has not been a recent intense wet weather event. Another interviewee stated competition with other municipalities for grant money can be challenging:

> …[other communities are] often looking for the same things that we are. Funding sources and who gets what done first and what's the priority, and we do work with the other communities…everybody thinks their problem is the worst, and they want the money first.

Resourcefulness

Most interviewees mentioned challenges affecting and arising from diminished economic resourcefulness. Interviewees commonly stressed the prohibitive cost of sewerage infrastructure projects, describing the financial requirements as "costly," "expensive," and "monumental." Region-wide, one interviewee said "when you look at the scope and the magnitude and the cost of what it would really take to alleviate the entire problem from the Wisconsin border to the Indiana border, it's a bite out of the budget that no one would want to take." Yet even within an individual municipality, another interviewee said that necessary sewerage infrastructure projects would cost the municipality "hundreds of thousands of dollars. You do what you need to do with the day's cost of construction. It's a lot of money."

Most interviewees who mentioned diminished economic resourcefulness stated that prohibitive costs of operations and management require the municipality to be more selective about which projects it funds and limit its management plans to less costly initiatives. When municipalities do receive funding, they may have to distribute it toward other types of infrastructure projects that have also been underfunded over time. One interviewee stated that, “now we’re beginning to get a little more money to do some infrastructure stuff, but when it comes in we have to allocate it toward the most important needs of the city, and right now the needs are streets and alleys. So we’re gearing most of the money toward that right now.” Another interviewee said that:

> …because the system is what it is, and money is not infinite, we have to work within the constraints of what we have. And so a lot of times it’s sandbags and pumps after the rain event. And I think that is frustrating for the Public Works department, as well as the residents.

Overall, most municipalities indicated that there are no inexpensive opportunities to complete the kinds of projects desired for sewerage infrastructure; consequently, most municipalities must focus on cheaper alternatives until sewerage infrastructure rehabilitation becomes a necessity. To quote on interviewee, “long term planning, it all comes down to money. Everyone’s hurting for money.”

Rapidity

None of the interviewees mentioned challenges affecting or arising from diminished economic rapidity. One interviewee mentioned that it took at least 15 years for the municipality to allocate money toward an identified sewerage infrastructure project. Other interviewees referenced applying for money as they prepare annual budgets, though there was no indication of whether or not an annual review of the budget was detrimental to economic rapidity. Otherwise, the interviewees did not provide specific or general timeframes required to receive funding for sewerage projects.

4.1.e: Environmental

Environmental challenges were the least discussed of all challenges. None of the interviewees discussed potential environmental degradation caused by sewerage systems, including sewerage overflows. Any discussion of environmental challenges generally emphasized how environmental conditions can adversely affect the sewerage infrastructure.

Robustness

None of the interviewees discussed how sewerage systems may negatively impact environmental robustness, although almost all touched on how diminished or altered environmental robustness may affect sewerage infrastructure. The majority of interviewees commented that rain events are becoming more frequent and intense, though only one suggested the increase may be directly attributable to "global warming." Some of the interviewees stated that soil conditions around sewerage pipes may change over time, potentially exacerbating infrastructure damage or causing collapses. Some interviewees also stated that infrastructure damage can occur from infiltration of roots into pipe joints.

Redundancy, Resourcefulness, and Rapidity

None of the interviewees mentioned factors attributing to or arising from diminished environmental redundancy or resourcefulness. Many of the interviewees discussed that intense rain events are occurring far more frequently than in previous decades; however, none of the interviewees focused on time associated with environmental deterioration that may arise from the sewerage system.

4.2: Projects

Projects were categorized as either technical, administrative, social, economic, or environmental, and then further analyzed concerning robustness, redundancy, resourcefulness, or rapidity. Similar to municipal sewerage system challenges, the majority of projects focused on improving technical, economic, and social management. Overall, interviewees primarily focused on relatively small-scale and short-term projects achievable given other constraints, mostly economic, that affect management decisions.

4.2.a: Technical

Interviewees generally drew on their expertise of the municipal sewerage system to emphasize projects affecting technical components, though they typically emphasized issues relating to robustness and redundancy. Projects often aimed to identify and implement means of extending the life of sewerage infrastructure, rather than entirely replacing aging or deteriorating sewerage technology. Nevertheless, interviewees often suggested they are aware of what projects should be completed and how to complete them, but they are again limited by other factors, typically administrative, social, or economic.

Robustness

All interviewee mentioned projects intended to manage for the technical robustness of the municipal sewerage system. These projects typically constituted the primary function of the departments managing for the sewerage system. One interviewee described the projects:

> …there's constant repair work being performed every day on the different sewers. Even though it may be one or two at a time, you still proactively address the issues that are out there. And then there's a constant survey each year of the system.

All interviewees spoke about general maintenance and repairs, including sewer lining, replacing old or non-functional pipes, rehabilitating collapsed pipes, or clearing out blockages to increase infrastructure capacity. Projects managing for technical robustness are, according to some interviewees, coordinated with other infrastructure projects. One interviewee said, "you don't want to pave the street and then have a sewer cave in a year after that…so all this stuff is kind of working together, the street improvements and the sewer repairs." As the first quotation indicates, many of these technical projects are identified by conducting regular inspections of the sewerage infrastructure.

Redundancy

Most of the interviewees discussed projects to manage for technical redundancy of the municipal sewerage systems. Projects generally fell into three categories: (1) efforts to increase public technical redundancy, (2) efforts to increase private (individuals, businesses, or other non-public entities) technical redundancy, and (3) MWRD-funded projects. Public technical redundancy involved projects associated with constructing retention ponds, relief sewers, or restrictors to supplement the sewerage infrastructure's ability to store and convey wastewater without causing flooding. Some interviewees stated the municipality is also seeking to expand green infrastructure including bio-swales and permeable pavements to increase infiltration and reduce runoff. Private technical redundancy involved projects to encourage residents to make technical adjustments that will supplement public efforts and the abilities of the sewerage infrastructure. These projects included assisting residents with the installation of overhead sewers, disconnection of downspouts to the sewerage line, and encouraging residents to cultivate rain gardens. Finally, several interviewees mentioned reliance on the MWRD to devise plans and projects to assist with technical redundancy, often related to expansions of the TARP system. One interviewee said of the MWRD:

> …maybe they might come up with another Deep Tunnel project, or several Deep Tunnel projects. The water situation out here in the suburbs, that would probably be the best way, or to build a big reservoir that would take some of the pressure away. Once again, that's the engineers to sit down and think through all that stuff. But eventually, they'll

> come up with something to relieve a lot of this backup into peoples' houses. They're working on that all the time, so they'll be coming up with something.

Resourcefulness

Most interviewees suggested that money, not technological competence, is the biggest limiting factor in their municipality's ability to conduct technological projects; therefore, most interviewees did not indicate there were efforts underway to manage for the ability to use technology. Some interviewees, however, mentioned that different municipalities have access to different technology, and so they will sometimes negotiate opportunities to share equipment.

Rapidity

None of the interviewees directly mentioned any projects underway to increase the efficiency of technology. In fact, many interviewees mentioned projects to install restrictors, which typically slow the process of stormwater infiltration into the sewerage system; however, the benefit of restrictors is that they help prevent flooding of basements, which may ultimately save both residents and the municipality time in terms of clean-up activities. One interviewee stated that this approach to technical rapidity is a departure from previous municipal efforts:

> …in the past we didn't want to have any standing water on the pavement. We would clear inlets and let the water go down so there's no standing water on pavements. Now we're kind of refocusing our efforts to let the water stand a little bit longer so the sewer system can keep up, and once the rain slows or stops, then we can go out and start clearing inlets, and we reduce the strain on our sewer system.

4.2.b: Administrative

When discussing administrative projects, interviewees generally mentioned ongoing management practices, rather than efforts to change internal operations, planning, or structure. While most discussed projects were intended to ultimately contribute toward strengthening some other component of the municipal sewerage system, interviewees' comments on administrative structure often illuminated ways in which municipalities respond to different types of challenges.

Robustness

All interviewees mentioned municipal approaches to managing for administrative robustness. Interviewees tended to describe an administrative culture of either planning for the future or reactively improvising according to needs as they arise. Only a few interviewees fell into the latter category. One of these interviewees said:

> I guess just to keep your head above water, treading to keep your head above water is what we're doing right now, and so far we're okay…Going into the future? We don't have any plans, 'Hey, starting two years from now, this is how we're going to start doing things.' I think it's mostly just basically rolling with the punches. If we have a problem, we get it repaired.

The same interviewee provided a brief anecdote to illustrate this approach:

> …just last year or the year before last, I think this city spent like 40-something thousand dollars on a sanitary main that collapsed. And it was a larger job than what public works can do. It was an emergency. It wasn't some, "Oh, let's go out and get bids," this was something that, dammit, needed to be done immediately. The street was caving in. So we had a local guy that we use and contractor, and he came out, and we had it televised, and the two places where the top of the main was actually crushed in, they put a new main there.

Interviewees who described an impromptu approach to administrative robustness suggested that conditions—particularly the lack of funding and uncertainty about future needs—require managers to be prepared to accommodate any changes in law and ready to respond to emergencies as they arise.

Despite the widespread acknowledgement of challenges that arise from changing laws and emergencies, most interviewees stated that their municipality engages in planning to determine financial resources and identify necessary projects. Interviewees often indicated timeframes, typically not exceeding five years, which they use to project outward when setting goals for sewerage infrastructure projects or financial investments and gains. Interviewees who mentioned planning as an important part of their administrative strategies indicated mixed results: some found they were currently able to keep up with project demands, whereas others felt their management was reactive rather than proactive due to financial constraints and demands from emergency repairs. All interviewees, however, expressed concern that their current level of planning and project management may not be sustainable as constraints tighten in the future.

Redundancy

Many interviewees discussed ways in which the municipality incorporates administrative redundancy to disseminate responsibility among different groups and entities. Most municipalities had Public Works departments that, according to an interviewee, generally oversee budgetary matters and day-to-day operations of the sewerage system, in addition to Engineering departments that plan and implement major technical infrastructure projects. Many interviewees also mentioned contracting out to private engineering groups to complete major infrastructure projects.

Describing administrative redundancy regarding separations in public and private responsibility, one interviewee stated that his municipality maintains a firm policy not to assist private residents with sewerage challenges, thereby forcing them to manage their own protection and clean-up projects:

> …we get all kinds of calls. [Residents will] say water is backing up, but there's nothing we can do. Once everything subsides, it will eventually go out of their house. And a lot of them have an issue, but once again that's not our responsibility. That's the way the ordinance is written.

Many other interviewees discussed active efforts to increase private residents' sense of responsibility over their own private sewerage lines through education and outreach, though they often expressed frustration at a lack of success through outreach alone. One interviewee mentioned having success with establishing a Water Infrastructure Committee heavily populated by residents, to create additional checks and balances on municipal programs and provide a resource for residents to become engaged and informed about sewerage systems.

Finally, one interviewee described strategies to increase administrative redundancy within the municipality's Public Works department by ensuring that all employees are capable of completing most tasks.

> …because we don't have, some departments have a water department, a sewer department, street. We're all one department. You can go from a water break, to snow plowing, to a pre-construction meeting, to cleaning up [streets]…I mean that's just—everybody does everything.

This interviewee described a strategy in which increasing inner departmental administrative redundancy compensates for diminished administrative resourcefulness. While other interviewees mentioned that insufficient staffing poses a challenge, no others specifically detailed strategies for overcoming diminished administrative resourcefulness; therefore, one cannot assume many or all other municipalities stress the importance of ensuring that all employees are capable of completing most tasks.

Resourcefulness

Most interviewees did not discuss efforts to expand the administrative resourcefulness of municipal sewerage systems; however, some interviewees mentioned that they often work with neighboring municipalities to share equipment or complete mutually beneficial sewerage infrastructure projects. One interviewee said that, when not directly working with other municipalities, he often monitors how other communities are managing their system for ideas about how those strategies may apply to his own community.

Other interviewees discussed projects that have arisen due to administrative resourcefulness. Two interviewees discussed efforts to change municipal laws to favor strategies that will require stormwater detention on lots or residents to disconnect downspouts from the sewerage system. One municipality formed a Water Infrastructure Committee for residents to engage them in the policy and management process and demonstrate infrastructure needs. The same community was also attempting to purchase homes within the flood plan and convert them into open plots, allowing more water to infiltrate rather than running off into the sewer. Lastly, some interviewees demonstrated an ability to capitalize on challenges to make quick, progressive changes. One interviewee said:

> …the emergency repairs, the reactive, helps me with the preventative. Because I can go to the board or to the residents and say, listen we've spent over 400 thousand dollars in emergency repairs. If we would replace this and be preventative, I can do triple the amount of, you know, square footage and not have these problems.

Interviewees who described this phenomenon characterized their involvement as active; that is, they did not merely suggest that improvements occur shortly after challenges like pipe collapses and floods, but that they actively attempt to use administrative and public frustration to create momentum for completing necessary sewerage infrastructure projects.

While some interviewees mentioned that that their municipality takes an improvisational approach to managing sewerage system challenges, none of these interviewees describes efforts to increase the municipality's ability to improvise beyond attempts to increase revenue.

Rapidity

None of the interviewees described efforts to increase the speed with which management strategies and policies are created, or to increase the rate of the administrative process from project initiation to project completion.

4.2.c: Social

Discussed social projects generally took two forms. Some projects focused on educating the public so they become more aware of how the sewerage system works and what the municipality is doing to improve the system. Other projects strived to prepare residents for intense wet weather events, usually by bypassing education alone and actually investing time or money in ensuring that residents' homes had proper flood protection technology. Other projects were discussed, including providing opportunities for residents to become more integrally involved in the management of sewerage infrastructure, though these efforts generally received less attention.

Robustness

Most interviewees did not explicitly frame their projects as intended to protect or increase social robustness, though almost all interviewees indicated that the consequences of not completing other, technical projects would be diminished social robustness. Technical projects typically focus on preventing flooding and ensuring that sewerage infrastructure works as intended, which in turn mitigates challenges faced by the public due to basement backups and other flooding-related inconveniences. Two interviewees stated that regular sewer infrastructure maintenance can prevent sinkholes from forming that may cause harm to passing motorists, while one interview stated that overflows may pose a public health risk to residents who come into contact with untreated wastewater.

