Enhancing Performance of Small Water Systems through Shared Management

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Abstract

This paper identifies opportunities to enhance management capacity for small community water systems through cooperative management. Shared management is a non-structural form of regionalization that would not require reluctant water system owners to give up ownership of their systems, thereby eliminating two of the main obstacles to regionalization. This paper provides a background on various aspects of small water systems, performance, and regionalization in North Carolina, before exploring the shared management regionalization alternative. We identify opportunities for cost savings through capturing economies of scale in this unique regionalization alternative by recognizing the tasks and duties of running a water system that would be affected by consolidation of management and operations. Finally, the feasibility of implementing a shared management regionalization effort is explored.

Introduction

Community water systems, defined by the United States Environmental Protection Agency (EPA) as water systems that serve at least 25 residential customers or at least 15 residential service connections year-round, come in various sizes. The vast majority of community water systems in the United States are *small water systems*, defined by EPA as those serving up to 3,300 residential customers. EPA requires all community water systems, regardless of size, to meet or exceed its standards on drinking water quality, testing, monitoring and reporting. Hence, each state is required to monitor every single community water system and to ensure its compliance with the federal and state standards. Because of the small size of their customer bases, small water systems face greater challenges than larger water systems in meeting those standards while operating their systems in a sustainable manner. Small water systems that do not meet the standards require corrective action, imposing additional responsibility on the state in monitoring the many small water systems scattered across the state.

Researchers have studied alternatives that would assist small water systems overcome their challenges. One of the most cited alternatives is to consolidate water systems into larger systems. However, many water system owners have opposed the call for regionalization in order to avoid losing control of their systems.

This paper considers a different form of regionalization: the consolidation of water management and operations, but not ownership, with each system served by large regional teams of highly trained personnel. This form of non-physical consolidation would eliminate the single largest obstacle to regionalization – present owners' loss of control over their systems– while improving the management and operations of the small water systems through the use of shared, semi-centralized teams of full-time professional managers and certified operators collectively responsible for multiple neighboring small water systems. The managers and operators would be based in centers within short proximity to the water systems they manage and operate. This new approach utilizes the advantages of economies of scale through sharing resources to benefit the systems, but the feasibility of the approach as a strategy has not been studied rigorously. This paper attempts to fill this gap.

Literature Review

Challenges Facing Small Water Systems

The overarching challenges facing small water systems have been documented in numerous reports. A National Research Council committee on small water supply systems published a book on the conditions of small systems (1997), and an Environmental Protection Agency Office of Inspector General evaluation (2006) confirmed the findings. Other studies have described similar challenges facing small water systems (Rubin, 2001; Ottem et al, 2003; Raucher et al, 2004; Keuhl et al, 1999; Dziegielewski and Bik, 2004; USEPA, 2002). An inherent problem facing all small water systems is the financial constraint due to the small size of their customer bases. Often, the customers of small systems are located in rural areas and have lower incomes than people living in larger, urban areas who are served by the larger water systems (Rubin, 2001). With low revenues, high unit costs and pressure to keep rates affordable for their customers, small systems are challenged to raise the funds they need for operations, maintenance, and capital improvements. Some small systems can subsidize their capital expenditures by obtaining low-interest loans and grants provided by government agencies, but non-community water systems are ineligible for these funds. Furthermore, small systems often are unable to borrow money from lenders because of the small profits generated by these loans (NRC, 1997). Due to these limited financial resources, small systems confront problems of operator training and retention, leaving the systems to be operated by less-qualified individuals (NRC, 1997; USEPA Office of Inspector General 2006). In fact, many small water systems serving fewer than 500 people are owned and managed by homeowners associations, apartment complex landlords, mobile home park owners, church officials, and other part-time volunteers whose role as the system manager is not their primary occupation (Raucher et al, 2004; NRC, 1997). These individuals are responsible for complying with current and new regulations and for planning for the long-term sustainability of their systems. With a lack of managerial and financial capacity, small systems violate EPA standards at much greater rates than their larger counterparts (NRC, 1997; USEPA Office of Inspector General, 2006).

In the past four decades, federal and state government agencies have largely addressed the problems of small water systems through grants and highly subsidized loans to help fund capital investment. However, non-community water systems and some investor-owned community water systems are ineligible for these funds. With federal and state allocations decreasing over time, and with pressure being put on recipients of these funds to make their debt payments on time, small water system managers and policymakers are beginning to explore alternative options.

In addition to providing capital assistance, government also has attempted to help the problem by providing technical assistance and trainings provided by third parties, providing benefits to the systems that take advantage of these services (USEPA Office of Inspector General, 2006). However, this approach is limited in coverage, as it only helps the individual systems that receive assistance.

An Alternative to Benefit Small Water Systems: Regionalization

Proposed alternatives that could benefit small systems collectively tend to target the economies of scale that are present in the water industry. One study estimates that the unit cost of water produced can be reduced by 15 to 30 percent as systems are doubled in size (Shih, Harrington, Pizer, & Gillingham, 2004). The alternatives proposed that target capturing these potential economies of scale include various forms of regionalization and privatization.

Regionalization of water systems has been studied extensively in the past. The published literature on consolidation of small water systems is exploratory in nature, and generally focuses on describing the forms of consolidation, sometimes referred to as regionalization (Raucher, Harrod, & Hagenstad, 2004; U.S. Environmental Protection Agency, 2002), what factors may lead to the success or inhibit the successful implementation of consolidation efforts (Raucher, Harrod, & Hagenstad, 2004; Jesperson, In the Bluegrass State: Water System Consolidation Works, 2003; Jesperson, Regionalization: Forced, Voluntary, and Somewhere in Between, 2004; Kemp-Rye, 2004), and the potential costs of physical interconnections based on distances between neighboring water systems (Ottem, Jones, & Raucher, 2003; Castillo, Rubin, Keefe, & Raucher, 1997). Analyses of the benefits of consolidation are limited to qualitative descriptions of the potential benefits and the advantages consolidation projects have as an alternative to other solutions to the problems of small water systems, and they do not measure the actual achieved benefits of past consolidation projects.

Beecher and her colleagues produced a comprehensive review of hundreds of reports and articles in the literature (1996). The authors found that the literature on regionalization of water systems could be divided into seven categories: 1) economic analyses focusing on potential efficiency advantages of regionalization, including cost modeling; 2) utility operations, including systems analysis and modeling of regionalization alternatives; 3) natural resource perspectives on how regionalization might affect water quality and quantity, including watershed management analyses; 4) implementation of regionalization, including the practices and policies that have been used to effect change; 5) policies and institutions, including analysis on intergovernmental coordination and analysis of issues involving governmental authority; 6) case studies of regionalization, and 7) general planning and public administration (Beecher, Higbee, Menzel, & Dooley, 1996). Of these categories, this paper contributes most directly to the state-of-knowledge in the utility operations area – particularly in the systems analysis field – while exploring the policies and institutions within which shared management and operations of water systems may be achieved.

Systems Analysis in Analyzing the Potential of Regionalization of Water Systems

Systems models borrowed from operations research have previously been used to study the potential for and the effects of regionalization of water and wastewater utilities. One study reviewed the system models literature on regionalizing wastewater utilities (de Melo & Camara, 1994). The models found by these authors were mainly focused on meeting water quality standards at minimum cost through regionalizing wastewater treatment utilities, while some models attempted to optimize other objectives, including reliability, environmental impacts, and effluent reuse. On water system regionalization, one study utilized Geographic Information Systems analysis techniques to determine the feasibility of physically interconnecting small water systems with medium or large systems nearby, based on distance and the cost-effectiveness of the interconnection (Castillo, Rubin, Keefe, & Raucher, 1997). The authors screened for geographic barriers, used a simple cost-effectiveness criterion, and modeled the restructuring of small systems in 17 states. The authors concluded that physical interconnections with large systems are feasible for about 35 percent of the small community water systems on average across the United States; however, the feasibility was much lower – usually within the range of 10 to 20 percent – for many states. The authors expanded on the model and considered the feasibility of operating the small water systems as satellite systems to large utilities, without physically interconnection. The authors found that nearly all of the small systems are within 60 miles driving distance to a large utility (Castillo, Rubin, Keefe, & Raucher, 1997). A more recent study attempting to update these results found that over half of urban small water systems are located within 5 miles or less of a large system, while fewer than 25 percent of rural small water systems are that close to a large system (Ottem, Jones, & Raucher, 2003). In addition, people living in areas served by rural small systems have lower incomes and higher poverty rates than people living in areas served by urban small systems, making the additional costs of physical interconnections between rural small systems and a large system even more onerous for the customers (Ottem, Jones, & Raucher, 2003). The authors conducted their analysis based solely on point to point distances and did not consider costs or driving distances.