Redundancy

Most interviewees did not discuss projects intended to manage for or increase social redundancy. Two interviewees said that they will occasionally assist homeowners with pumping out flooded basements, with one interviewee stating this service only applies to senior citizens.

Resourcefulness

Most interviewees mentioned management strategies for increasing social resourcefulness, focusing primarily on (1) public education, (2) public preparation for challenges, or (3) public engagement in the management process.

The majority of the interviewees who addressed social resourcefulness said their municipality focused on general education. An interviewee said that educational efforts should focus on issues residents can feasibly accomplish. Topics emphasized included how to prepare for flooding, how to protect homes from flooding, how to manage private sewerage lines, how to manage clean-up after flooding, opportunities for residential green infrastructure, which substances should not be disposed of sewers, and how to minimize contribution to flooding. Interviewees stated that methods of communicating with the public included newspapers, leaflets, flyers, municipal webpages, public meetings, and cable television spots. Interviewees generally did not state how frequently the municipality attempts to educate the public. One interview indicated that education efforts usually take place after a major disturbance has already occurred.

Some interviewees stated that their municipality takes an active role in helping residents prepare for flooding beyond education. One interviewee said:

> …we've opted to give people grants for putting in newer systems…And we've had over 150 people take advantage of that over the last three years. And we've seen our reports of flooding drop dramatically, so the last couple of major storms we've had - we used to get like in the range of 3-400 people calling and telling us about flooding, now we're down to like 50-60. So, that's a big difference. So the people that were having problems took advantage of the opportunities we provided, which was a lower cost, it was costing us $200,000 a year to operate that system, which we continue to do today and into the future, because we see it as a benefit to everybody.

Other interviewees stated part of the incentive to help residents fund or install flood protection infrastructure is that, despite the upfront cost for municipalities, this management strategy ultimately results in a "win-win for everybody."

Only one interviewee mentioned efforts to increase public engagement in management planning and strategies. This interviewee said:

> …we formed a water infrastructure committee. And got the residents involved. And we met twice already. That's a big help with selling the community to tell them or show them what we need…But the residents are getting involved.

Due to community involvement in management decision making, the interviewee estimated that the municipality has been able to shift from implementing only reactive projects, to implementing reactive projects half of the time and proactive projects the other half within the span of two years. This added engagement helped the municipality explain and justify rate increases to achieve a sustainable level of service.

Rapidity

None of the interviewees described management strategies for increasing social rapidity. Indeed, some strategies—such as installation of restrictors—requires social rapidity to diminish in order to increase technical and social robustness.

4.2.d: Economic

While interviewees generally asserted that they are not wholly responsible for municipal finances and may be unaware of specific details about some projects, each one emphasized the importance of municipal efforts to identify and obtain sources of revenue. Interviewees also discussed methods of attempting to conserve available funds in order to pay for more expensive projects.

Robustness

Every interviewee mentioned municipal projects to manage for economic robustness of the sewerage system.

All municipalities stated that they applied for grants and funds from county, state, and federal sources, including the MWRD, the IEPA, and FEMA. To quote one interviewee: "we always look for grants. Any way we can find free money or something to help us we go after it." Other interviewees emphasized their reliance on bonds:

> …we take it to the voters by referendum to get the community's support to issue bonds. General obligation bonds. So we've done that for street improvements, storm, and sanitary sewer rehab. Major work for the last 25 years…We don't come out and seek $25 million in bonds. We do it in smaller increments, like a two-year window where we're going to get improvements done…

The interviewee emphasized that bonds end up increasing property taxes for, sometimes, several years; nevertheless, issuing bonds was one of the primary sources of revenue, if not always the most preferred.

Interviewees also emphasized the importance of maintaining service fees and taxes. One interviewee stated that, "the majority of the projects we do are locally funded through our own taxing ability." While many interviews stated that money from residents' water bills accounted for an important part of the municipality's budget, one interviewee said that internal taxes and fees alone are "not enough" to cover all necessary costs of managing the sewerage infrastructure.

Redundancy

While all interviewees mentioned multiple revenue sources—including local fees and taxes, county, state, and federal grants, and bonds—most of the interviewees did not mention efforts to identify or devise additional sources of revenue outside of the general categories mentioned. One interviewee stated the municipality is looking into methods for requiring residents to pay fees based on the amount of impervious surface on their property to help cover water and sewerage infrastructure costs.

Resourcefulness

Interviewees suggested that almost all projects for repairing and rehabilitating sewerage infrastructure are uniformly expensive; therefore, none of the interviewees indicated any ability to reduce the cost of necessary construction. Some interviewees indicated they focus primarily on point repairs because they are more affordable options for extending the life of the sewerage infrastructure.

Nevertheless, many interviewees mentioned strategies to help the municipality conserve as much funding as possible. The most commonly mentioned strategy was regular inspections and careful planning for sewerage projects. One interviewee stated that the municipality is conducting a "sewer study…it's a couple-year process and we're working on that, and that will give us a good idea of the best use for our money as far as long-term and short-term projects for sewer improvements." Though sewer studies, inspections, and planning often require time and financial investments, interviewees generally indicated they were important components of conducting project cost-benefit analyses.

Other strategies for conserving money through upfront investments included assisting residents with flood control protection, buying homes in floodplains, adding more stormwater pumps, and installing green infrastructure. One interviewee said municipalities must "strategically" focus on projects that will have a good return on investment:

> …those are progressive, more proactive, front-end type of programs. And there's more out there, and we just have to brainstorm…[the municipality] doesn't have a lot of money, but if you have a board that's willing to say, 'Okay, let's spend some money on programs that are targeted at specific issues that you have,' and not just spending money to make it look like we're doing something. That's the worst way to be, I think. Proactive. You get community members saying, 'Hey, you've got to do something,' so then we go out and

> spend a lot of money on a study, and then spend a lot of money on something else, with no clue about whether or not it's going to work. That doesn't help anything.

Rapidity

Aside from efforts to repair and rehabilitate infrastructure, as well as strategies for increasing economic resourcefulness and robustness, none of the interviewees discussed projects directly intended to decrease the rate at which money is lost for sewerage infrastructure projects. Similarly, no interviewees discussed projects to increase the rate of return on investments.

4.2.e: Environmental

Interviewees generally did not discuss municipal efforts to improve the environment as a means of also improving the sewerage system outside the context of green infrastructure recommendations.

Robustness, Redundancy, Resourcefulness, and Rapidity

None of the interviewees mentioned projects to manage for environmental robustness, redundancy, or rapidity. Regarding environmental resourcefulness, some of the interviewees stated that their municipalities are encouraging residents to add rain gardens to help capture stormwater, though no efforts were mandated or strongly emphasized by managers of the sewerage system. One interviewee expressed doubt the rain gardens are effective at reducing residents' risk of flooding.

4.3: Organization

Many interviewees discussed ways in which different actors within and outside the municipality organize and influence management of the municipal sewerage system. Based on information provided by interviewees, data relating to organization of actors was characterized as internal/external and public/private/collaborative. Data in this section illuminates the ways in which different municipal groups work with and influence one another within municipalities.

4.3.a: Internal

Interviewees generally characterized management of municipal sewer systems as an effort on the part of various municipal departments and residents. Collaboration between these groups, particularly among different municipal actors and departments, was generally viewed as strong and highly advantageous for management. Residents were often described as the group with the greatest influence over determining the course of policy, but they often had the least direct control.

Public

All interviewees mentioned the responsibility of the municipal Public Works department for overseeing day-to-day maintenance of the sewerage infrastructure, as well as several non-sewerage projects, including snow clearing, garbage cleanup, street maintenance, hazardous waste disposal, tree planting and maintenance, animal control, sidewalk replacement and other responsibilities. Many municipalities have a separate Engineering department that oversees major construction and technical projects, including those related to sewerage infrastructure. Some municipalities that do not have a separate Engineering department rely on private engineering groups as their official city engineers. One interviewee described the difference between the Public Works and Engineering departments:

> …if there's a broken pipe that causes a street collapse or something, that's all done by [Public Works]. We [Public Works] do spot repairs. We're all responsible for cleaning the sewers…And then, our engineering staff is responsible for all of the major replacements, like when we're replacing complete sewers on a block, that's all done through our capital program…They do all the major reconstruction of all the major sewers that we have.

Despite the technical and managerial focus on Public Works and Engineering departments in overseeing sewerage systems, one interviewee acknowledged the social components of the municipality's responsibility to manage infrastructure:

> …I think part of our job as a municipality is to help educate the residents about the services that we provide and why we provide them and the manner that we do. We don't arbitrarily choose to address one issue a certain way over another way; it's something that has been thought about on a larger-scale, and the different approaches to dealing with any given issue is something that is contemplated by all the hundreds of municipalities in Illinois, and in the country…it's our opportunity to help [residents] understand.

While no other interviewees explicitly mentioned edification of private citizens as part of their mission to manage the municipal sewerage system, it is reasonable to presume that most other interviewees would agree with this sentiment based on their concerns regarding the public's understanding of how sewerage systems work and their efforts to increase awareness and preparation.

Most interviewees described other municipal leadership—including mayors, village presidents, village managers, and village boards—as having an essential role in overall management of the sewerage system. While these individuals do not, of course, have a role in day-to-day maintenance or implementing major repair projects, interviewees typically described them as necessary for identifying and allocating funds toward sewerage infrastructure projects. Moreover, according to an interviewee:

> …whenever there's a new village president, there's a new focus on things…[municipal leaders] are ultimately in charge. They get elected. So you kind of have to do what they say, but the village president is not an engineer, so they may say that we have a flooding problem, and then things will move from there in the engineering department.

Some interviewees acknowledged that municipal leaders may enable departments to increase investments in infrastructure, whereas other leaders may focus resources elsewhere. Thus, uncertainty can emerge as administrations transition over time.

Private

Some municipalities were clear that the municipality is only responsible for publically owned sewerage pipes; private citizens are entirely responsible for the upkeep and maintenance of private lines that feed into the municipal system. According to an interviewee:

> …this is one that's always a sticking point. [Municipality] code and, it says that residents are responsible for anything outside the outside diameter of the village pipe. Which means up to and including the tie in to the village mains. Which could be across the street, you know, a lot of people say, 'Well, it's in the street, or it's in the parkway, the village right of way.' Doesn't matter. It's the homeowners all the way up to and including the tie in to our sewers…

Other interviewees relayed similar information about the responsibilities of private citizens, which in some cases appear not to be clear or fully understood by individual residents.

Despite the clear separation of responsibilities expressed by some interviewees, most interviewees indicated that the public plays an important, yet often indirect, role in guiding management of the municipal sewerage system. The role of the public was explained by one interviewee who said:

> …the people are the ones that drive the system. The people that have the needs drive the system. That's why the community pretty much works together and says, 'Well, here's an issue we've got to tackle,' and they go to their elected officials and ask them to work on it.

The conviction that private residents are the ultimate focal point of municipal efforts to manage the municipal sewerage system was widely shared among most interviewees. Some interviewees acknowledged the influence of private residents as a relationship less marked by persistent mutual interest in improving infrastructure, stating that residents often can shift municipal priorities by “complaining” or issuing “complaints” to elected officials after they have experienced some disturbance. Nevertheless, interviewees typically indicated that, while complaints directly to the Public Works or Engineering departments do not always result in immediate policy change, complaints directed to elected officials and mobilize swift and progressive action.

Collaborative

All interviewees emphasized the importance of some level of internal collaboration between different groups, either between (1) municipal leaders and municipal departments, (2) two separate municipal departments, or (3) the municipality as a whole and residents.

Interviewees stressed the importance of collaboration between municipal leaders and municipal departments. Indeed, one interviewee said, “the biggest issue is to make sure that you have collaboration between the policy makers, the elected officials, and the professional administrators, the staff, the people who are responsible for the operations.” Interviewees indicated that municipal leaders will set policy, but they will often seek advice from departments that have specialized knowledge of sewerage system needs.

Some interviewees stressed the importance of collaboration between individual departments, specifically the Public Works and Engineering departments. Interviewees indicated that these departments work closely together to share information and ensure that projects are conducted effectively and efficiently.

Finally, some interviewees also acknowledge the importance of collaboration between the municipality as a whole and residents. An interviewee commented that collaboration between these two groups is essential for management, and “if one or the other doesn’t want to help the other, then you’re going to have some faults in the system.”

4.3.b: External

Interviewees suggested that despite challenges arising from differing opinions on projects, assistance from agencies outside of the municipality and collaboration on projects is highly beneficial. No interviewees mentioned that private citizens or agencies outside the municipality play an influential role in the administrative organization of the municipal sewerage system.

Public

All interviewees acknowledged that other public organizations outside the individual municipality are essential components of the overall system. Each interviewee mentioned the role of the MWRD in issuing permits, offering funds, and overseeing regional projects. Fewer interviewees acknowledged the role of the state government—particularly the IEPA—in creating policy and offering funding. Interviewees also mentioned the role of the federal government, though they included such agencies as the EPA, FEMA, and the Army Corps of Engineers. One interviewee described the relationship between multiple levels of government and municipalities by saying that each level of government is regulated by the level above it; therefore, while the federal government often does not have a direct impact on municipalities, its influence is filtered through state government and then, again, through the MWRD. To quote that interviewee: "It kind of flows down, no pun intended."

Private

None of the interviewees discussed the influence of private individuals or organizations outside of the municipality. Some individuals discussed relying on private contractors to complete major sewerage infrastructure projects, although none indicated that the private entity has any significant decision making authority or influence over management decisions.

Collaborative

Most interviewees mentioned collaborative efforts between the municipality and organizations outside of the municipality that are relevant to managing the internal municipal sewerage system. Collaboration occurred between (1) two or more municipalities, (2) a municipality and private contractor, or, according to one interviewee, (3) a municipality and a public utility. Interviewees discussed relationships between the municipality and other public organizations, such as the MWRD, IEPA, and EPA, in hierarchical terms rather than as a relationship between equals and, therefore, these relationships were not considered collaborative.