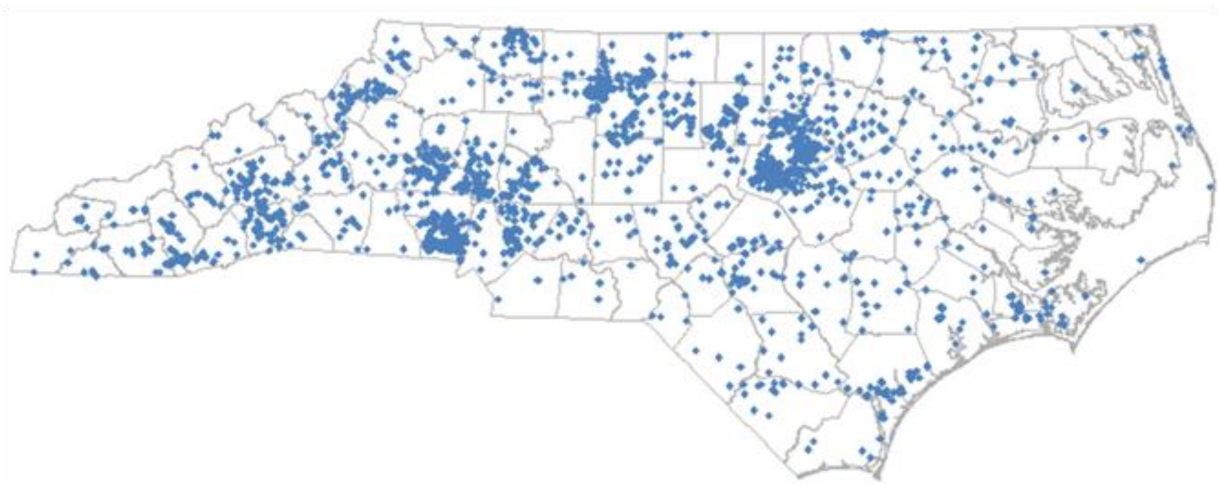
Building on these results, we analyze the potential of management restructuring on small water systems. There are a few forms of management restructuring alternatives, including: 1) transferring ownership of small systems to larger utilities nearby, 2) transferring ownership to a private company that operates several small systems scattered across the state, and 3) setting up management co-operatives that manage several independently owned systems in a locality. This paper will mostly consider the third option. The EPA has advocated for the use of management restructuring as an alternative for small water systems (USEPA, 2006). Although some of these alternatives have been studied (NRC, 1997; Garcia et al, 1999; Cowan et al, 2005; Beecher et al, 1996; Raucher et al, 2004) and encouraged by some states, very few states have adopted policies or provided substantial economic incentives to promote these options (USEPA, 2007).

Current Status and Practices of Small Water Systems in North Carolina

Prevalence of Small Water Systems in North Carolina

The study area features the state of North Carolina. Small water systems are scattered across the state of North Carolina, as shown in Figure 1. They are present in rural counties, such as in the eastern counties of the state, as well as in urban and suburban communities. There is a high concentration of small water systems around some of the largest cities in North Carolina.

Figure 1 Location of Small Community Water Systems in North Carolina in 2008



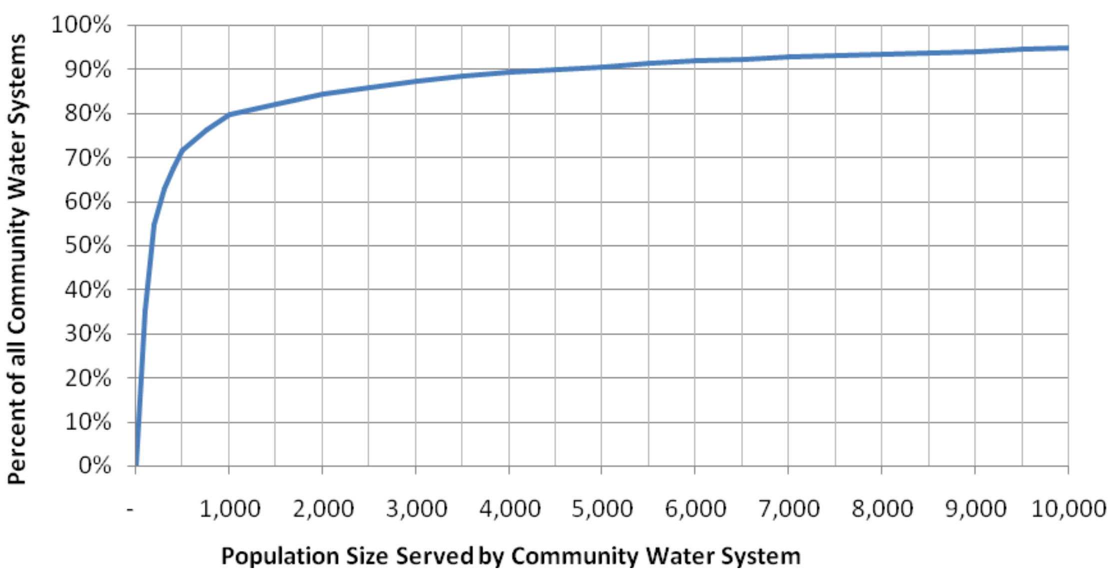
Like many states in the southeastern United States, North Carolina has a large number of small community water systems (see Table 1). The Federal Safe Drinking Water Information System (SDWIS), maintained by EPA, annually publishes a database of all active water systems in the United States. Using the data available on water systems in 2007, the state of North Carolina had 2,157 active community water systems, 1,898 of which were small systems serving fewer than 3,300 individuals each (88 percent) – more small water systems than any state in the nation behind Texas, New York, California, and Washington (USEPA, 2008). Compared to other states in the southeast region, North Carolina, Georgia, and Mississippi have a proliferation of small water systems, whereas Alabama, Kentucky, and Tennessee have relatively fewer small water systems.

Table 1 Community Water Systems in EPA Region IV (Southeast United States) in 2007

	Number of Community Water Systems			Population Served		
State	All CWS	Small CWS	(%)	All CWS	Small CWS	(%)
AL	539	257	48%	5,326,372	390,957	7%
FL	1,825	1,434	79%	18,281,444	784,719	4%
GA	1,731	1,512	87%	7,879,320	600,570	8%
KY	406	164	40%	4,863,941	235,888	5%
MS	1,149	945	82%	3,002,291	1,022,254	34%
NC	2,157	1,898	88%	7,000,138	707,478	10%
SC	627	476	76%	3,539,305	284,013	8%
TN	490	228	47%	5,687,416	266,013	5%

Although small water systems serve only 707,500 North Carolinians, or 10 percent of all community water system-served citizens in the state, they represent 88 percent of the number of community water systems in the state. Not all small water systems serve the same number of customers. It is clear that North Carolina also has an abundance of *very small water systems*, defined as those serving fewer than 500 individuals each. In fact, as shown in Figure 2, half of the community water systems in North Carolina served fewer than 200 individuals each in 2007, and 70 percent of the systems served fewer than 500 individuals. The challenges faced by small water systems are exacerbated by the size of the very small systems, which are more likely to be owned and managed by non-professionals or part-time volunteers.

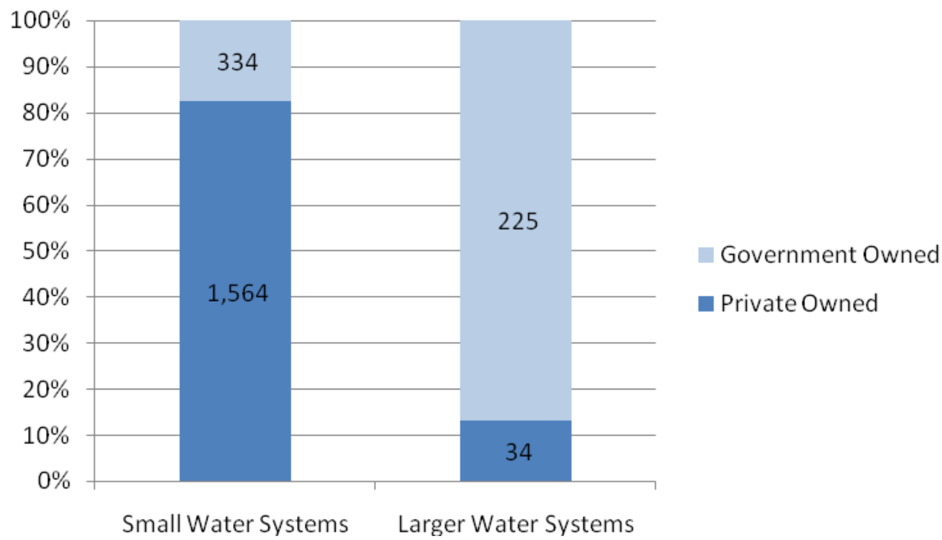
Figure 2 Cumulative Frequency Distribution of Community Water Systems in North Carolina Based on Population Size Served in 2007



Ownership of Small Water Systems in North Carolina

Water systems are generally either owned by local governments or are privately owned in North Carolina (state or federal ownership of systems are very rare in the state). As shown in Figure 3, 82 percent of small water systems were privately owned in 2007, compared to only 13 percent of the larger water systems (USEPA, 2008). Private ownership is even more prevalent among very small systems: 93 percent of all systems serving fewer than 500 individuals were privately owned.

Figure 3 Ownership of Community Water Systems in North Carolina in 2007



There are several forms of private ownership of water systems. In North Carolina, water systems are owned by individuals, non-profit associations, for-profit agencies, or for-profit companies that own or operate several systems statewide. As shown in Figure 1, there is a high density of small water systems around the largest urban and suburban cities. Although these large cities own and operate their own water system, suburban subdivisions, and mobile home parks in these urban communities oftenopt to install a new water system rather than connect to the city's existing system and pay the connection and impact fees that are assessed on all new connections.

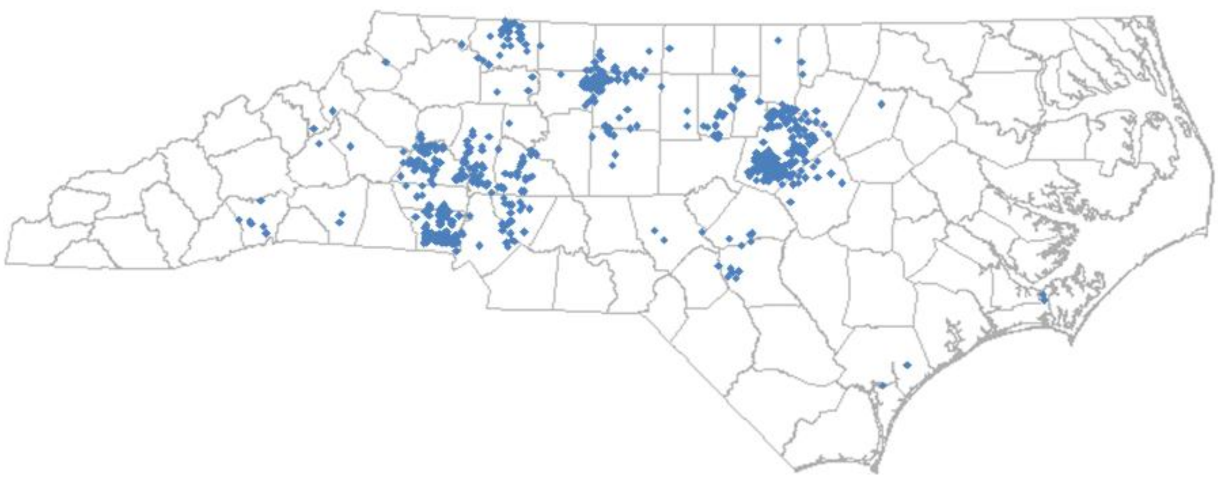
In fact, many of the state's 1,898 small water systems serve individual subdivisions, mobile home parks, or apartment complexes. A keyword search on the names of the systems yielded 365 small water systems with "mobile home park" or "mobile" or "mhp" or "trailer" in the name of the systems, and 616 small systems with "subdivision" or "s/d" (USEPA, 2008). The keyword search resulted in identifying 18 small systems with the word "apartments" in the name of the system, although the names of the other systems suggest that hundreds of other small systems provide service to apartment complexes without the word "apartments" appearing in the name (USEPA, 2008).

About half of the privately owned, small water systems are owned by for-profit companies that own and operate multiple systems across the state. Those companies owning more than five small community water systems statewide are listed in Table 2 (NCDENR, 2008). The eight owners are for-profit companies that own 802 small water systems, 42 percent of all of the small water systems in the state, and 51 percent of all of the privately owned small water systems. Aqua North Carolina is a subsidiary of Aqua America, a large for-profit professional water service provider; Aqua North Carolina owns 666 small water systems across the state, shown in Figure 4. For the most part, Aqua North Carolina has acquired urban and suburban small water systems centered on large cities, with only a handful of rural small systems.

Table 2 Owners of More than Five Small Community Water Systems in North Carolina in 2007

Owner	Number of Small Community Water Systems Owned	Percent of All Small Community Water Systems
Aqua North Carolina Inc	666	35.1%
Carolina Water Service Inc	77	4.1%
CWS Systems Inc	19	1.0%
Corriher Water Service Inc	13	0.7%
Fox Run Water Company Inc	8	0.4%
Scientific Water & Sewage	7	0.4%
Affordable Residential Communities	6	0.3%
Oak Ridge Communities llc	6	0.3%

Figure 4 Locations of 666 Small Community Water Systems Owned by Aqua North Carolina in 2008



The 49 percent of privately owned small water systems that are not owned by one of the eight owners listed in Table 2 are primarily owned and managed by single-system owners whose primary duties are not water service provision. Almost all of these 762 systems are managed by homeowner association groups, apartment complexes, and the individuals who own the mobile home parks that the water system serves. These owners are often part time volunteers with little or no experience or education in water provision, and they are responsible for the adequate management, operations, maintenance, and finance of the water systems upon which their customers rely for public health.

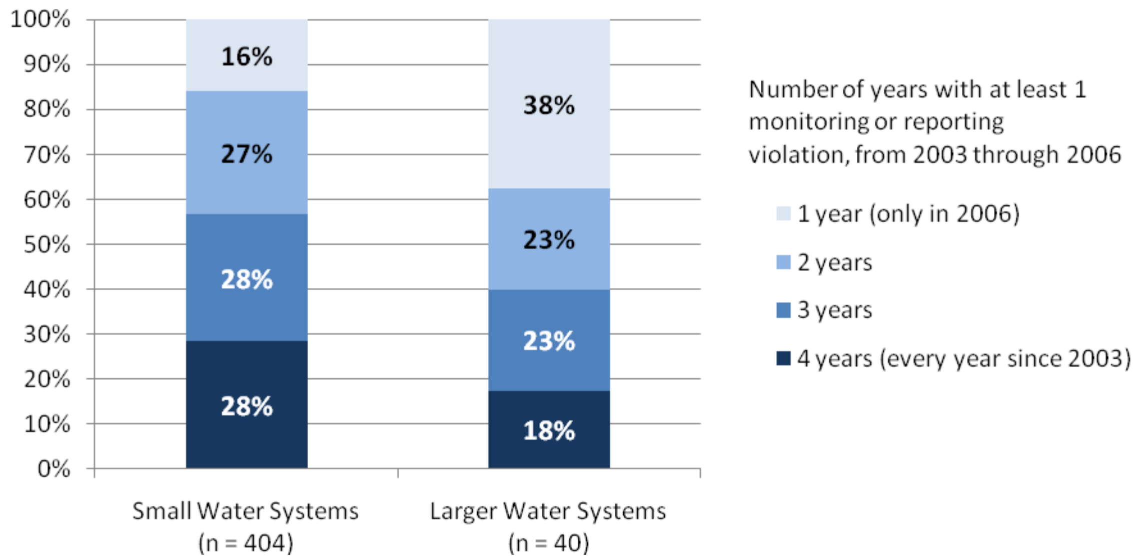
Performance of Small Water Systems in North Carolina

Since every community water system must abide by the standards and regulations set by the Environmental Protection Agency and the North Carolina Department of Environment and Natural Resources (DENR), there is a lot of duplication of efforts in testing, monitoring, and reporting among the 2,157 community water systems in the state, 88 percent of which are small water systems. Furthermore, much time and effort is spent by DENR in monitoring and regulating the small systems.

Due to the challenges described previously, and the lack of full time professional ownership and management of the systems, small systems have historically been faced with greater technical, managerial, and financial difficulties than the larger systems. A review of a sub-sample of 321 local government-owned and not-for-profit community water systems found that small community water systems in North Carolina are more frequently located in smaller, older, more rural towns and contain populations with lower income and higher poverty rates than larger water systems (Environmental Finance Center, 2006). The ratio of operating revenues to operating expenses (including depreciation) is on average lower for small water systems in the sub-sample, indicating that the small systems were not recovering their operating expenses through their water rates as successfully as the larger water systems. Sixty five percent of small water systems in the sample did not even recover their full operating expenses through their revenues, operating in the “red” in 2005, compared to only 21 percent of larger systems (Environmental Finance Center, 2006). Without sufficient revenue to cover operating expenses, North Carolina’s small water systems are not able to invest in new infrastructure.

Data on violations of EPA standards and regulations, which the EPA requires each state to collect, confirm that small water systems face greater managerial and technical deficiencies than larger systems. Eighty four percent of all small water systems in the state were in violation of at least one EPA regulation between the fourth quarter of 2006 and the third quarter of 2007, compared to only 71 percent of the larger water systems (USEPA, 2007 January). In the same time period, while small systems numbered 88 percent of all community water systems in the state, they accounted for 90 percent of all systems that were in violation of any of the standards during the year, 95 percent of all systems that were in violation of treatment technologies (possibly indicating technical or financial difficulties), and 91 percent of all systems that were in violation of monitoring or reporting requirements (possibly indicating managerial deficiencies) (USEPA, 2007 January). Beyond the cross-sectional level of analysis, yearly data on violations suggest that small water systems are more likely than larger water systems to violate standards repeatedly, year after year. See Figure 7 for historic data from 2003 through 2006 on monitoring or reporting violations of community water systems that were active in all four years and violated standards in 2006. Of all the small water systems that violated monitoring and reporting standards in 2006, 28 percent had violated the standards in each of the four years in the study period, compared to only 18 percent of the larger water systems (NCDENR, 2007). Conversely, 38 percent of the larger water systems that had monitoring and reporting violations in 2006 had a clean record for each of the three prior years, compared to only 16 percent of the small water systems (NCDENR, 2007). These results indicate that the historic prevalence, as well as the cross-sectional incidence, of violations is greater for small water systems than for the larger systems.