Most interviewees stated that their municipality works with or relies on other municipalities to manage the sewerage system. Municipalities will often share equipment or collaborate with neighbors to complete projects that will benefit both communities. The relationship between municipalities was generally described as positive, with one interviewee saying:

> …as far as villages and cities working together, we're all close-knit, and we all work together. Like I say, if something comes up we assist each other, we do that also too. Like I say, some of the communities they don't have a lot like some others. We have some equipment, they have other [equipment]. Everybody tries to do it together: to do what they can to maintain these sewers.

A few interviewees said that collaboration with other municipalities can sometimes be challenging, "because some communities will have different ideas than we will have, so it can get kind of messy." Nevertheless, this interviewee and others who mentioned occasional challenges insisted that relationships are general positive and productive.

Some interviewees also mentioned that they collaborate with private contractors who have specialized knowledge or skills to help complete studies or major rehabilitation projects. While none of the interviewees directly stated whether these relationships are positive or negative, they indicated that these efforts are not uncommon, therefore suggesting that the collaborative efforts are productive.

Finally, one interviewee described a similar relationship as that between municipalities and private contractors, except instead with public utilities. The municipality stated that the utilities are sometimes willing to offer equipment and services to help the municipality conduct inspections of the sewerage infrastructure.

4.4: Summary of Findings

Attending to resiliency attributes yielded several important findings, particularly relating to technical, social, and economic considerations. Consistent with the literature, interviewees emphasized that the paramount concern for municipal sewerage system professionals is the maintenance of technical infrastructure. Yet the technical solutions appear to be projects that municipal professionals largely have the skills and knowledge to apply, but are economically unfeasible. Insufficient funding prevents most professionals from implementing large-scale projects that would have long-term benefits. Professionals instead pursue small-scale repairs that are more cost-effective, but also more likely to require additional repairs in the near future. Uncertainty about impending technical disturbances and available revenue is a perpetual concern, leading some professionals to avoid long-term planning altogether in favor of a more extemporized approach to sewerage maintenance as issues arise.

Interviews consistently suggested that technical and economic attributes are the greatest concern for municipal sewerage system professionals, yet most interviewees also stressed challenges associated with social attributes. Interviewees often expressed frustration that individual residents were reluctant to protect themselves from issues that arise from sewerage system disturbances, and that residents were also often uninformed about how the municipality manages the sewerage system. Nevertheless, some interviewees stated that harnessing residents' strong emotions can be useful since residents are more likely to support larger infrastructure repairs following major disturbances such as flooding or pipe failures.

Internal organization usually has the greatest and most direct effect on management of municipal sewerage systems. Beyond the municipal government, management is hierarchical, with the federal government often having the smallest direct effect on individual municipalities but nonetheless influencing decision making via state and county governments. Consequently, many municipalities turn to other municipalities, private contractors, or public utilities to assist with infrastructure repairs.

Chapter 5: Discussion

> *…it's not a Cook County issue or a [municipality] issue or an Illinois issue…it's a country problem. Infrastructure is the hardest thing—that has always been neglected.*
>
> — Municipal Public Works Director

5.1: Disturbances to Municipal Sewerage System Resilience

Consistent with much of the available literature about the challenges of managing sewerage systems, technical and economic challenges were the most frequent and potentially disruptive for all interviewees. Yet the perspective gleaned by these interviews stress the extent to which, with regard to municipal sewerage system management, technical and economic challenges are often tightly coupled but also mediated by the system's administrative component. Several interviewees explained that technical deficiencies in the system are the direct result of insufficient funds to complete necessary repairs; therefore, the municipal administration focuses more on point repairs, temporary solutions, and alternative technology to maintain system functionality. Further, the EPA (2008: 44) acknowledged that smaller communities—which it defines as those with populations of fewer than 10,000 people—may "lack the technical, financial, and managerial capacity to optimally construct, operate, manage, or maintain wastewater treatment facilities or systems". In this study, however, only one of the municipalities included had a population of fewer than 10,000 residents; nevertheless, each of the municipalities discussed challenges arising from the interlocked technical and economic dimensions. In fact, the interviewee representing the municipality with the smallest population placed less emphasis on technical challenges than most other interviewees. This singular observation does not, of course, undermine assertions by the EPA or others that smaller communities are usually less capable of meeting the demands required for proper sewerage system maintenance. What it does suggest is that the idea of what defines a small community should possibly be expanded given the magnitude of necessary municipal sewerage system projects. Rather than emphasizing isolated statistics like population or budgetary numbers, analyses should instead examine the disparity between economic capacity and economic needs. Subsequent policies intended to aid communities in need would, then, target more appropriate metrics indicating a municipality's technical, financial, and managerial capacity.

There is ample literature detailing the linkage between municipal sewerage systems and social dimensions, usually regarding residential flooding, public health, and beach closures. Despite being connected to the regional MWRD system, which during particularly intense wet weather events can overflow into Lake Michigan and expose beaches to untreated wastewater, none of the interviewees discussed concerns related to social issues external to their individual municipality. Further, only one interviewee directly framed sewage overflows as a potential public health concern within municipalities. Nevertheless, interviewees strongly underscored their concern about sewerage system flooding into residential basements. While it was seldom mentioned directly, it is reasonable to believe the interviewees were concerned about the full challenges to finances, public health, and general wellbeing associated with flooding.

Rather than specifically emphasize these financial and public health losses associated with insufficiently managed municipal sewerage systems, interviewees instead spent considerable time discussing challenges that arise from residents' lack of knowledge about infrastructure operations, management, or protection strategies. Several complex administrative, economic, social, and cultural factors can affect residents' awareness and preparedness for floods (Scolobig *et al*., 2012); however, few studies specifically attend to residents' awareness of risks and protection strategies for sewerage system induced flooding. Due to the paucity of research directly connecting sewerage system overflows, residential awareness, and consequences for municipalities, interviewees were not expected to stress frustrations with a lack of public preparedness. No interviewee suggested that lack of public awareness and preparedness posed as significant a threat to overall system functionality as, for example, infrastructure deterioration or economic constraints. Yet interviewees often characterized the lack of social resourcefulness as a persistent and challenging problem with actual economic, administrative, environmental, and technical consequences. The consequences could be positive if awareness and preparedness were strong, and negative if they were not. A lack of social resourcefulness was attributed to higher cleanup and repair costs for both municipalities and residents, while strong social resourcefulness was linked to progressive policy shifts, more green infrastructure, and increased sewerage system capacity. Yet some interviewees found social challenges resulting from a lack of awareness and preparedness as opportunities to push for stronger administrative support of infrastructure rehabilitation projects, and have often found progressive management decisions are made at points of heightened social unrest.

Other challenges concerning the administrative and environmental resiliency dimensions of municipal sewerage systems received far less attention, although results do not indicate these challenges as insignificant or unimportant for management. Interviewees generally discussed administrative challenges—often relating to uncertainty in planning or differences between the municipality and other public agencies—as unavoidable and inevitable, rather than as obstacles that could be overcome. One interviewee expressed this idea, stating that "if something does change and the law does change, and we're going to have to comply, then you make the changes to comply with the law. That's about all you can do, you know?" Exogenous administrative decisions about laws, management requirements, and budgetary apportionments constrain internal administrative capabilities to plan and finance projects. Consequently, municipal sewerage system managers are faced with enormous uncertainty in annual operations.

There were few differences in responses among interviewees representing municipalities with different sewerage systems (separate, combined, or separate and combined) when discussing major challenges. Interviewees from all three separate system communities described the infrastructure as being approximately 50 years old, whereas several interviewees from the combined or separate and combined system communities said sewerage infrastructure was older than 100 years in some locations. While some of the separate sewer system interviewees mentioned that infrastructure is beginning to corrode and deteriorate, interviewees with other types of systems generally used much stronger language to describe the condition of their infrastructure, including "disintegrating" and "crumbling." None of the separate system interviews strongly emphasized administrative challenges, although some mentioned challenges included tighter constraints due to external laws, competition for funding sources, and ensuring that lot redevelopment does not adversely impact the sewerage system. Given that there was little consistency between interviewees, and that each of these challenges was expressed by interviewees from other municipalities, there is insufficient evidence to suggest that municipalities with different sewerage systems experience significantly different administrative challenges. Similarly, no mentions of social, economic, or environmental challenges suggest these dimensions affect municipalities differently based on their type of sewerage system.

No characteristics were always true for all municipalities above or below the Cook County average for community wealth, although some general trends were observed. Overall, interviewees from municipalities with less community wealth suggested they were already in a position where they were unable to complete all necessary projects due to a lack of available resources, whereas many of the interviewees representing municipalities with more community wealth suggested that they were currently able to complete all or most necessary sewerage system projects. Consequently, some less wealthy municipalities described a more improvisational approach to planning and administration, versus the bigger emphasis on short term planning in wealthier municipalities. Many communities with less community wealth focused on point repairs and temporary solutions to technical challenges, whereas wealthier communities were more likely to mention larger infrastructure projects. According to one interviewee:

> …there are communities that can afford to do it and there are communities that can't, and they'll find themselves doing a lot of point emergency repairs. And it works. I mean, you fix it and it's flowing again, and there you go. So it's just putting a Band-Aid on it.

Thus, temporary projects and repairs are able to extend the life of sewerage infrastructure, but they are more likely to require additional repairs in a shorter amount of time than municipalities that pursue long-term solutions. While wealthier communities generally mentioned being better able to currently complete all necessary inspections and maintenance, all communities expressed concern about whether they would be able to sustain their level of maintenance into the future. Even one interviewee, who described the municipality's strategy as the "Cadillac" of sewerage maintenance programs, expressed concern that a future lack of funding may significantly disrupt their ability to manage the sewerage system. Aside from technical, administrative, and economic challenges, there was little difference in the content of discussions concerning social and environmental challenges, although interviewees from municipalities with greater community wealth tended to describe social challenges—especially related to social awareness and preparedness—more often than interviewees from less wealthy municipalities. One interviewee from a wealthier community described the residents by stating that, "it's a highly affluent, educated…clientele, so people are smart enough, they expect good service, they expect their infrastructure to be functional and safe, and so that's our daily challenge and our daily charge." While no other interviewees directly linked residents' socio-economic status to an observed lack of awareness and preparedness about the municipal sewerage system, it is possible that residents from wealthier communities are more likely to participate in public administration, and therefore create the appearance of less awareness and preparedness for flooding hazards.

Only one interviewee represented a non-home rule community below the Cook County average for community wealth; thus, it is difficult to determine and isolate a strong correlation between the effects of non-home rule status that differ from communities with home rule status. It may be worth noting, however, that the interviewee from the only less wealthy non-home rule community described the management plan in terms more similar to those of a wealthier community. That is, the interviewee described the management strategy as primarily proactive, based on multi-year plans, and involving creative strategies to reduce costs and include more residents in the management process. Still, it must be stressed that conclusive results cannot be achieved concerning the relationship between a municipality's home rule status and its sewerage system management based on the lack of available data.

5.2: Strategies for Managing Municipal Sewerage System Resilience

Prominent strategies for managing municipal sewerage systems usually addressed the challenges interviewees described. Consequently, the most thoroughly discussed strategies were day-to-day or short term technical projects, including point repairs, sewer lining, emergency repairs, and in some cases, major rehabilitation and replacements. Yet most interviewees described conducting point repairs or other smaller scale, less permanent solutions to help extend the infrastructure life at a smaller cost. Some interviewees described an awareness of necessary projects, but explained that economic challenges limit the frequency and type of projects they are able to pursue. Thus, many municipal sewerage system management strategies reflect the type of challenges faced, but are unable to match the severity of challenges. To quote one interviewee:

> …so long as the sewer stuff is still holding up, then I really have no major issues or problems with it. We've got it all listed with our priorities of what we'd like to see done, but it's not happening like you'd like to see it done, so you just have to go along with whatever comes our way. That's basically what it comes down to.

While not all interviewees described their municipal capacity in such constrained terms, almost all expressed concern that they will become increasingly limited in their capacity to achieve all goals in the future because technical projects are, again, constrained by the type and extent of economic challenges.

Consequently, almost all interviewees described strategies for increasing funds or decreasing economic losses in order to implement technical projects. Economic projects generally involved pursuing grants and other funding sources made available by the county, state, or federal government. While almost all interviewees stressed the continual search for funds as the primary economic projects the municipality conducts, some of the interviewees stressed that they are not directly involved in the process of creating the budget, identifying loans, or allocating municipal funds toward sewerage infrastructure systems. While most interviewees described the relationship between departments that manage the municipal sewerage system and officials responsible for budgeting as strong and essential for the overall functionality of the sewerage system, they also described encountering pulses of economic investment in infrastructure following intense wet-weather events. These observations suggest that social and administrative responses to isolated disturbances can often be the deciding factor in which of several competing needs receive municipal funds. Therefore, while technical projects are dependent on the balance between economic challenges and projects, economic projects, to an extent, are dependent on administrative responses to social challenges.

Relationships between dimensions of municipal sewerage systems are not, however, always one-way. While technical and economic projects are dependent on administrative projects, administrative projects are simultaneously shaped by the nature of technical and economic challenges. Perhaps the best example of this relationship is the difference between municipalities whose administrative strategies rely more on planning and proactivity versus those whose administrative strategies rely more on improvisation and reactivity. Several interviewees characterized the technical and economic dimensions of municipal sewerage systems by one common factor: a high degree of uncertainty. Sewerage infrastructure may unexpectedly collapse and require emergency repairs, and funds may drastically fluctuate annually or be irregularly redistributed depending on municipal needs. Interviewees who described a stronger ability to adapt to uncertainty tended to characterize their administration as one that relies heavily on planning, scheduled inspections, and routine. Conversely, interviewees who described being less able to adapt to technical and economic uncertainty—usually due to economic constraints—tended to characterize their administration as one that makes short term plans and attempts to conduct regular inspections, but instead often reacts to challenges as they arise. Some interviewees described efforts to resist the need to reactively manage problems by clearly defining different management responsibilities for different departments and groups within the municipality, or by changing municipal laws to help minimize burdens on the sewerage system.