Figure 7 Four Year History of Repeating Monitoring or Reporting Violations Among Community Water Systems that were Active from 2003 through 2006, and have Violated Standards in 2006



These statistics hint at the greater need for management and technical capacity building among small water systems in North Carolina. Customers of these systems may also benefit from a change in the status quo, possibly reducing their health risks if a new initiative is implemented that would ultimately provide better managerial and technical capacity to their system.

The Tasks and Responsibilities of Running a Water System

One of the greatest dangers in the profession of a water manager is to assume that management responsibility stops at providing customers with a sufficient supply of water. Water systems require experienced management in a multitude of areas, and managers are expected to be experts in a variety of fields – or at least to effectively oversee other employees who are.

Beyond the operational goal of providing a sufficient supply of water, water systems must meet regulatory requirements. Thus they require constant testing, monitoring, and reporting. Water system infrastructure decays over time and requires constant maintenance and planning. If the demand for water approaches the maximum supply of the system, a system expansion will require engineering design and construction. Sometimes municipal ordinances, or other local, state, or federal laws, may affect the planning or operations of a water system, requiring the water system managers to seek legal advice. Financing the water system is of great importance, with water system managers expected not only to recover all operating expenses through revenues, but also to be able to fund capital investments into the system over time. Since water provision falls in the realm of public health and public service, it is also important to provide customers with a high level of customer service. Similarly, water system managers must provide human resources support to the employees of the system. Further, since the field of water service is constantly changing with new regulations and new research, continuing education of the water system managers and operators is necessary.

The dynamism of managing a water system creates an exciting but very challenging position. The challenges are even more exacerbated for managers of small water systems, many of whom are part-time employees or are not trained to be water professionals. Ignoring or short changing any of the responsibilities noted above can produce drastic consequences and ultimately endanger public health.

The tasks and responsibilities of running a water system can be summarized in the following 10 categories, some of which may overlap: operations; construction and equipment; monitoring and reporting; customer service; finance; planning and engineering; human resources; continuing education; legal; and leadership and planning. Differences between small and large water systems are noted in the descriptions below. This list was generated after discussions with water system managers, and feedback was solicited.

Operations

Every water system is required, sometimes by law, to have a designated Operator-in-Charge (ORC) who is ultimately responsible for ensuring the operations of the treatment facility, distribution network, and/or cross connection controls. For systems that discharge treated wastewater into receiving streams, an ORC is also required to assume responsibility for the discharge in order to obtain approval of the National Pollutant Discharge Elimination System (NPDES) permit. ORCs are required to be trained and licensed to operate the equipment, with different grades of licenses required based on the complexity and type of equipment used. For large systems, ORC positions may be filled by different individuals who report to the manager of the system, and they may supervise other operators. Within small systems, oftentimes the ORC is responsible for the entire operation of the system. Sometimes the ORC of a small system is a hired professional who reports to the owner-manager of the system, while other times the ORC assumes the other responsibilities of the water system manager. Some very small systems may even contract out and share an ORC together, although in the North Carolina ORCs may only serve five or fewer water systems.

Daily duties of operators of treatment plants include administering chemicals, testing and monitoring water quality, interpreting the results of the tests, and acting accordingly to make necessary changes. This requires the operator to be present at the treatment site at least once a day, unless the system uses remote sensoring and monitoring equipment that can be used in an off-site location.

For very small water systems, ORCs may also be responsible for the maintenance of the distribution system, repairing water lines, replacing water meters, and replacing and rehabilitating sections of the distribution section. Other small systems might split the responsibilities of operating the treatment facilities and maintaining the equipment and distribution network between two ORCs. Finally, a crew should be appointed for distribution system flushing and valve maintenance, as well as a line location crew to protect the distribution network from damage.

Administration, Leadership and Planning

The water system managers have specific administrative duties, as well as grander objectives to accomplish, including:

- Review and interpret analytical reports, such as testing trends, work orders (complaints), pumping records and sales records (to determine unaccounted for water and monitor the efficiency of the system),
- Coordinate and encourage communication between the different ORCs, operators, maintenance and line crews and all other personnel. Communicate with all departments, including the regulators, the media, neighboring systems, and the governing board if applicable.
- Develop policies and procedures, including but not limited to day to day operations. Such policies and procedures include Developer Guides, Asset Management, Inventory Control, and so forth. Small water system managers should also be developing these policies,
- Make recommendations for future expansions requirements based on demand, development trends, population changes, and anticipated or existing changes in Public Water Supply guidelines,
- Resource planning for future needs,
- Coordination with neighboring systems for emergency interconnections when necessary,
- and provide environmental stewardship.

Construction & Equipment

All water systems need to purchase chemicals (for disinfection, coagulation, and/or fluoridation where appropriate). The amount of chemicals purchased will depend heavily on the demand for water within the community. Large systems are able to purchase chemicals in bulk amounts at a reduced price, an advantage that small water systems would not be able to use without consolidation and cooperation.

Construction and equipment required by water systems typically include treatment facilities, pumping stations, pipes, storage tanks (elevated or ground storage), water meters, drilling equipment for wells and road work, and ample repair supplies for the materials used in the system, such as PVC piping or ductile iron. Water system field personnel require tools for leak detection, drilling and construction. Small water systems may share or even rent some of these resources.

Monitoring & Reporting

All systems are required by law to routinely sample, test and report the drinking water quality. Systems also conduct preventive and diagnostic monitoring. Some systems have a testing laboratory in-house. Others, including small water systems, typically contract out with third-party labs for all of their testing, but are still required to conduct their own monitoring and sampling. All systems must produce an Annual Water Quality Report that is available to the public and delivered to all of their customers.

Customer Service

If a system charges its customers directly for their water usage, they are likely to be reading meters periodically, through manual reads, drive-by radios or using fixed networks, as well as billing and collections. Small systems without the capacity to carry out these tasks sometimes contract out to private third-party companies, while many small water systems – especially the private, very small ones – do not charge their customers for their usage, but may include the water bill as part of the "rent".

Additionally, systems must man the phone lines to answer customer service calls, and to provide public relations and public education. Small systems typically do not carry out many public relations tasks except when needed.

Finance

This is a vital task of running a water system proficiently. Without adequate funds and through poor fiscal policies, managers may "run a system into the ground" through constant deliberate or unintentional neglect.

Finance tasks include the following:

- Purchasing
- Accounting
- Investing (when appropriate)
- Taxes
- Asset Management
- Cost analysis and rates setting

- Financial reporting and budgeting
- Applying for, obtaining and managing external funding
- Capital reserve building to fund future capital needs
- Inventory control

All water systems, regardless of size, should be carrying out these tasks, or should hire an accountant with decision making powers to ensure the sustainability of the system.

Human Resources

Regardless of system size, if the water system owner-manager hires at least one additional employee (including an ORC), they are responsible for providing adequate human resources services. Poor services may lead to difficulty in retaining well trained staff, especially for small systems.

In addition to entrance/exit orientation, human resources duties include developing an Employee Handbook and guidance documents, recommending changes in benefit packages and methods for maintaining those, implementing and reviewing employee evaluation procedures and payroll-related recommendations for budget purposes, and providing means for Safety Training and providing safety supplies and equipment.

Legal

For systems in communities with growth and development, managers or their legal staff must initiate easements and user agreements, and coordinate with developers for conveyance documents. They must also keep accurate records of these documents. Small, private systems that serve apartment complexes or mobile home parks are not likely to face these issues, but must still be aware of local ordinances that affect the operation of their system, including new laws and new regulations that are upcoming.

Planning & Engineering (for Growing Systems)

For systems that have a growing service population, new construction, upgrades or rehabilitation usually requires planning and engineering services. Few systems employ their own engineers and produce the plans in-house – most contract out these duties. The engineers must provide typical drawings using construction standards that are used be all firms and developers, and the engineering plans must be approved by the State. Small systems that are growing must also find the funds to pay for expensive infrastructure capital projects.

Continuing Education

All ORCs and operators are required to take continuing education classes to maintain (or obtain) their licenses. Unless required for professional licenses, water system managers-owners are not required to attend trainings, but are invited and encouraged to attend. Typically, owner-managers of very small water systems often do not attend trainings due to lack of knowledge and sometimes due to lack of funds to pay the registration fees.

Regionalization of Small Water Systems through Shared Management

As explained above, water systems managers are responsible for many different aspects of managing, operating, and investing in their systems; they must carry out these duties themselves or must supervise others carrying out these duties. However, unlike water operators, who are required by state law to be professionally trained and licensed in operating the different water system technologies, water system managers and owners are not required to be licensed or trained in accounting, business, law, operations management, water system operation, or any other field that might be useful in their duties. Some of the large water systems require training and education of the management team, often using the licensing and professional education requirements of other professional associations as models – for instance, managers of a large water system may be required to maintain a Professional Engineering license. Large systems also are more likely to split the management duties among different individuals in an organizational hierarchy.

Small water systems, on the other hand, are more likely to centralize management of the system, with one or two individuals bearing the burden of managing all aspects of the water system. As explained previously, small water systems are often owned by homeowners associations, apartment complexes, mobile home park owners, and other individuals whose primary occupation is not the water system management. With a lack of professional training at the owner/manager level, lack of time and desire to be educated in water system management, a lack of support in the form of trained and certified individuals, and an institutional environment that does not require training and certification of water system managers or owners, managers of small, privately owned water systems may lack the skills and training to do their jobs well.

One of the proposed solutions to many of the small water system challenges is to consolidate and regionalize small systems. Regionalization of water systems provides the potential for capturing economies of scale by eliminating duplicative efforts across systems, purchasing materials in bulk at lower unit prices, sharing equipment and resources among regionalized systems, and reducing the monitoring and reporting requirements if the systems are consolidated into one system. Further, by consolidating staff, regionalization provides a greater avenue for hiring, training, and retaining full-time, professional staff responsible for managing and operating the systems by offering greater wages and benefits packages. By pooling together the customer bases of the water systems, regionalization also makes it possible to spread the costs of operating the systems among a greater number of customers and, due to lowering costs through capturing economies of scale, lower the rates that customers pay for water services.

Current Forms of Regionalization in North Carolina

Regionalization of water systems in North Carolina has taken on several forms, from bulk water sales between systems to the use of multi-jurisdictional authority ownership. A report to the governor of North Carolina by the State Water Infrastructure Commission (SWIC) in 2007 noted that regional cooperation between systems on billing and operations and maintenance support are "common," and that selling and purchasing bulk water between systems are also common practices (SWIC, 2007). Purchasing water necessitates a physical interconnection between water systems and eliminates the purchasing system's need for a water treatment plant. In 2007, 348 out of the state's 2,157 community water systems – 16 percent – were purchase systems (USEPA, 2008). In both cases – the purchase of bulk water and cooperation between systems on billing or other operations – ownership and management of the water systems remain in local control and unconsolidated.

A form of ownership regionalization also occurs in North Carolina, although is primarily utilized by new water systems being created as opposed to a consolidation of ownership of existing systems. While the majority of government owned water systems are municipally owned and managed, nearly 30 percent are owned by multi-jurisdictional authorities such as County Water and Sewer Districts, Water and Sewer Authorities, Sanitary Districts, Metropolitan Water Districts, and Metropolitan Sewer Districts (SWIC, 2007). Few of these "regional" systems are small water systems. Additionally, about half of the privately owned small water systems are owned by the for-profit companies that own and operate multiple systems across the state (listed in Table 2). The remaining privately owned systems, however, remain independently owned and managed.

Barriers for Regionalization in North Carolina

The 2007 SWIC report to the governor acknowledged that, despite state initiated financial incentives for regionalization in the form of higher priority ranking for various infrastructure grants and loans, "there are drinking water and wastewater systems in the State that are not ready to take part in a regional effort" (SWIC, 2007). Distance to neighboring systems and rough terrain makes physical interconnections very expensive and difficult to achieve for many small water systems. Quoting from the Ottem, Jones, and Raucher report (2003), the SWIC report noted that half of the urban small water systems are within five miles of a larger system, whereas only 25 percent of rural small systems are. In fact, half of the rural small systems are at least 10 miles from the nearest larger system. Further, rural small systems are found to be serving communities with lower income and higher poverty than the urban water systems, and are thus less likely to be able to fund interconnections.

Beyond these barriers to regionalization, the SWIC report also attributes the following reasons for the general reluctance to regionalize among water systems (SWIC, 2007):

1. A lack of start-up funds to pay for the expensive physical interconnections and other administrative costs;
2. Higher costs for rural small water systems that are further away from neighboring systems, and requiring greater funds to physically interconnect these systems, despite financial constraints based on the their small, rural customer base;

3. Regulatory and legal barriers that do not encourage the use of regionalization, such as the use of riparian laws for water rights which protect communities' allocations to water despite unsustainable growth rates; and importantly,
4. Unwillingness of system owners to relinquish control over and autonomy of their water systems.

With water system owners unwilling to give up control of their systems, with the high cost of physically interconnecting systems, and with difficulties in raising the required funds for these costs, new forms of regionalization should be considered.

New Model for Regionalization: Shared Management of Small Water Systems

For the purpose of this research, we study a non-structural form of regionalization of small water systems. In this model, small systems do not necessarily have to be physically interconnected, and the small water system owners do not relinquish ownership of their systems, eliminating both of those major barriers to regionalization.

In a new "shared management" model, neighboring small water systems, independently owned, are grouped together and managed and operated by a regional team of trained, licensed, full-time professional managers and operators. Each regional team of managers and operators would be based from one center, and would manage and operate a collection of small water systems, driving out to their systems for necessary tasks and conducting the rest of their duties from their home base. The water system owners would maintain ownership and ultimate responsibility for their systems, but all decision making duties, including rate setting, would be conducted by the trained regional team of managers. Each regional team would run their group of systems *collectively*, sharing resources, finances, and personnel, saving costs through economies of scale through purchasing and through hiring full time staff. The model is essentially a regional centralization of the management and operations of clusters of small water systems.

Potential Benefits of Shared Management

Consolidating the management and operations functions of various small water systems may lead to overall cost savings. For example, by sharing equipment and purchasing materials in bulk, the regional management team would lower the per-system cost of operations. In addition, a regionalized management and operations team would be incentivized to improve the technology of small systems in order to minimize their time and labor costs. For example, in order to cut down on travel time to visit each system to monitor operational performance, the regional team may invest in remote monitoring technologies. Improving technology may improve the operational efficiency (and therefore financial condition) of the small water systems. By pooling together the customers of all of the small water systems that are managed by the centralized team, the regional managers could spread out the costs and create a financial plan for the collection of systems that would gradually raise rates and avoid significant and sudden rate shocks for customers of each water system. Finally, the pooled financial resources of the regionalized systems would improve the credit ratings of those systems and would place the shared management team in a better position to apply for and receive funding for capital improvements than any one of the small water systems could have accomplished independently.

By combining management and operations of multiple small water systems, the following duplicative tasks and duties may be eliminated, or may be improved upon:

- Staffing across systems may be reduced: one professional, full-time manager could manage multiple systems, in place of multiple part-time managers managing one system at a time. ORCs, operators, maintenance and line crews may be shared among systems, as long as they are certified to operate the technology of all of the water systems.
- Chemicals may be bought in bulk at lower per unit costs
- Developing policies, standards and guides would be streamlined: one set across all systems
- Resource planning for the future: regional managers may make regional decisions about the allocation of their water resources to benefit the customers of the entire region, instead of one specific system's customers
- Communicating with the media, governing boards, regulators and other stakeholders would become more efficient across the multiple systems
- Construction equipment would be shared, and the increased buying power of the regional management team might be allow it to purchase expensive equipment – such as backhoes – instead of renting one, thereby reducing long term operating costs for the systems
- The regional management team could invest in creating an in-house lab for the group of small water systems, also reducing long term costs of contracting out externally,
- Meter reading, billing and collections could be consolidated under one team, removing duplicative efforts
- Financing of multiple systems would be consolidated, reducing the amount of time needed for bookkeeping and reporting, and also provides greater purchase power for the regionalized systems, a better credit rating and lower interest rates
- All personnel would be trained, including the managers, due to the availability of funds, and the greater likelihood of the regional managers for holding professional licenses.

In addition to the expected cost savings that could be brought about by sharing management, it is also anticipated that replacing the current independent managers of small systems, particularly the untrained part time or volunteer managers, with teams of highly trained, professional managers would improve the technical performance of the small systems. In fact, there is statistical, empirical evidence that shared management of small systems is associated with lower incidence of violation of EPA standards. Data on violations of drinking water standards show that 15 percent of all community water systems in North Carolina had at least one violation in 2005 (USEPA, 2007 January). Comparing the small water systems with shared management – those owned by the three largest for-profit companies (Aqua North Carolina, Carolina Water Services, and CWS Systems) – to the small systems that are mostly independently owned reveals that 18 percent of the independently owned systems violated EPA standards, compared to only 11 percent of those with shared management.

We used a probit model to test the effect of shared management on violating at least one EPA standard in 2005, while controlling for source of water, system size and ownership type (privately owned or government owned); the proxy for shared management in this model was ownership by one of the three largest companies. The results of the model are shown in Table 3. Shared management was strongly negatively associated with violating EPA drinking water standards in 2005, statistically significant at the 1 percent level. The model yielded similar results when limited to only small community water systems. These results support the hypothesis that institutional arrangement may be an important factor in the performance of water systems.