Interviewees' descriptions of social projects suggest that municipal efforts to actively change social conditions through technical and administrative projects may be more effective than educational efforts alone. Interviewees often stated that their municipality engages in efforts to raise awareness about sewerage system operations and opportunities to prepare for flooding, yet many of these interviewees also described residents' lack of awareness and preparedness as a major challenge for the sewerage system. One interviewee, however, described his municipality's decision to invest money in grants for residents to install overhead sewerage systems rather than gravity systems, which are intended to reduce basement flooding. The interviewee stated that over a period of a few years since instating the policy, the number of flooding reports following intense wet weather events dropped from a range of 300 – 400, to a range of 50 – 60. Another interviewee stated that after his municipality created a Water and Sewer Infrastructure Committee designed to educate residents and involve them in management decisions, the municipality as a whole has been able to invest more money toward infrastructure and become significantly more proactive in its management approach. These two examples provide different approaches to solving social challenges, yet appear to be more effective than traditional methods of information dispersal. The first example bypasses the need to educate residents by investing directly in technology to increase preparedness, which according to the interviewee, ultimately saves the municipality money. The second example demonstrates efforts to educate residents by allowing them to actively engage in the process and understand first-hand the costs required to fund infrastructure.

Many government laws and programs affecting sewerage systems focus on wastewater treatment and water quality concerns related to pollution, yet none of the interviewees discussed municipal projects to improve the quality of local or regional waterways. Some interviewees mentioned that municipalities are encouraging residents to add rain gardens, although the emphasis was more on stormwater retention rather than stormwater filtration. While tensions between the focus of municipal governments and other public agencies were not explored in depth, the discrepancies between their goals may contribute to increased constraints on municipal sewerage system management. Major challenges related to infrastructure included maintaining the technical functionality of sewerage infrastructure and being able to allocate sufficient funds among competing municipal infrastructure projects, but many environmental laws and programs focus on a different set of problems. Even functional and properly maintained sewerage systems can cause ecological and public health risks due to the potential for untreated wastewater and stormwater discharges. Therefore, while many county, state, and federal programs strive to eliminate ecological and public health risks, there are fewer programs that enable municipalities to achieve the goals most important to them; that is, regular and appropriate infrastructure rehabilitation to maintain functionality.

Interviewees described some projects that differed between communities with CSSs and those with SSSs. One interviewee representing a municipality with both types of sewerage systems said the main difference is that blockages from fats, oils, greases, or other materials that are sent down sanitary drains are more common in separate sewer systems. Other interviewees managing separate sewer systems mentioned efforts to prevent inflow and infiltration—or sources of clean water—from entering sanitary sewers, thereby unnecessarily increasing the amount of wastewater treated and making communities more vulnerable to flooding. According to the interviewee, a large storm is able to flush any blockages in a CSS away. Another interviewee also representing a municipality with both types of sewerage systems said the municipality was making efforts to replace CSSs with SSSs to help mitigate flooding during intense wet weather events. While there were some major differences among types of technical projects pursued by municipalities with different types of sewerage systems, it did not appear that sewerage system type significantly affected municipal projects focused on administrative, social, economic, or environmental dimensions.

Community wealth did appear to affect the types of projects municipalities pursued to manage sewerage system resilience. Most of the municipalities with community wealth below the Cook County average relied more heavily on improvisational and reactive administrative decisions and temporary technical solutions. Conversely, municipalities with greater community wealth engaged in regular planning and routine monitoring of sewerage infrastructure. These results suggest that community wealth may correlate with the municipality's overall capacity to provide functional and sustainable infrastructure to residents. While interviewees from municipalities with greater community wealth tended to discuss social challenges to the sewerage system more often than interviewees representing municipalities with less community wealth, there was no major difference in a municipality's engagement in social projects when comparing community wealth. Most municipalities, regardless of community wealth, engaged in some projects to manage for social dimensions in some capacity. The level of engagement in social projects varied by municipality but was not, again, directly or indirectly associated with community wealth based on the results. The willingness for many communities to engage in social projects may be due to the fact that efforts to engage and educate residents are often low in cost and easy to achieve, although the efficacy of these projects is more difficult to measure.

None of the data suggested that a municipality's status as a home rule community has any bearing on its strategies for managing sewerage systems. The lack of a correlation, however, is due primarily to insufficient data.

5.3: Organization of Actors in Municipal Sewerage Systems

Perhaps the key finding relating to the way in which actors organize to manage sewerage systems is that, based on interviews included in this study, perceived challenges do not emerge from faults in the municipal organization. In fact, the vast majority of interviewees described both internal and external municipal sewerage system organization as strong, beneficial, and highly collaborative. Perhaps the strongest connections described were those between different departments and officials within individual municipalities, and between administrative agencies in separate municipalities. According to most interviewees, elected municipal officials generally identify, obtain, and allocate funding sources, while the Public Works and Engineering departments plan and implement projects. Many interviewees described this organizational structure as beneficial because it distributed responsibilities that require very different skills, knowledge, and time commitments. None of the interviewees commented on whether or not the separation of municipal professionals responsible for the budget and those who manage the sewerage systems results in an incomplete exchange of information, which is a possible negative consequence of creating strong distinctions between budgetary and technical personnel.

Further, the strong relationships interviewees described between separate municipalities appeared to primarily result from necessity. Interviewees often cited the expense of completing major sewerage infrastructure projects individually as one reason why municipalities choose to work collaboratively. Another reason why municipalities choose to work with other organizations, including separate municipalities and public utilities, adds a temporal component to the needs-based reasoning. Axelrod (1984) argues that "what makes it possible for cooperation to emerge is the fact that players might meet again…the future can therefore cast a shadow back upon the present and thereby affect the current strategic situation" (12). Similarly, some interviewees explained their willingness to assist other groups with services, usually by lending equipment, is fostered by an understanding that at some point in the future, they may also lack necessary resources and will have to rely on others for assistance. Thus, given the limits to their individual management capacities, municipalities have understood that the pursuit of individual interest also requires collaboration.

The importance of collaboration within and between municipalities was expressed by the majority of interviewees, with no significant differences based on type of sewerage system or community wealth. Given the abundance of communities with either CSSs, SSSs, or both, it is reasonable to infer that sewerage system type would not be a hindrance to a municipality's ability to work productively and collaborate with other municipalities. Regarding community wealth, while municipalities with higher community wealth were generally described as more capable of managing for uncertainty and completing necessary projects, economic challenges remain persistent and fundamental for all municipalities. Thus, it is also reasonable that municipalities should choose to assist one another and pursue less expensive collaborations regardless of their relative wealth. Finally, municipalities are generally in non-competitive relationships with one another regarding sewerage system wealth. In fact, given their association with the MWRD, municipalities may have even more reason to collaborate. Due to the interconnections of all sewerage infrastructure in the regionally managed system, disturbances in one municipality can lead to disturbances in several other municipalities; therefore, it is in the best interest of individual municipalities to ensure that their neighbors are also able to manage their sewerage systems effectively.

Interviewees described other relationships—specifically with residents and with county, state, and federal governments--as less directly involved in sewerage system organization yet still highly influential and, occasionally, more likely to incite challenges. Some interviewees described the lack of attention given to individual municipal needs by county, state, or federal agencies requires municipalities to comply with programs that, according to the interviewees, may not yield strong benefits for specific localities. These external government agencies are far more removed from the internal organization than public entities existing within the municipality, but their impacts can profoundly affect municipal operations. Finding solutions, then, that simultaneously achieve national, state, county, and municipal goals poses a significant organizational challenge. Extending that line of actors further, residents also have goals that differ from the municipalities, and their lack of awareness about the sewerage system or readiness for disturbances can prompt them to demand changed management strategies. Therefore, granting ample opportunities to not only educate, but enable active engagement in processes across governmental levels may be an effective and efficient means of bringing differing goals into alignment. Nevertheless, despite the challenges that some interviewees mentioned regarding working with residents or other government agencies, most asserted that their working relationships were positive and helped improve conditions within the municipality.

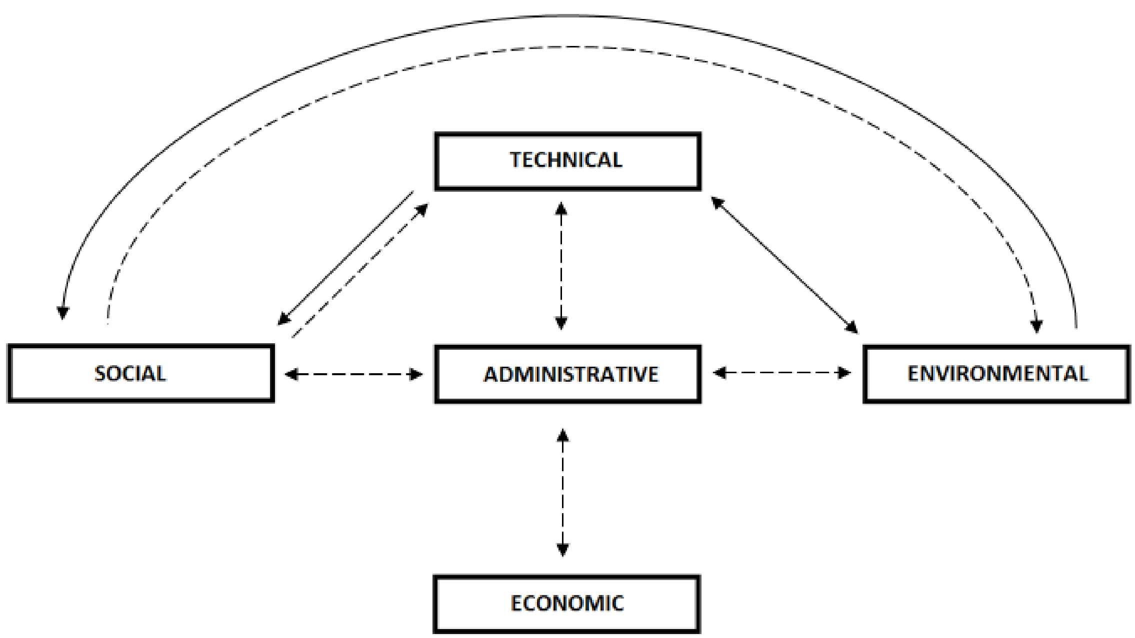
5.4: Relationships between Municipal Sewerage System Attributes

As mentioned in previous sections, results from interviews in this study suggest that the matrix of resilience attributes in Table 1 does not reflect system components that can be isolated and managed independently of one another. Instead, each of these attributes interact with each other in complex but not entirely inexplicable ways depending on established parameters of the system context. Enhancing or diminishing an individual resilience attribute can impact the optimality of other attributes. Mapping out interactions of attributes within a system can assist policy analysts and managers with identifying sources of tension and opportunities for improvement within a system.

For example, most interviewees drew connections between a lack of public awareness and preparedness (diminished social resourcefulness) with increased public vulnerability to flooding and other preventable sewerage system disruptions (diminished social robustness). Many municipalities, then, attempted to improve social robustness by also improving social resourcefulness through education and outreach efforts. Despite these social projects, many interviewees found that progress was nominal at best. Using resilience theory to map out relationships between system attributes can allow analysts to identify other relationships that achieve the same desired outcomes for improved social robustness; managers can then modify that relationship so improved social resourcefulness becomes less fundamental to achieving goals. Two interviewees described ways in which their municipality followed this procedure. One municipality began investing in grants to incentivize residents to install flood protection technology, and another interviewee created a Water and Sewer Infrastructure Committee to give residents an opportunity to actively engage in the management process. The first municipality demonstrated an awareness that social resourcefulness and social robustness are positively affected by improvements in both policy innovations (administrative resourcefulness) and the capacity to maximize funds (economic resourcefulness). Municipal managers, then, created an innovative policy that improves both social resourcefulness and robustness by protecting residents from floods without having to rely on public education to motivate residents into taking action. The second municipality chose to add an additional balance to the management process by creating a committee for residents (enhanced administrative redundancy) to enhance community engagement and, therefore, community competence about infrastructure issues. Both municipalities reported enormous benefits in cost savings, decreased reports of flooding, and administrative capacity to move forward with progressive infrastructure projects. The matrix of attributes in Table 1 is an essential component for beginning to understand relevant issues within a system, but relationships between system attributes must be established to plan and predict the outcomes of new management strategies.

Figure 5 depicts broad relationships between municipal sewerage system dimensions in Cook County identified in interviews. Solid lines depict relationships in which one dimension has a direct, often immediate and unmediated, effect on another dimension. For example, a sewerage pipe that is blocked, collapsed, or filled beyond capacity may back up into residents' homes. Thus, the relationship between the pipe (technical) and the home (social) is direct and unassisted by conscious, willful decision-making. Environmental variables, such a particularly intense wet weather event, may cause pipes to exceed capacity and flood homes; therefore, there is also a solid line connecting the environmental dimension to the technical and social dimensions. Further, technical dimensions of sewerage systems and directly affect environmental dimensions by polluting waterways.

Figure 5. Relationships between Municipal Sewerage System Dimensions

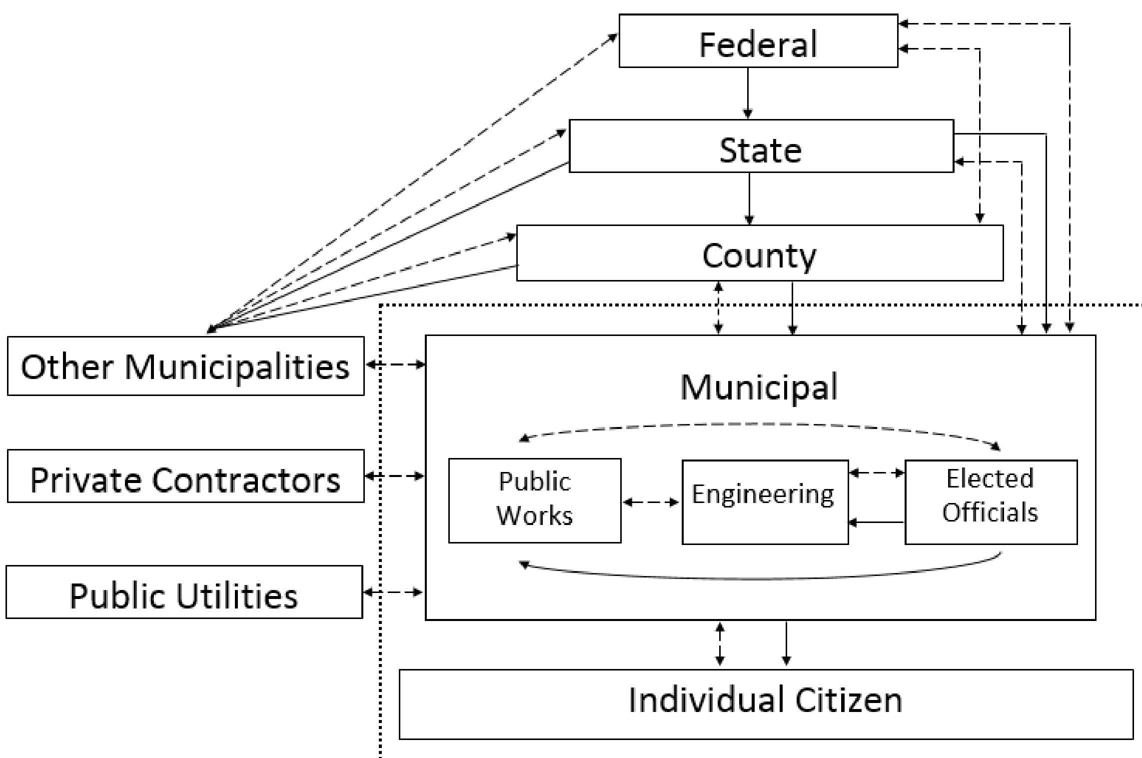


Conversely, dashed lines depict direct relationships that are necessarily mediated by some kind of conscious, willful decision-making that can be influenced by the actor's surrounding environment. For example, dashed lines connecting social dimensions to technical and environmental dimensions underscore the ability for citizens to alter sewerage infrastructure or their surrounding environment based on their decisions, actions, and beliefs. Residents who dispose of fats, oils, and greases into the sewerage system have a direct effect on creating infrastructure blockages, but the negative relationship between social and technical dimensions hinges on the decision-making of individual residents, rather than a steadfast rule that residents looking to dispose of fats, oils, and greases will use their sewerage system. Similarly, residents' impacts on their environment—like deciding to develop a home and, therefore, reducing open space for infiltrating stormwater—are direct, albeit mediated by their knowledge and choices. Finally, all aspects have similar effects on the administrative dimension of municipal sewerage systems. Indeed, technical challenges like widespread deterioration of infrastructure will not necessarily result in direct administrative action. Administrative decision making is influenced by a number of different factors, including public pressure, financial resources, and personal interest.

Put another way, managing for relationships marked by solid lines require technical solutions, whereas managing for relationships marked by dashed lines entail persuasion, education, politics, and other social solutions. Of course, as this section argues throughout, management decisions are rarely conceived and implemented entirely within a single relationship or dimension; instead, managing one relationship or dimension requires managing several across multiple scales. As another example, a municipality may wish to manage the technical-environmental relationship by expanding the capacity of its sewers. Doing so would not only require a municipal administration that is willing to manage this relationship, the administration will also need access to sufficient economic resources, technical knowledge, and social support for the project. Assuming the municipality is able to mobilize its administrative, technical, economic, and social dimensions toward managing the technical-environmental relationship by expanding pipe capacity, the municipality must also consider these relationships across scales. Some interviewees stressed that even if they were to increase the capacity of their sewerage pipes, the capacity problem would not be resolved because municipal pipes feed into the MWRD system, which they are not able to adjust. Thus, the municipality must manage its relationship with the MWRD, which then must manage its own administrative, technical, economic, and social relationships dimensions to assist the municipality.

The model in Figure 5 depicts observed relationships but it does little to explain them. The breadth of this model must be understood contextually and further refined before it can be utilized for both explanation and prediction. How actors organize around and within the municipal sewerage system contributes to an understanding of context because it highlights hierarchical relationships, power dynamics, responsibility, and potential points of leverage. Figure 6 depicts the organization of municipal sewerage systems in Cook County based on interviewee descriptions. Solid lines depict relationships in which one actors has direct authority over another regarding management of municipal sewerage systems, whereas dashed lines depict relationships in which actors collaborate or exercise indirect authority over another actor. The dotted box separates internal and external relationships and actors affecting individual municipalities. The figure only depicts relationships described as important by interviewees. Other direct, indirect, and collaborative relationships are certain to exist; however, these relationships were not mentioned in interviews.

Figure 6. Organization of Municipal Sewerage System Management



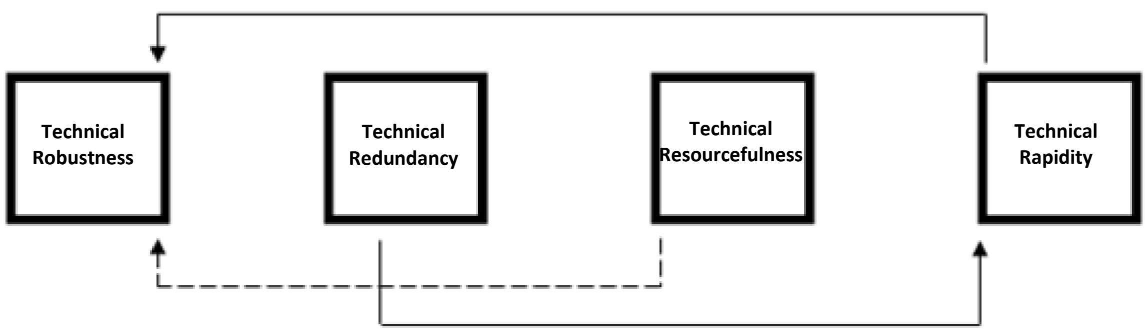
Individual citizens provide the foundation for municipal sewerage system management, though they were depicted as having the least direct and indirect influence over municipal management strategies. Thus, outside of their role as a source of revenue through service fees, individual citizens provide the ultimate test as to whether or not management strategies are effective. As a result, municipal officials may be more responsive to input from individual citizens, explaining why several interviewees noted that policies and management strategies typically evolve rapidly after large numbers of citizens are negatively affected by sewerage system disturbances. Within municipal government, elected officials set policy and finalize the budget—granting them authority over other departments—although they also work closely with the Public Works and Engineering departments to ensure that their strategies serve individual citizens.

External public entities generally have less direct influence on municipal sewerage system strategies as their scope move from county, to state, and finally to federal. Each level of government offers financial resources to municipal governments for sewerage infrastructure projects, although other municipalities are also competing for the same funds. Further, interviewees mentioned state and county government as regularly asserting direct control over municipal sewerage systems by passing legislation which is seldom tailored for specific municipalities. Consequently, municipal officials are often constrained in terms of planning, funding, and completing infrastructure projects. Municipalities, partially, adjust to these constraints by working with other municipalities, private contractors, or public utilities to help with infrastructure projects, occasionally in exchange for other services.

Illumination of these organizational relationships was not central to this study, although how actors interact with one another emerged as an important and influential aspect of municipal sewerages system management. Decisions of municipal managers are invariably affected by the flux of direct and indirect relationships with other actors. Therefore, a better understanding of these relationships may further clarify how managers prioritize different and often conflicting projects.

The explanatory and predictive capacity of resilience theory for municipal sewerage systems can be further extended by refining the relationships between system dimensions depicted in Figure 5. Indeed, interviewees often described interrelations between the properties of robustness, redundancy, resourcefulness, and rapidity. As an example, figure 7 represents commonly mentioned relationships between properties of the technical dimension. Unmediated relationships, depicted by solid lines, make up most relationships between different technical components of a sewerage system. Technical rapidity may have immediate effects on technical robustness because infrastructure strained beyond its capacity or with several blockages may cause pressurization which exacerbates the deterioration of pipes. Technical redundancy can increase rapidity by increasing the system's overall capacity which, in turn, may reduce the risk of pipe deterioration due to pressurization. Some interviewees also linked minimal technical resourcefulness—specifically a lack of knowledge about how to best solve technical problems—to diminished technical robustness. However, this relationship is marked by a dashed line, representing mediated relationships. The inability to properly maintain infrastructure and solve technical challenges—that is, a lack of knowledge—diminishes administrative robustness in that the capacity for managers to effectively plan and implement strategies becomes severely limited. A less robust administration, then, may allow threats to technical robustness to become more extreme, contributing to infrastructure deterioration.

Figure 7. Relationships between Technical Properties

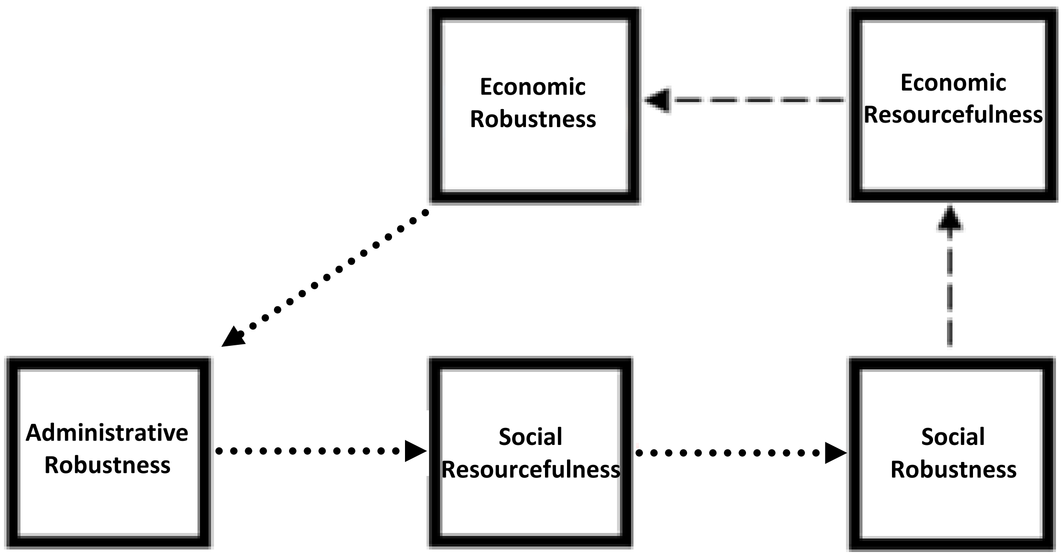


Relationships between technical properties in Figure 7 that were not established does not mean they did not, do not, or cannot exist. Moreover, many relationships exist among different properties of many types of dimensions (i.e., administrative, social, economic, and environmental). Additional research may identify new relationships or enhance the understanding of already established relationships. Yet what is already clear based on the relationships between system properties (Figure 5) within the broader organizational structure (Figure 6) is that the ultimate purpose of municipal sewerage system management is the maintenance of service to end users (social dimension) while minimizing or eliminating negative externalities. Public agencies, most prominently municipal government, (administrative dimension) are the actors responsible for overseeing maintenance. Infrastructure (technical dimension) provides the service that public agencies maintain, although they are limited almost entirely by their ability to finance necessary maintenance strategies (economic dimension). The natural environment (environmental dimension) can affect and be affected by municipal sewerage system management strategies, and can contribute to the unpredictability of system processes. In a perfect system ruled by engineering resilience, these relationships would exist without disturbances and they would need only to be robust to continue. Yet the reality of disturbances, unpredictability, and trade-offs require the properties of redundancy, resourcefulness, and rapidity to maintain functionality. Effective managers must therefore intentionally and strategically create or modify relationships between properties to achieve specific outcomes.

Two interviewees described ways in which the municipalities they represented altered relationships between properties to solve challenges to social resourcefulness. Many interviewees described frustration that residents are often misinformed or uninformed about proper protection of their homes against sewerage system backups. To solve this problem, many interviewees stated their municipalities were embarking on efforts to educate residents about the sewerage system with flyers, advertisements, and public meetings. Their management strategy can be represented as:

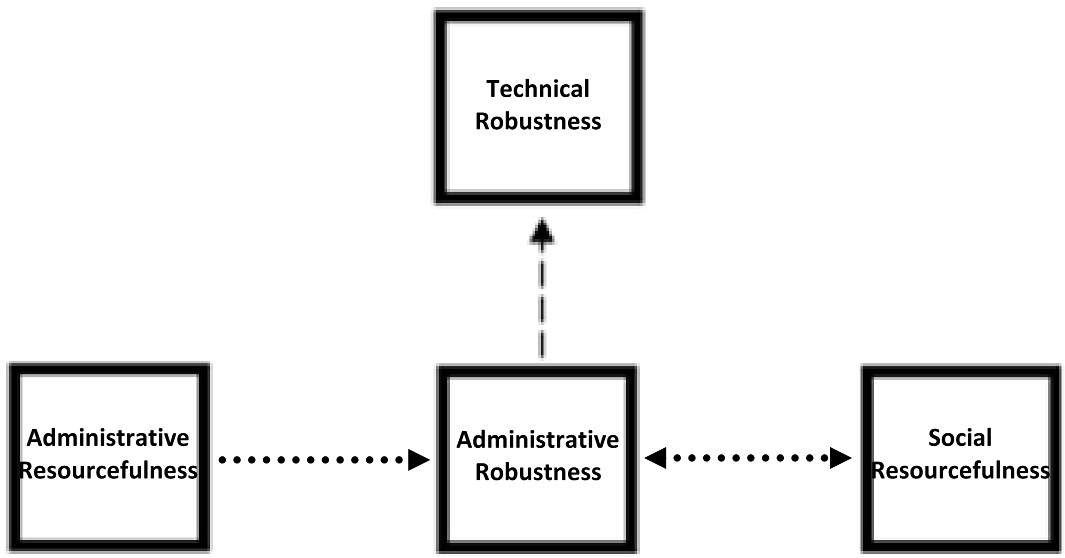
Relying on their economic and administrative robustness, the municipalities planned and implemented strategies to manage social resourcefulness specifically with the intention of improving public competence. A more knowledgeable public could, theoretically, take action to prepare for flooding, in turn reducing municipal clean-up and management costs, or it could catalyze greater public support for infrastructure projects. Yet educational efforts alone can only attempt to manage what residents know; they have no control over whether residents will put their knowledge to use. Thus, the consequences of educational policies to improvement awareness about sewerages systems are largely unpredictable. According to many interviewees, education efforts yielded limited success in terms of increasing preparation for flooding events, support for infrastructure projects, and reducing criticism of municipal managers.