Table 3 Probit Model Estimating the Effects of Shared Management on Violating EPA Drinking Water Standards in 2005 among North Carolina's Community Water Systems

Variable	Coefficient
Shared Management (owned and managed by a statewide, multi-system company)	-0.2571***
	(0.0797)
Privately Owned (vs. Government Owned)	0.0051
	(0.0941)
Service Population (in 1,000)	-0.0004
	(0.0013)
Surface Water Source (vs. Groundwater)	0.2124
	(0.1550)
Purchase Water System (vs. Treatment System)	0.0952
	(0.2129)
Surface * Purchase	0.0574
	(0.2701)
Constant	-1.0174***
	(0.0864)

*Notes: n = 2,168. Standard errors in parentheses. *** significant at the 1% level.*

761 of the community water systems in the sample were owned and managed by one of the three statewide companies.

Limits to Shared Management

If regionalization can lead to cost savings through economies of scale, what is there to stop adding more and more small water systems to a single team of shared managers and operators? If each time a small system is added to the regional team the overall per-system cost of operations unconditionally lowers, wouldn't total costs be minimized by grouping *all* small water systems and using only one team of managers and operators working out of one center, located presumably in the middle of the state?

This extreme is unrealistic and also infeasible. Although adding a small system to a group would theoretically lower the average per-system costs by eliminating duplicated efforts and sharing resources, at the same time it would add additional costs to the center, providing a trade-off of costs.

As small systems are assigned to a center, the center's capacity for handling all of its systems will be reached, and an additional manager and/or operator must be hired to share in the added workload on the existing staff. Therefore, as more small systems are clustered within one group, the center increases size and requires additional salaries and materials, offsetting – at a lower rate – some of the cost savings achieved by adding the water systems to the group. More importantly, as small water systems are added to the group, and the coverage of the center's shared managers and operators expands outwards geographically, average distance and travel time between the center and its small systems increases. This creates diseconomies of scale to operating costs that counter the cost savings from economies of scale of adding small water systems to the group. We will explore this effect in an optimization model, along with the general feasibility of implementing a shared management regionalization intervention, in the next chapter.

Feasibility of Implementing Shared Management Regionalization of Small Water Systems in North Carolina

Distance between Small Water Systems

In order for the shared management intervention to be successful, there must be a relatively high density of small water systems in areas where a regional team is to be based. If water systems are scattered and distant from each other, centralized operators would have to travel long distances each day to conduct their onsite activities. Ottem, Jones, and Raucher used GIS analysis to identify that the median distance between North Carolina's very small water systems and their nearest medium or large system is 6.8 miles, whereas the median distance between the small water systems and their nearest larger system is 10.6 miles – both are greater than the national average (2003).

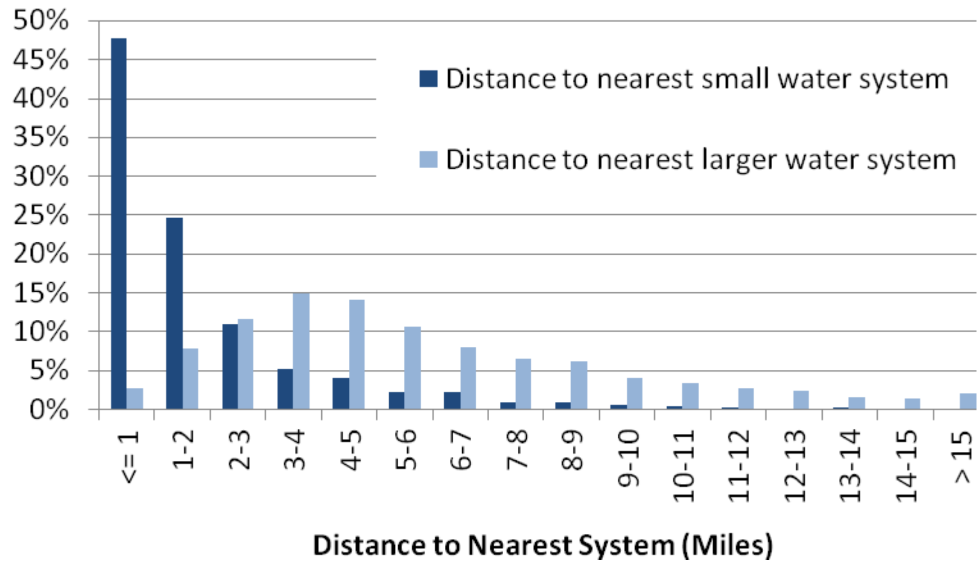
The shared management approach explored in this paper would group small water systems with each other, not pairing them with larger systems. Since there are more than 1,800 small water systems in North Carolina, inter-system distance should be much smaller between small water systems.

To calculate these distances, we mapped out every single active community water system, small and large, in North Carolina. Using publically a available GIS polygon shapefile of slightly more than 500 water system service areas,[1] we created a centroid point for each water system (NCCGIA, 2008). We supplemented these 500 points by using the centroid of all of the water source intake points of water systems not already included (NCCGIA, 2008). Finally, for the approximately 300 active community water systems that still did not have an identifiable location, we used online searches to find their physical location or street mailing address, located the building using Google Earth, and manually created a point for the location. In the end, we had a shapefile with one point for all 2,146 active community water systems in North Carolina. Out of the 2,146 water systems, 1,880 are small water systems: the number of systems declined from 1,898 to 1,880 recently. A map of all 1,880 active small community water systems in the state is shown in Figure 1.

Using the location data, we calculated the distance between each small water system with its nearest neighboring small water system, as well as its nearest larger water system neighbor. The distribution of shortest distances for all 1,880 small water systems is shown in Figure 8. On average, there is a very high density of small water systems in the state. The median distance to the nearest small water system is 1.1 miles, and 72 percent are within two miles' distance of another small water system. Only 8 percent of small water systems are further than 5 miles from the nearest small water system. Our results show slightly smaller distances between small water systems and their nearest larger system neighbor than the results shown by Ottem, Jones, and Raucher: the median distance we calculated was 4.9 miles.

[1] Created by the North Carolina Rural Economic Development Center and posted online by the North Carolina Center for Geographic Information and Analysis.

Figure 8 Distribution of Distance between Each of 1,880 Small Community Water Systems in North Carolina and their Nearest Small or Large Community Water System



As shown in Figure 8, small water systems are much closer to other small systems than to larger systems. Ottem, Jones, and Raucher had explored the model of non-structural regionalization by allowing larger, municipal systems to operate small systems as satellite systems (2003). The approach we explore in this paper is different, in that the center of operations would not necessarily be based out of a larger municipal system (many of whom are reluctant to take on the responsibility of running small systems that may be financially unsustainable and create additional cost burdens on their current customers). Our approach groups small water systems together and does not require participation of larger systems, which are farther away than other neighboring small systems are. The potential for using shared management is high because of the close proximity of small systems to each other. With the majority of small systems within two miles of each other, a center that is based anywhere near one small system could be a very convenient base of operations for many, if not all, of its water systems.

Number and Location of the Shared Management Centers

As explained previously, there are tradeoffs between increasing the extent of regionalization and keeping driving distances between centers and their assigned water systems manageable. How many regional management teams are needed to cover the 1,880 water systems? Where should they be located, and which small systems are to be assigned to them in order to minimize total center-system distances?

For this analysis, we utilize optimization models of facility location from the field of operations research. We tradeoff minimizing the number of centers required within a study area, and minimizing the total distances between centers and its assigned water systems. A combination of two linear optimization models, a set covering model and a p median model, are used, alternating between minimizing the number of centers and minimizing the total center-system distances. The same combination of models was used by a doctoral student at the University of North Carolina, Chapel Hill in a different application (Kim, 2007). Details about the methodology, including the linear optimization specifications, are included in Appendix A.

First, a study area was selected to test the methods and optimization models. The State of North Carolina is split along contiguous county lines into 17 multi-county planning and development regions called Regional Councils. A Council of Government assists local governments within its Regional Council on various matters of planning, conveniently providing an avenue that the State might utilize in implementing a statewide effort to regionalize small water systems through sharing management. The five counties comprising the Upper Coastal Plain Council of Governments (see Figure 9) were selected as the study area. The five counties are: Northampton, Halifax, Nash, Edgecombe and Wilson. As shown in Figure 9, this region includes rural as well as urban counties, and is home to 55 small community water systems, shown in Figure 10.