One interviewee described an alternate strategy for achieving similar results that can be represented as:



Dotted arrows reflect relationships the management strategy directly affects, whereas black arrows reflect expected consequences of the strategy. The municipality offered grants to residents partially covering costs of installing home flood protection infrastructure. Because this strategy emphasizes preparation rather than education, the municipality is able to directly manage the relationship between social resourcefulness and social robustness which yields known reductions in management costs and, therefore, improved economic resourcefulness and ultimately enhanced economic robustness. The above representation reflects the intention of strategies emphasizing education alone, but a policy offering flood protection installation grants ensures improvements in social robustness and increases the likelihood that the municipality will enjoy decreased management costs and more available funds. Indeed, the interviewee described the policy as enormously successful, sharply decreasing the number of reported floods and saving the municipality money. Nevertheless, while offering grants may eschew the need for residents who are knowledgeable about the sewerage system, it may not be a wholly successful policy for municipalities that value educated residents as a desirable outcome in itself. Further, strong economic robustness may be a prerequisite for municipal policies offering upfront grants, therefore requiring some municipalities with fewer available funds to find alternate strategies for achieving similar results.

A different municipality devised yet another method for managing social resourcefulness, represented as:



The municipality demonstrated its administrative resourcefulness by establishing a Water and Sewer Infrastructure Committee to modify their administrative robustness, inviting residents to participate in administrative processes for planning management of municipal infrastructure. Participation in the committee increased residents' knowledge about the sewerage system and, according to the interviewee, was very instrumental in supporting more proactive sewerage infrastructure projects. While many municipalities manage social resourcefulness by implanting administrative strategies that affect residents, this municipality created a relationship where residents can also affect administrators. The consequence was a more knowledgeable municipal population, and an administration with more freedom to pursue infrastructure projects.

Managers hoping to use resilience theory to identify opportunities for devising strategies that improve the sewerage system must understand not only important challenges, ongoing projects, organizational characteristics, and available resources, but also the relationships between key system attributes. After identifying a particular system property to enhance, the manager can then target sets of secondary, or even tertiary relationships that—if manipulated—can potentially promote the desired effect on the property. Once those sets are isolated, the manager can craft different policies and strategies around those relationships. Strategies best able to maximize the desired effect while minimizing negative externalities will likely become official policy.

5.4.a: Evaluating System Relationships

Given the significance of relationships between system attributes when understanding and creating management strategies, care must be taken to properly shift the understanding of how dimensions, properties, and their relationships are each evaluated. This study began under the hypothesis that resilient systems encompass robustness, redundancy, resourcefulness, and rapidity in each of five dimensions: technical, administrative, social, economic, and environmental. The tacit assumption was that more robustness, redundancy, resourcefulness, and rapidity resulted in more resilience. Each property could be individually "diminished" or "enhanced" from an unspecified "optimal" state to improve overall resilience. Results from this study challenge those assumptions.

Several interviewees mentioned using restrictors to slow the rate at which stormwater enters sewerage infrastructure. Water stands on streets for a longer time, but the risk of the sewer reaching capacity and backing up into residents' basements decreases. Restrictors intentionally decrease technical rapidity, but they help prevent basement flooding the consequences of which may take even longer to rectify. Thus, the effect of restrictors on the overall system rapidity depends on the perspective of the actor in the system, but they also undermine the assumption that faster action benefits system resilience. An analogous example comes from some interviewees' mention that root infiltration into sewerage infrastructure can contribute to pipe collapses. The challenge from root infiltration is partly environmental, but it resists classification as a consequence of "diminished" environmental robustness: a growing root is seldom indicative of an unhealthy or non-functional ecosystem. It might be argued, instead, that root infiltration is a challenge spurred by "enhanced" environmental robustness, in that the roots are strong enough to infiltrate and disrupt the infrastructure.

What becomes evident is that optimization of a system property is determined by the compatibility of its relationship with other properties for achieving an outcome desired by managers. For example, while allowing trees to grow and proliferate may be understood as enhanced environmental robustness in some contexts, the risk of root infiltration makes them incompatible with sewerage system managers' goal to increase technical robustness. Therefore, enhanced environmental robustness can be, in specific contexts, non-optimal for sewerage system managers. Yet vegetation can also help intercept stormwater runoff and be an important part of overall flood control management strategies. Municipal managers must carefully balance the costs and benefits of vegetation, and be able to effectively prevent or control adverse effects like root infiltration. In another example, poor public health creates an incompatible relationship between social robustness and administrative goals for community wellbeing, or administrative robustness. This finding suggests the manager's job is not to linearly push each property toward its own optimal steady state while abating external disruptions. Complex systems contain properties that, in their movement toward a steady state, inevitably disturb the movement of some other property. It is the manager's responsibility, then, to bring disparate and conflicting attributes into relative harmony and guide them in the direction of a unified system-wide steady state. Doing so does not lapse into pursuit of engineering resilience, which assumes that systems can and do exist at a steady state except for when discrete issues temporarily disrupt them. Instead, managers continually move *toward* an ideal steady state through a persistent hands-on approach, while understanding that constant disturbances will never allow them to fully arrive at the steady state.

5.5: Municipal Sewerage Systems and the Adaptive Cycle

Resilience is a form of adaptive capacity, and can be represented by the adaptive cycle (Holling, 2001). Resilience theory is not yet developed enough to ascertain precisely and definitively where in the adaptive cycle a system resides, yet based on results pertaining to technical, administrative, social, economic, and environmental dimensions, municipal sewerage systems appear to have entered the late conservation phase. Systems in this phase of the adaptive cycle are characterized by high connectivity, increased uncertainty, stymied growth, reduced flexibility, and increased dependence on existing structures and processes (Holling, 2001; Walker & Salt, 2006; Wu & Wu, 2013).

The municipal sewerage systems in Cook County demonstrate extremely high connectivity, or reliance on others, in all dimensions. Some interviewees emphasized the difficulty of managing sewerage systems because they are so tightly connected to roads, water infrastructure, and development of buildings. According to one interviewee: "we could show a hefty number of repairs, but each time we repair one it has an effect on somewhere else…everything collaboratively has an effect on the sewer system." Attempting to manage and implement projects affecting sewerage infrastructure often requires municipalities to complete major construction work on other forms of infrastructure, incentivizing some municipalities to wait until rehabilitation is needed for two or more types of infrastructure. Municipalities can then couple infrastructure needs into one project at a lower overall cost. Administratively, sewerage managers depend on an extensive network of internal and external officials, agencies, and departments, including elected politicians, Public Works and Engineering departments, public utilities, private contractors, the MWRD, the IEPA, and the EPA. Administrative connectivity not only creates overlapping policies and management strategies, but also manifests itself physically in the interconnected network of sewerage pipes that lead to the seven wastewater treatment facilities owned by the MWRD. Socially, residents have few options beyond reliance on the municipal sewerage system for the conveyance and treatment of their wastewater. Residents do have considerable agency to protect their own homes from flooding, but they also rely to some extent on their neighbors at large to reduce their contributions to sewerage system flooding since all residents are connected to the same system. Municipal sewerage system managers are economically connected to administrators, granting and loan agencies, and service rate payments for providing a consistent and sufficient source of revenue. Disturbances affecting this rigid funding system constitute one of the primary challenges discussed by all interviewees. Finally, sewerage infrastructure was—and often continues to be—built based on historical hydrographic records which, according to many interviewees, no longer match current trends in rainfall intensity. The sewerage system relies on the majority of wet weather events to not fluctuate significantly from historical trends; otherwise, water in the system will exceed capacity and potentially lead to raw wastewater discharges into waterways and basements.

Increased uncertainty was heavily emphasized regarding technical and economic dimensions and, to a lesser extent, administrative and environmental dimensions as well. As discussed in other sections, interviewees regularly mentioned challenges associated with unexpected technical repairs and cleaning after infrastructure collapses, pipes become blocked, or other emergencies arise requiring immediate attention. Dependence on the available infrastructure is strong, but the age and deterioration of sewerage infrastructure—in addition to other factors, including social conditions, pipe material, and proximity to other forms of infrastructure---has often become so severe that sewerage system must be prepared for unexpected construction projects. Associated with this technical challenge, interviewees regularly expressed concern about the uncertainty of economic dimensions, including the availability of future funding sources to sustain current management programs as well as the ability of current budgetary allotments to cover costs of unexpected projects. Similarly, interviewees expressed concerns about uncertainties related to administrative priorities as officials cycle through office, respond to social concerns, and determine financial allocations depending on budgetary constraints. Environmental variability and the growing intensity of wet weather events were another source of uncertainty for managers.

A lack of growth and advancements in technical, social, and economic dimensions were significant deterrents observed by interviewees. Major advances in wastewater treatment were made in the 20^{th} century, and innovations continue to this day; however, many sewerage systems built in the 19^{th} century continue to be used in many municipalities. Several projects have been introduced to upgrade sewerage infrastructure, increase the longevity and point repairs, curb the frequency of raw wastewater discharges, and increase infrastructure capacity, and some interviewees described their confidence that technological advances will continue to ease the process of sewerage management into the future. Nevertheless, one of the benefits of massive civil engineering projects like sewerage systems—that is, their permanence—can also be their detractors. Despite several advancements and efforts to extend the lifespan of the sewerage system, the system itself continues to grow old because complete rehabilitation or replacement is so challenging. Other aspects of municipal sewerage systems demonstrate little growth. Socially, interviewees found residents undergoing cyclical responses to persistent challenges despite efforts to make the public more aware of sewerage system operations and prepare them for disturbances. Some interviewees attributed residents' inability or unwillingness to understand sewerage operations and protection strategies to an inhibitive out-of-sight, out-of-mind mentality. Most interviewees also expressed not only a lack of growth in funding for infrastructure projects, but an actual decrease in financial resources that they expect to continue into the future.

Some interviewees also mentioned a trend of decreasing administrative flexibility due to more exogenous rules dictating management practices within municipalities. These interviewees described how county, state, and federal rules may require the municipality to conduct practices that are unnecessary, inefficient, and costly, which then requires the municipality to neglect maintenance of other infrastructure projects. One interviewee stated:

> …by the time [a law] gets to me, you get it done. I don't know where it originates from, I don't know what the people who are for it say, and the people who are against it. By the time it gets to me, it's a done deal, and we're doing it.

Interviewees who described similar challenges demonstrated a lack of involvement or influence in policies that originate from outside the municipality. While many interviewees cited collaboration with the MWRD and other agencies as a strength of sewerage system organization, others conveyed a sense that their management strategies are increasingly inflexible due to policies established by external agencies.

5.6: Policy Recommendations

Municipalities are increasingly dependent on structure, procedures, and resources that are characterized by connectivity, uncertainty, inadequate growth, and inflexibility. Yet a systemic release phase regime shift need not entail the literal widespread collapse of municipal sewerage infrastructure across counties, states, or the nation. The adaptive cycle is, first and foremost, a representation of a theoretical construct; in reality, not all systems move through all stages in the adaptive cycle or experience destructive regime shifts (Walker & Salt, 2006). Policymakers and managers can manipulate system components to organize changes and small-scale releases of resources to minimize or altogether avoid the release phase and move from the conservation phase directly into the reorganization phase. Either through broad systemic policies, a suite of targeted discrete policies with attention to system-wide effects, or some combination of the two, policymakers may be able to move municipal sewer systems directly to the reorganization phase with minimal losses.

Coordinated action at all levels is necessary to move the management of municipal sewerage systems onto a more sustainable path; however, local, county, and state governments can also begin taking independent action to manage regime shifts without having to wait for higher levels of government to begin taking action. A successful regime shift for wastewater infrastructure hinges largely on identifying new approaches to financing and gaining public support for projects. Sometimes managers could simply adapt their use of already existing tools and programs, while other times they may want to consider strategies with far less precedent in the United States. This section will provide recommendations to policymakers and managers at various levels of government who oversee or influence municipal sewerage systems in Cook County. Recommendations are intended to move sewerage management toward a system that emphasizes greater accountability for local impacts on sewerage infrastructure, technology that will reduce inputs into sewerage infrastructure, and more efficient project implementation through greater community support and consistently available funds adequate for meeting project requirements.

Municipal: Organize Water & Sewerage Infrastructure Committees

Interviewees frequently emphasized difficulties educating residents about the larger sewerage system and gaining support for larger infrastructure projects. While only one interviewee mentioned the availability of a Water & Sewerage Infrastructure Committee within the municipality, the success attributed to the Committee suggests it may provide a relatively simple and effective supplement to ongoing educational efforts. A more educated community may, however, become a more critical community, so municipalities must be careful not to move from one social challenge (uninformed community members) to another (partially informed and more critical community members). Still, an effective educational campaign may promote more conversation about managing municipal infrastructure, which managers can potentially harness to implement projects that a less informed public may be inclined to oppose.

Regularly convening committees not only bring together Public Works and Engineering department professionals, elected municipal officials, and residents, but also granting unelected residents the opportunity to become actively involved in decision making and planning processes could give residents a better understanding of the need for infrastructure improvements, the associated costs of improvements, and the potential consequences of inaction. Committees could share ideas, express concerns, mediate conflict, and collaborate toward building a stronger municipality through improved infrastructure management practices. In smaller communities, residents who are involved with the committee may relay key learnings to neighbors and friends.

While the specific dynamics of current committees—including resident demographics, residents' influence on policy, and Committee influence on the larger municipality—remain largely unknown, developing opportunities for residents to participate more fully in local governmental processes may be a more effective means of not only educating residents about how to protect themselves and manage their inputs into the sewerage system, but also convincing residents that investments in infrastructure improvement are worthwhile.