Figure 9 The Study Area: Upper Coastal Plain Council of Governments Region

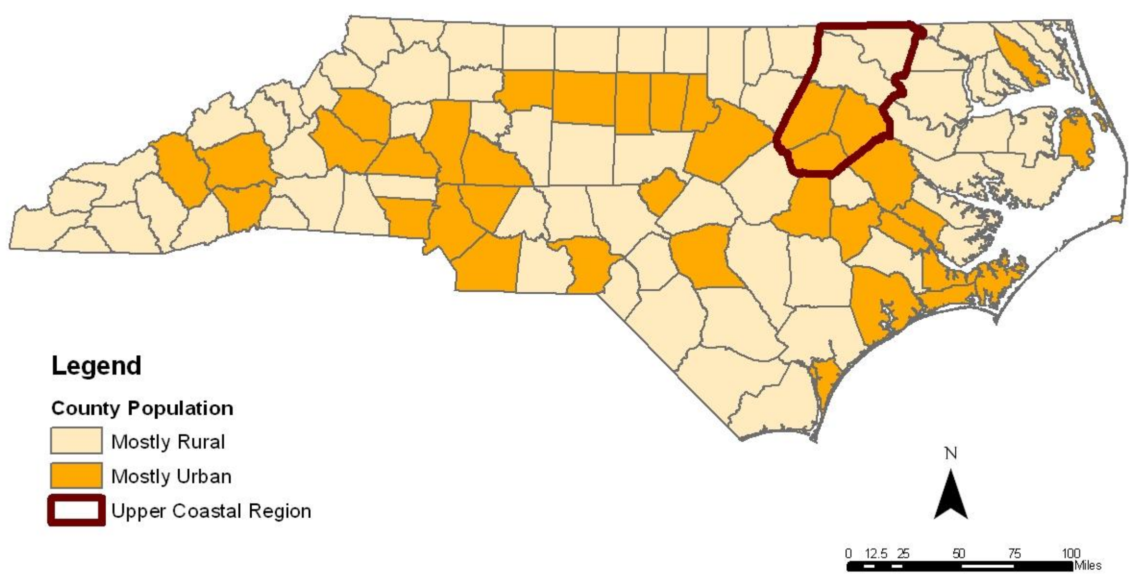
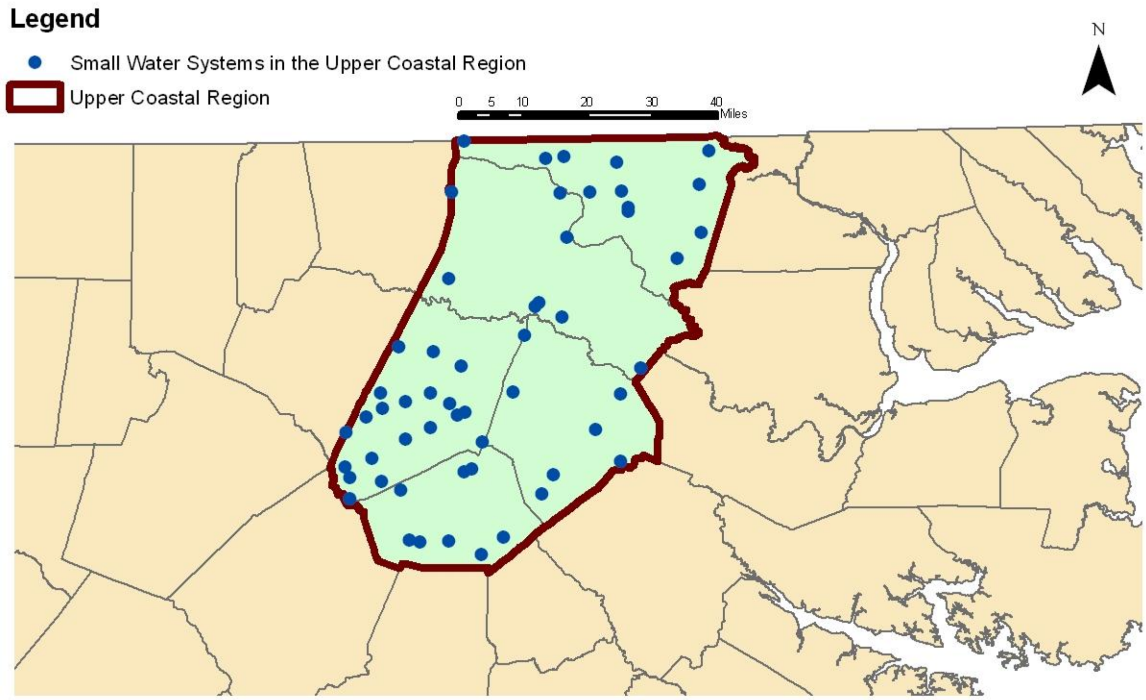


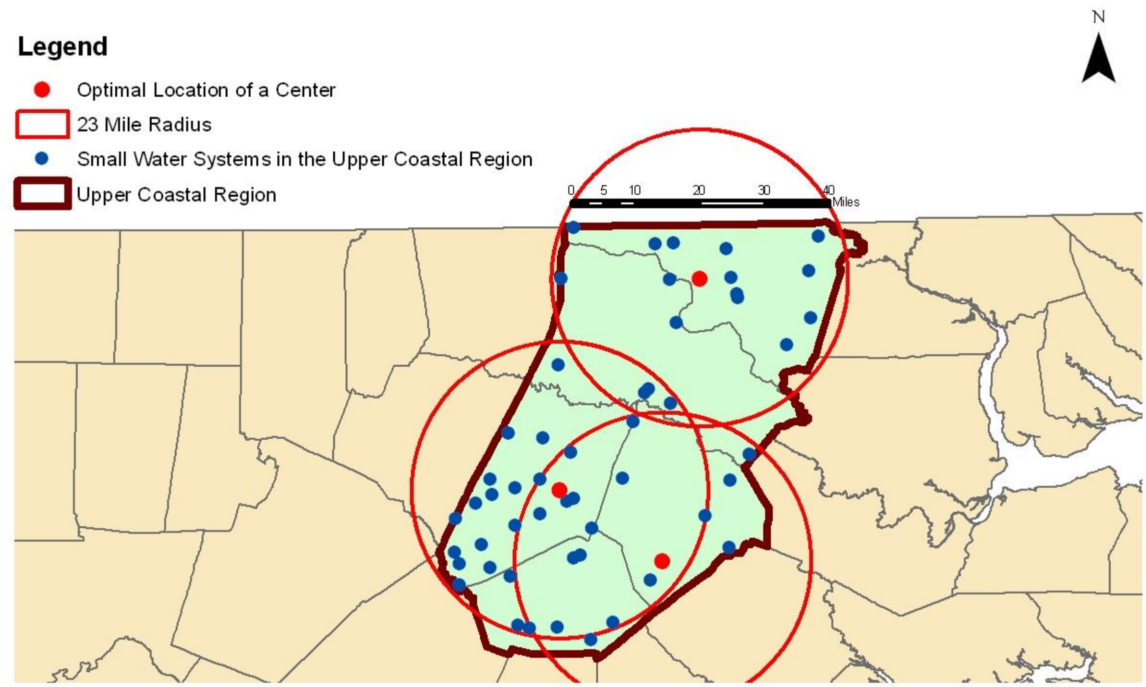
Figure 10 Small Community Water Systems in the Upper Coastal Region



As shown in Figure 10, the small water systems are scattered across the region, with pockets of higher density areas especially in the urban counties, and also areas with few or no water systems. The number and distribution of small water systems in this region provide a good case for testing the spatial effects of system location on the optimization solutions.

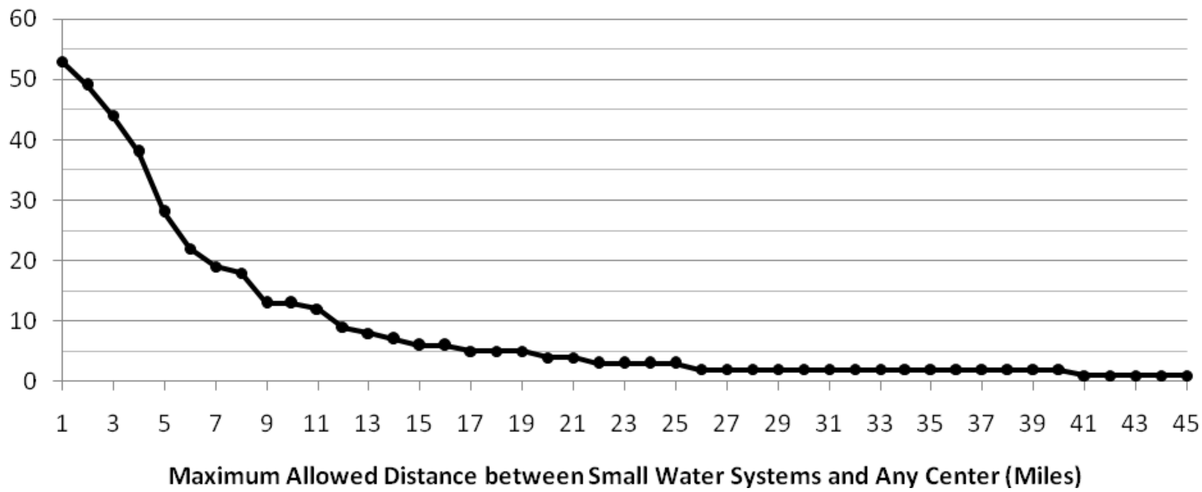
The first optimization model used is a set covering model that minimizes the total number of centers within the region, subject to requiring that each water system be within a fixed maximum distance radius of one of the assigned centers. The model works by locating a center exactly where one small water system is currently located, and uses the inputted maximum distance constraint to test the distance of each water system to its nearest center. If a system is too far from all centers, the centers are either relocated, or more centers are added, until the constraints are met. For example, if centers are not allowed to be more than 23 miles from any small water system in the 5 county area, the optimal (minimal) number of centers required to meet the constraints is three, located as shown in Figure 11. As shown, every single small water system is within a 23-mile radius of at least one center.