Municipal: Implement Tiered Water and Sewer Rates

Between 70 and 80 percent of all water and wastewater utilities charge rates sufficient to cover operations and management costs, but insufficient for funding major infrastructure improvement projects (Anderson, 2010). Considering that local water and wastewater fees account for the majority of funding for local infrastructure projects, adjustments in rate fees could significantly affect municipal capacity to implement larger scale, proactive, and long-term projects. Yet raising water and wastewater rates to cover the true cost of operations and depreciation of infrastructure could meet resistance, particularly among low-income communities. A more palatable option may be to implement a tiered rate structure that ties the cost of water and wastewater services to the amount of water actually consumed.

Wastewater utilities do not calculate sewer fees uniformly in all municipalities, but a common method (described by some of the interviewees) is for utilities and municipalities to charge according to the amount of water consumed, assuming that most water will ultimately also move through a wastewater treatment plant. Municipal managers could set a benchmark for minimal water use required per month per average household, then additional benchmarks to reflect average use, above average use, and intensive uses of water. Water consumption by volume at or below the benchmark for minimum average use could be set at a rate consistent with or slightly above current water rates. Households exceeding that benchmark, however, would pay a higher rate for their entire monthly consumption of water. Through a tiered rate structure, most households would likely have to pay rates closer to the true cost of operations, but households for which cost is not a deterrent can maintain current levels of water consumption while other households can adopt conservation strategies to reach preferred cost levels. Rate benchmarks can also be set by individual municipalities so the cost of water and wastewater services also reflects the socioeconomic needs of the community. Active infrastructure committees can take the lead on educating communities on how a tiered rate structure may improve the community, as well as how individual households can conserve water.

Municipal and County: Offer Grants, Loans, and Waivers to Individual Homeowners for Flood Protection and Water Conservation

According to interviewees, attempts to incentivize residents to invest in home improvements through traditional educational means (newspaper articles, fliers, advertisements, etc.) have limited efficacy. Establishing infrastructure committees is one means of bridging the knowledge gap between municipal managers and the public, but they may primarily attract residents already interested in infrastructure. Rather than depending on educational efforts alone, municipalities and county governments may be able to encourage homeowners to invest in home flood protection technology through some combination of grants, loans, or waivers.

Between 2007 and 2011, the estimated cost to property owners from issues with urban flooding is $660 million (CNT, 2013). Offering grant or loan programs to individual residents may significantly lower the cost of flood damage and mitigate criticism of municipal governments, which many interviewees cited as a major challenge to the sewerage system. Some municipal budgets may allow for already available funds to be reallocated for small grants or loans, although other municipalities with less flexible budgets may be able to raise money to cover upfront costs in other ways. If an increased rate structure is adopted, a portion of the additional revenue could be set aside for immediate return investments in upgrading or constructing flood protection technology in high-risk homes. Municipalities could also increase penalty fees for late water and wastewater bill payments to generate some revenue for home investments. Opportunities may also exist for municipalities to form partnerships with companies that construct and install flood protection technology to reduce costs for both residents and municipal governments. Rather than providing grants and loans for select types of flood protection technology, municipalities may also require that grants and loans go to projects that use a specific company's technology, provided that the company offers its services at a reduced rate.

While county governments, such as the MWRD, are usually charged with promoting projects that will have a county or district wide impact, they could nonetheless begin offering loans or grants to particularly low income communities or communities at a high risk for flooding that could then pass the funds along to homeowners for investing in flood protection installation. The MWRD could also engage in fund transfers directly to homeowners. Similar wastewater treatment agencies sometimes offer rebate programs to homeowners who install high efficiency toilets, dishwashers, sinks, and other technology that both consumes large quantities of water and adds large quantities of water to the sewerage infrastructure (e.g., Sonoma County Water Agency, 2014; Metropolitan Water District of Southern California, 2014). The MWRD could implement a similar program that not only offers rebates to homeowners who install water conservation technology, but also to those who install flood protection technology. The MWRD has a much larger budget than individual municipalities, and may have more flexibility within its budget to reallocate some funds each year toward water conservation and flood protection rebate programs. If, however, the MWRD does not have enough flexibility within its budget to offer small grants or loans to municipalities or homeowners, it could attempt to obtain additional revenue by either increasing fees for sewer construction permits or increasing the cost of renting MWRD owned land. Either option could allow the MWRD to provide small rebates to many homeowners each year without directly burdening individuals by raising district-wide taxes.

County and State: Invest in Clean Water Technology and Green Infrastructure with Identifiable Cost Savings

The MWRD is already initiating projects that will save money and generate revenue at its wastewater treatment facilities by shifting toward the understanding of wastewater as a resource itself. The MWRD established a goal to become energy neutral within a decade by purchasing discounted electricity, investing in solar technology, and harnessing heat produced during the wastewater treatment process to provide energy through sewerthermal technology, which uses warm water produced during wastewater treatment processes to generate energy (MWRD, 2013a). The MWRD also plans to install nutrient recovery technology to utilize phosphorus in wastewater effluent to produce and sell as fertilizer (MWRD, 2013b). These projects should act as a model for other sewerage agencies. The MWRD and other agencies can go beyond these efforts, however, by pursuing additional technological innovations that will reduce energy costs and capitalize on the resource potential of wastewater. Further, provided that governments are able and willing to invest in separate infrastructure projects, effluent reuse technology for data centers, manufacturing operations, watering golf courses, and numerous other processes that do not require fully potable water can significantly reduce water consumption and provide managing agencies with an additional source of revenue. The MWRD can help fund upfront investments in clean water technology and green infrastructure in much the same way that it funds new grey infrastructure projects: bond sales, loans from the Clean Water State Revolving Fund (CWSRF), revenue from rented lands, sewer permit fees, investments, and taxes (MWRD, 2013).

Money saved and gained through these process can be used for several purposes, though managers should be careful to invest additional funds in projects that will yield additional benefits for the entire system. Sewerage agencies can use savings to upgrade or replace additional components of the wastewater treatment process, lend to municipalities for completing infrastructure projects, invest in regional green infrastructure, or offer research grants to students at local colleges and universities conducting applied research in the areas of wastewater management and infrastructure.

County and State: Increase Communication between Different Levels of Government to Minimize Policies Requiring Municipal Trade-Offs

Avenues are already available for municipal representatives to comment on proposed county and state policies; however, several interviewees expressed frustration that policies enacted by other agencies did not always align with the mission and goals of municipal government. While municipal governments tend to be responsible for the maintenance and operations of a small portion of the overall sewerage infrastructure network, larger governmental agencies are responsible for the entire system including its effects on the surrounding environment. Thus, municipal governments must often make trade-offs between projects they have identified as important, and projects that other governmental agencies have identified as important for the larger region.

For example, one interviewee described how new policies mandating more inspections of sewerage system might require municipalities to invest less time and money into fresh water infrastructure. When proposing policies and management strategies that will affect municipal operations, county and state agencies should also provide detailed recommendations for how municipalities can realistically achieve the goals of the proposed policy without sacrificing their responsibilities to other aspects of municipal infrastructure maintenance. Deliberate recognition of the constraints many municipalities face when complying with new policies should encourage governing agencies to provide additional assistance to municipalities with a demonstrated need. Cost-benefit analyses should consider not only costs to the agency proposing the policy, but the direct and indirect costs to municipalities that administer the policy.

Federal: Establish Water Infrastructure Finance and Innovations Authority Pilot Programs

Recent proposals for national infrastructure banks generally focus on transportation infrastructure or other construction projects that will yield additional revenue when completed through tolls or usage taxes. Water and sewerage infrastructure, which commonly rely on ratepayer fees, are often not foregrounded or even included in the discussion of infrastructure banks. Recently, however, discussion has progressed on the creation of a Water Infrastructure Finance Innovations Authority (WIFIA), modeled after the Transportation Infrastructure Finance and Innovations Authority, which would act as a national water and wastewater infrastructure bank. Establishing a bank that distinctly focuses on water and wastewater infrastructure may help ensure that different types of infrastructure projects (e.g., water and wastewater, energy, transportation) do not compete with one another for the same funds.

As proposed, the United States Department of Treasury would fund two WIFIA pilot programs up to $50 million annually over at least five years (AWWA, 2014). One pilot program, operated by the Army Corps of Engineers, would help pay for levees, dams, tunnels, and projects that help reduce flood risk. The second pilot program, operated by the federal EPA, would help cover the cost of projects already able to receive funding from the CWSRF and Drinking Water State Revolving Fund. Each WIFIA program offers loans covering up to 49% of the total cost of specifically large projects: those that cost at least $20 million in communities of 25,000 or more, or those that cost at least $5 million in communities with populations less than 25,000. Loans would be paid back over 30 years and accrue interest.

WIFIA programs would complement, rather than replace, the current CWSRF program. Currently, the CWSRF often balances the amount of money it can give to a single project against the amount of money available for other projects in the state. Consequently, many more expensive projects are not covered by the state fund because the CWSRF would have to decrease the number and amount of small loans it can award to other projects. The WIFIA programs may not only give communities access to a financial resource that can help them implement expensive large scale projects with long term solutions, but they may also make lending by the CWSRF more flexible to issue more loans for smaller projects.

Congress should accelerate implementation of both WIFIA pilot programs, although it should also require minimum annual funding of the programs beyond the first five years to ensure WIFIA remains a sustainable program. Congress should also require minimum annual funding of the CWSRF to ensure that the range of wastewater infrastructure projects continue to move forward. While the majority of wastewater infrastructure costs are and will continue to be covered at the state and local level, a larger federal investment will be needed to close the gap between what communities can afford and requisite costs of major infrastructure projects.

Chapter 6: Conclusion

> *People say that if you find water rising up to your ankle, that's the time to do something about it, not when it's around your neck.*
>
> — Chinua Achebe

6.1: Study Outcomes and Implications

The extent of sewerage infrastructure deterioration and the concomitant technical, administrative, social, economic, and environmental challenges are relatively well documented. However, the author did not identify any previous studies attempting to qualitatively assess important disturbances and management strategies identified by professionals responsible for maintenance of municipal sewerage systems. This study attempted to fill that gap in knowledge through interviews with municipal Public Works and Engineering department professionals in Cook County, Illinois using concepts derived from resilience theory. Data were collected through semi-structured interviews in which professionals were asked broad questions related to the background of the sewerage system, primary challenges, primary projects, and administration of the sewerage system. Interviews were then coded and analyzed according to twenty attributes of resilient systems identified in the resilience theory literature.

Interviewees overwhelmingly described a lack of available funding as the biggest challenge to management of municipal sewerage systems, which directly relates to the quality and quantity of technical projects the municipality is able to complete. Municipalities with greater community wealth generally, though not always, expressed greater capacity to complete necessary sewerage system projects—suggesting that wealthier municipalities are better able to meet the technical maintenance demands of sewerage infrastructure—although all communities suggested that economic constraints are likely to downgrade future projects. While not discussed in the identified literature, most interviewees also stressed the challenge of educating residents about how the sewer system operates and incentivizing them to protect their homes from basement backups. These findings suggest that education through information distribution alone is insufficient to change residents' behaviors, and that perhaps residents must become more actively engaged in management of municipal infrastructure to catalyze widespread action. None of the interviewees emphasized the potential effects sewerage infrastructure may have on the natural environment and local waterways, suggesting municipal professionals are either unaware of the problem or unconcerned because environmental protection is not always directly incorporated into mission.

Throughout the interviews, professionals also discussed the ways in which different actors organize around management of municipal sewerage systems through direct and indirect influences. The majority of organization occurred within the municipality, as elected officials, municipal departments, and residents interacted to determine or shift policies. However, municipalities would also work closely with other municipalities, private contractors, and public utilities to help move projects forward. Beyond municipal government, county, state, and federal governments had increasingly less influence over daily activities within municipalities, but they created policies that trickled down and strongly influenced how municipalities are able to prioritize and implement projects.

The qualitative application of key resilience attributes to municipal sewerage systems highlighted not only the degree to which attributes are interconnected, but the specific influences those relationships can and do have in response to specific management strategies. Understanding the relationships between attributes can be useful to policy analysts and managers who are attempting to predict how a specific policy decision might affect other aspects of the system being managed. Emphasizing the relationships between attributes also highlights the importance of understanding that the most resilient systems are not necessarily the systems with the most demonstrated robustness, redundancy, resourcefulness, and rapidity; instead, resilience is an outcome achieved by policymakers and managers able to keep system attributes at optimal levels relative to other attributes.

The findings from this study suggest that federal, state, and county agencies must move toward identifying new and innovative sources of funding that will not only allow municipalities to achieve an appropriate level of sewerage system functionality, but that will also improve all aspects of the system, including technical, administrative, social, economic, and environmental. Administrators at the county, state, and federal levels of government must also coordinate more closely with municipal professionals to ensure that decision-making is consistent with the mission of municipalities, and that new policies do not simply displace municipal burdens by requiring them to neglect other projects in order to comply with regulations. Within municipalities, professionals should identify new ways to engage residents directly in the management process rather than favoring passive forms of education. Recommendations were provided for how policymakers and managers can achieve these goals.

6.2: Suggestions for Future Research

Results from this study can be used to lead the direction on several future theoretical and applied research projects. This study coded broad discussion of municipal sewerages system challenges and projects according to the system attributes in Table 1; however, future researchers may wish to use qualitative methods to better understand resilience by more directly asking interviewees how each attribute is relevant to managing their social system, and whether there are any other relevant attributes not already covered in the matrix. Research that focuses on better understanding individual attributes may expand and clarify the matrix by creating greater distinctions between categories. Finally, several case studies both of systems that demonstrate resilience and systems that entered regime shifts would be useful for also confirming the value of the matrix of system attributes as a tool for measuring system resilience.

There are many opportunities for applied research as well. Being that one of the biggest challenges discussed was residents' lack of awareness about sewer system processes, engagement in municipal government, and preparation for likely disturbances, a qualitative assessment through interviews or surveys about residents' knowledge about sewerage infrastructure, reasons for preparing (or not) preparing for basement floods, and values that contribute to their behaviors.

Similarly, interviewees generally demonstrated very little concern for the environmental consequences of sewerage infrastructure despite contamination that can be caused by CSOs and SSOs. Both a qualitative assessment of municipal professionals' understanding of environmental consequences of sewerage system processes, as well as an in-depth evaluation of conflict that arises between municipal projects intended to maintain infrastructure and county, state, or federal projects intended to preserve water quality may be illustrative for creating greater harmony between different organizational levels.

Upgrades to wastewater and sewerage infrastructure are generally believed to yield nominal economic gains because they depend entirely on ratepayer fees. An economic analysis that examines the amount of money spent on sewerage infrastructure that is not replaced versus sewerage infrastructure that is replaced, with rates of revenue depreciation and economic losses over time, may provide greater clarity as to the costs of not maintaining sewerage infrastructure and the potential economic gains of investments in infrastructure.

Results from this study indicated that community wealth may correlate with a municipality's ability to maintain infrastructure; however, due to the relatively small sample size and emphasis of interview questions, the connection between these variables remains a matter of uncertainty. A qualitative and economically quantitative analysis comparing specific metrics of community wealth (using a broader definition than the one applied in this study) and specific metrics reflecting sewerage system maintenance may provide policymakers and managers with a better understanding of certain communities may be disproportionately unable to maintain their sewerage infrastructure.

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Appendices

Appendix A: List of Abbreviations

ASCE – American Society of Civil Engineers

Committee – Water & Sewerage Infrastructure Committee

CSO – Combined Sewer Overflow

CSS – Combined Sewer System

CWSRF – Clean Water State Revolving Fund

DOC – Department of Commerce

CWA –Clean Water Act of 1972

EPA – Environmental Protection Agency

FEMA – Federal Emergency Management Agency

IEPA – Illinois Environmental Protection Agency

MWRD – Metropolitan Water Reclamation District of Greater Chicago

NPDES – National Pollution Discharge Elimination System

PCB – Polychlorinated Biphenyl

SSO – Sanitary Sewer Overflow

SSS – Separate Sewer System

Stickney – Stickney Water Reclamation Plant

TARP – Tunnel and Reservoir Plan

WIFIA – Water Infrastructure Finance and Innovation Authority

Appendix B: Glossary of Key Terms

Administrative refers to decision-making processes, policies, and practices affecting the management of municipal sewerage systems.

Administrative Rapidity (ARp) reflects the rate at which ideas can move through administrative channels before being implemented as policy or management strategies. ARp allows managers to respond quickly in an official, non-improvisational manner to disturbances. Diminished ARp may increase the severity of disturbances that are allowed to continue for extended periods of time.

Administrative Redundancy (ARd) reflects the extent to which sewerage system administration is decentralized, granting different groups at the federal, state, county, municipality, and individual resident levels authority and flexibility to manage the sewerage system autonomously. ARd can exist within centralized systems, provided there are avenues of upwards communication within the hierarchy. ARd may also be characterized by checks and balances which allow certain groups to influence the management decisions of others. Diminished ARd is characterized by command and control policies, “one size fits all” regulations, and little-to-no ability to influence decisions above one’s place in the administrative hierarchy.

Administrative Resourcefulness (ARs) reflects the ability to improvise, innovate, and modify policy and management strategies. ARs is dependent on the availability of technical, economic, and other necessary resources, a level of autonomy, and the ability to make decisions quickly. Diminished ARs is characterized by administrations that rely heavily on existing procedures regardless of changing circumstances, the inability for groups or individuals to deviate from protocol, and a dependence on premeditated planning.

Administrative Robustness (ARb) reflects the active decision making, planning, policy creation, and execution of management strategies by sewerage system managers and administrators. ARb signifies that managers and administrators are working to improve one or more dimensions of the sewerage system. Diminished ARb is characterized by managers and administrators who are unable or unwilling to actively focus on sewerage system needs.

Challenges refer to factors that diminish sewerage system robustness, redundancy, resourcefulness, or rapidity, and the deleterious resulting consequences. The term “challenges” is used synonymously with the term “disturbances.”

Collaborative refers to communication and project implementation between two groups. Internal collaboration may occur between public and private actors, or within public and private actors. External collaboration may occur between two external actors, or between external and internal actors.

Disturbances refer to factors that diminish sewerage system robustness, redundancy, resourcefulness, or rapidity, and the deleterious resulting consequences. The term “disturbances” is used synonymously with the term “challenges.”

Economic refers to finances, budgeting, or revenue necessary to maintain or improve municipal sewerage systems.

Economic Rapidity (EcRp) reflects the rate at which revenue is either gained or expended in a municipality, or it can reflect the time-frame required for returns on investments. EcRp can be beneficial or detrimental to municipalities depending on whether one is examining economic gains or losses. Challenges to EcRp expedite the loss of financial resources or require an inefficient return on investments.

Economic Redundancy (EcRd) reflects the diversity of revenue sources a municipality can access to help fund sewerage system management. Increased EcRd may allow a municipality to maintain funding if one or more sources of revenue become unavailable. Diminished EcRd is characterized by reliance for all or more funds on a limited number of sources.

Economic Resourcefulness (EcRs) reflects the cost-effectiveness of sewerage system management, and the capacity of municipalities to achieve more goals while expending less money. EcRs allows municipalities to accomplish more, although they may be forced to resort to temporary or supplemental solutions, rather than addressing the root cause of system challenges. Diminished EcRs can either prevent municipalities from finding suitable cost-effective solutions due to the high cost of all alternatives, or result in funds being used inefficiently.

Economic Robustness (EcRb) reflects the amount of financial resources at a municipality's disposal, and the sufficiency of revenue to fund sewerage system management. Diminished EcRb inhibits a municipality from funding many or all sewerage system management projects, and may require a municipality to make trade-offs or entirely neglect necessary projects.

Environmental refers to natural processes that interact with municipal sewerage systems.

Environmental Rapidity (EnRp) reflects the rate at which the natural environment can provide services, recover from disturbances, or diminish due to disturbances. Similar to EcRp, EnRp can be positive or negative depending on whether or is analyzing environmental recovery or diminishment. Challenges to EnRP may result in environmental resources becoming permanently disturbed, or requiring significant time for services to become accessible to municipalities.

Environmental Redundancy (EnRd) reflects the capacity for municipalities to substitute, complement, or supplement environmental services. EnRd may be demonstrated by investments in environmental offsets, or identification of alternative environmental resources to replace resources that may have been disturbed by sewerage systems. Diminished EnRd is characterized by reliance on functionality and services of increasingly fewer environmental resources.

Environmental Resourcefulness (EnRs) reflects the capacity for municipalities to access environmental services to benefit the municipal sewerage system. EnRs may be characterized by the utilization of a river to discharge untreated stormwater from a separate sewer system, or by efforts to increase green space in a municipality to increase natural infiltration of stormwater before it runs off into sewerage infrastructure. Diminished EnRs is characterized by an increasing reliance on engineering solutions to solve sewerage system challenges.

Environmental Robustness (EnRb) reflects the general health and functionality of ecosystems and the natural environment, and is characterized by environmental processes and behaviors that would mimic those that would be observed in regions unaffected by anthropogenic influences. Diminished EnRb may be characterized by contaminated waterways, loss of habitat, or human-induced climatic changes.

External refers to actors, assemblages, interactions, and influence exogenous to individual municipalities, but affecting internal management.

Internal refers to actors, assemblages, interactions, and influence strictly within individual municipalities.

Organization refers to the way in which key actors assemble, interact, and influence one another concerning municipal sewerage system management.

Private refers to individuals, groups, or organizations not responsible for acting on behalf of the public who influence management of municipal sewerage systems (e.g., individual citizens, community groups, or businesses).

Projects refer to strategies and efforts for preventing, mitigating, controlling, or rehabilitating diminished sewerage system robustness, redundancy, resourcefulness or rapidity.

Public refers to individuals, groups, or agencies responsible for acting on behalf of the public when managing municipal sewerage systems (e.g., elected officials and government agencies or departments).

Rapidity refers to the ability to achieve goals at a rate appropriate for minimizing losses and future disruptions.

Redundancy refers to the reliance on multiple supplemental or repeating services to sustain municipal sewerage system functionality, operations, and management in the event that some services become critically disrupted.

Resourcefulness refers to the capacity to identify problems and priorities, mobilize and maximize available resources.

Robustness refers to categorical strength or resistance to disruptions.

Sewage refers to sanitary waste managed by the sewerage system. “Sanitary flow” is occasionally used synonymously with “sewage.”

Sewerage Infrastructure refers to all technical infrastructure used to convey, treat, pump, discharge, and otherwise manage sewage, wastewater, and stormwater. To remain consistent with common phrasing, the phrase “sewerage infrastructure” is sometimes replaced with the phrase “sewer system.”

Sewerage System refers to the technical, administrative, social, economic, and environmental attributes that affect, determine, or comprise system inputs and outputs affecting the management of sewage, wastewater, and stormwater.

Social refers to end-users of services provided by municipal sewerage systems.

Social Rapidity (SRp) reflects the rate required to restore normal community services and resources, such as access to roads, clean beaches, functional wastewater infrastructure, or dry basements. Diminished SRp may be a consequence of diminished SRd, and requires residents to wait for longer periods of time for disturbances to subside.

Social Redundancy (SRd) reflects the availability of services or resources that provide relief to residents after disturbances, either by providing alternatives or assisting residents with remediation. For example, municipalities may provide guide residents on detours after closing flooded roads or assist residents whose basements flooded with clean-up efforts. Diminished SRd cuts residents off from disturbances services or resources until the disturbance subsides.

Social Resourcefulness (SRs) reflects the extent of residents’ knowledge about sewerage system operation, their ability to prepare for disturbances to the sewerage system, and their level of engagement in sewerage system management. Diminished SRs leaves residents confused about how municipalities are managing sewerage systems and uncertain about how they can contribute to mitigating disturbances.

Social Robustness (SRb) reflects the general wellbeing of municipal residents, characterized in part by public health, safety, access to resources, and freedom from disturbances. Diminished SRb may expose residents to untreated wastewater, prevent them from accessing public spaces like roads or beaches, diminish their use of private spaces like basements, or reduce their access to functional sewerage infrastructure.

Stormwater refers to runoff from wet weather events managed by the sewerage system.

Technical refers to municipal sewerage infrastructure or technology requiring specialized knowledge or training to construct, operate, or maintain.

Technical Rapidity (TRp) reflects the rate at which physical sewerage infrastructure, including technology used to supplement or repair sewerage infrastructure, functions. TRp allows municipalities to manage technical aspects of the sewerage system quickly. Diminished TRp may result in sewerage infrastructure that is unable to accommodate the rate of inputs or technical solutions that are too slow to entirely minimize in challenges, potentially leading to wastewater discharges, flooding, or other disturbances.

Technical Redundancy (TRd) reflects the capacity for a sewerage system to substitute, complement, or supplement the service requirements of municipal sewerage infrastructure (i.e., pipes, manholes, etc.). These alternative technologies often focus on enhancing specific aspects of the sewerage infrastructure, such as overall capacity or rate of conveyance. Diminished TRd may result in sewerage infrastructure that is unable to meet increasing demands caused by changes in the system.

Technical Resourcefulness (TRs) reflects the availability of technical equipment and resources within a municipality, and the ability of sewerage system managers to use those resources to solve technical problems. TRs may benefit a municipality by allowing it to complete projects in-house and address challenges quickly and efficiently. Diminished TRs may be characterized by managers with limited technical knowledge, or who are unable to complete projects due to unavailable technical equipment.

Technical Robustness (TRb) reflects the strength, endurance, and level of deterioration of physical sewerage infrastructure. TRb is characterized by infrastructure that is sturdy, functional, and capable of resisting disturbances. Diminished TRb may result in infrastructure that is highly vulnerable to disturbances.

Wastewater refers to any combination of sewage and stormwater managed by the sewerage system.

Appendix C: Semi-Structured Interview Questions and Example Prompts

1. Can you tell me about the technicalities of the sewage system in your city/town?
    a. *How much of the system is combined, and how much is separated?*
    b. *How old is the system?*
    c. *How much of the system is publically owned?*

2. Tell me about how your sewage system is administered?
    a. *How do different departments within the municipality communicate regarding sewage management?*

b. *How do municipal laws affect administration? County laws? State laws? Federal laws?*

3. What are the biggest threats to sewage infrastructure and administration over the next 20-30 years?

    a. *What would be the financial cost of upgrading the sewer system?*
    b. *Does public opinion affect preparation for these threats and challenges?*
    c. *How might these threats affect residents?*
    d. *How might these threats affect the environment?*
    e. *How might these threats affect the economy?*

4. What will it take to make your sewage infrastructure and administration resilient in the face of those threats and challenges?

    a. *Are there deficiencies in collaboration within municipalities?*
    b. *Are there deficiencies in collaboration between municipalities?*
    c. *Is public involvement part of the solution to increasing resilience?*
    d. *Are there plans for mitigating future threats?*

5. What questions do you have for me?

Appendix D: Interview Code Books

Primary Code	Secondary Codes	Tertiary Codes
Challenges	Technical	Robustness
		Redundancy
		Resourcefulness
		Rapidity
	Administrative	Robustness
		Redundancy
		Resourcefulness
		Rapidity
	Social	Robustness
		Redundancy
		Resourcefulness
		Rapidity
	Economic	Robustness
		Redundancy
		Resourcefulness
		Rapidity
	Environmental	Robustness
		Redundancy
		Resourcefulness
		Rapidity

Primary Code	Secondary Codes	Tertiary Codes
Projects	**Technical**	**Robustness**
		Redundancy
		Resourcefulness
		Rapidity
	Administrative	**Robustness**
		Redundancy
		Resourcefulness
		Rapidity
	Social	**Robustness**
		Redundancy
		Resourcefulness
		Rapidity
	Economic	**Robustness**
		Redundancy
		Resourcefulness
		Rapidity
	Environmental	**Robustness**
		Redundancy
		Resourcefulness
		Rapidity

Primary Code	Secondary Codes	Tertiary Codes
Organization	**Internal**	**Public**
		Private
		Collaborative
	External	**Public**
		Private
		Collaborative