Figure 11 Example of the Optimal Solution of the Set Covering Model: Minimizing the Number of Centers in the Region While Ensuring that Every Water System is No More than 23 Miles Away from at Least One Center



By adjusting the maximum allowable distance, the optimal number of centers required in the region changes (see Figure 12). Unsurprisingly, if the maximum distance is as small as 1 mile, nearly every small water system would need its own center. By allowing systems to be slightly further from centers, the minimum number of centers required within the region very quickly drops. If systems can be 5 miles away from centers, the region would need 28 centers appropriately located. If systems can be 10 miles away from centers, the region can do with just 13 centers. Four centers appropriately located would cover all of the systems with a maximum one-way distance of 20 miles.

Figure 12 Minimum Number of Centers Required in the Region While Ensuring that Every Small Water System is Within the Maximum Allowed Distance between Systems and Centers

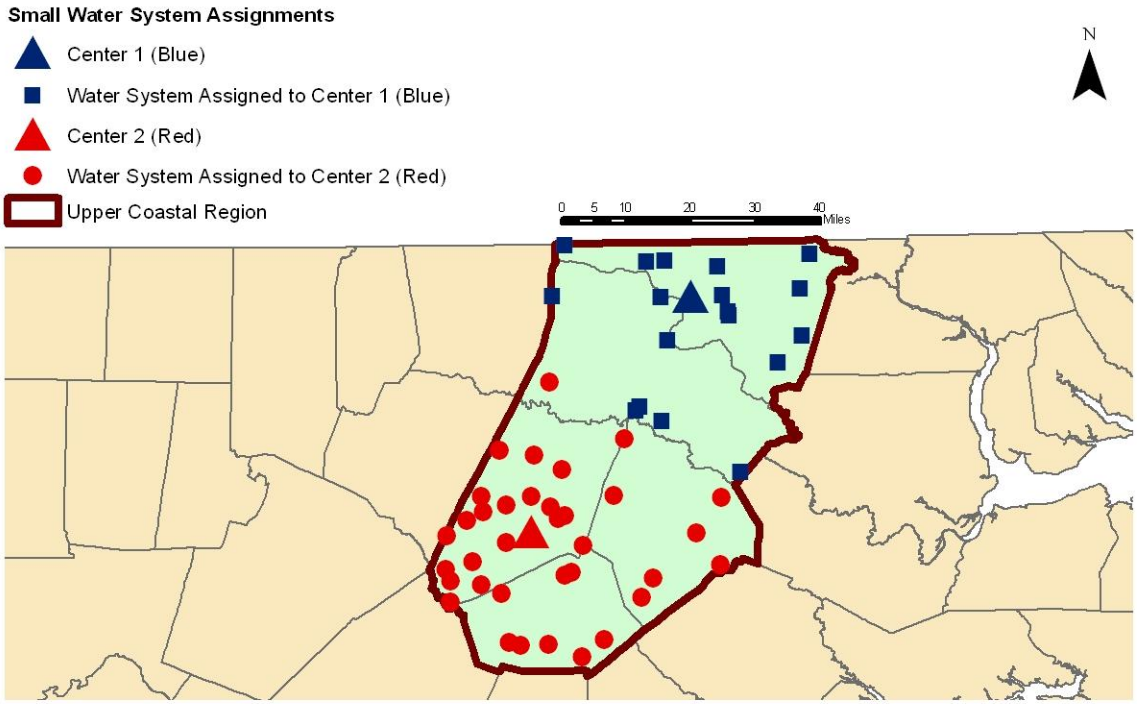


One of the problems with set covering models is that there may be several optimal locations for centers, and the model does not attempt to locate the centers closer to more densely populated areas. Thus, the model will correctly identify the minimum number of centers required to cover the maximum distance constraint, but may locate centers at inconvenient, far away locations, requiring the operators to travel great distances each day to reach a cluster of small water systems. Ideally, the model would select a location for the center that is dense with small water systems in order to minimize total travel distances.

The second optimization model, the p median model, provides such a calculation. The p median model locates the centers directly over small systems and assigns the remaining small systems to one, and only one, center. The model then calculates and minimizes the total distance between the center and all of its assigned systems, subject to a fixed number of centers in the region, and requiring that each system is assigned to only one center. The model, therefore, will naturally locate centers in the areas with the greatest concentration of small water systems, conveniently minimizing total driving distances for the operators. However, there is no maximum distance constraint in this model, and far away, isolated systems will be assigned to its nearest center, but the center may be dozens of miles away.

Figure 13 shows the optimal location of the centers and optimal center-system assignments for the case of locating only two centers in the region. The centers are located in the areas marked with triangles, and the water systems are assigned to the appropriate center based on the color. In this optimal solution, 19 water systems are assigned to center 1 (blue), and 36 water systems are assigned to center 2 (red). As shown on the map, center 2 is located in the middle of an area heavily populated with water systems. Likewise, center 1 is located in the one small cluster of systems in the northern counties. It is not surprising that neither center is located in or near the areas that are mostly void of water systems altogether. However, there are one or two small systems that are about 30 miles away from their assigned centers.

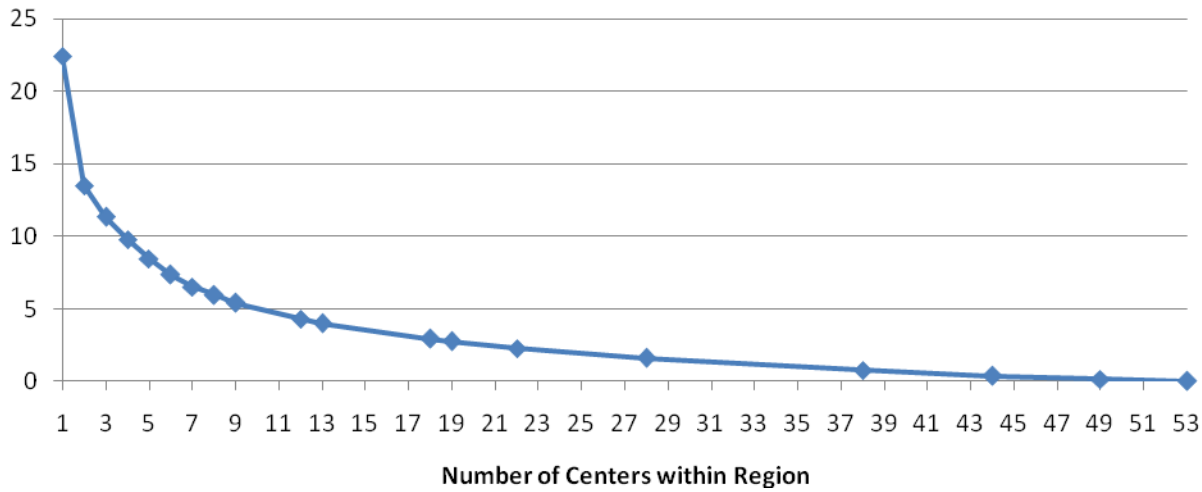
Figure 13 Example of the Optimal Solution of the p Median Model: Minimizing Total Distances between Two Centers and their Assigned Small Water Systems



The number of centers to be located in the region is adjusted, following the optimal solutions obtained from the set covering model, since it is clear that, for example 13 centers would cover all of the systems that 17 centers might. By using the results of the set covering model, we eliminated non-optimal scenarios from the p median model calculations.

By adjusting the number of centers to be located in the region, the total (or average) center-system distance dramatically declines, as shown in Figure 14. If only one center can be located in the Upper Coastal Plain Council of Government, its optimal location will only reduce average distances to the systems to 22.5 miles. By location a second center in the region, the locations are shifted so that the average center-system distance drops to 13.5 miles, a 40 percent reduction in average center-system distances! As more and more centers are added, average distances decline with diminishing returns. Hence, nearly doubling the number of centers from 28 to 49 will only decrease average distances from 1.6 miles to 0.14 miles, hardly worth the cost of setting up 21 new centers!

Figure 14 Average One-Way Distance between Centers and the Small Water Systems Assigned to Them (Miles)



Feasibility Assessment Conclusions and Future Work

If applied to different regions in the State, or to the whole State, the optimization models could be used to produce region-specific graphs similar to Figures 12 and 14. These graphs could be used to inform decision makers about the tradeoff between distance and the number of centers it would require to share management of small water systems in regions of the State.

The first lesson from this feasibility assessment is that small water systems are in very close proximity to each other, providing great opportunities for systems to share management and operations teams. Next, if restrictions are to be imposed on distances that shared management and operations teams can travel to their systems, graphs like the one in Figure 12 should be used to inform policymakers of the consequences of setting too restrictive a distance requirement. If small water systems in the Upper Coastal Plain Council of Government are allowed to be 10 miles from their nearest center, at least 13 centers would be required. At the other end of the spectrum, these graphs may provide information about apparent minimum thresholds on the number of centers to be located in the region. Figure 12 shows that the minimum number of centers reaches a threshold of about 5 and does not decline significantly unless center-system distances are greatly increased. By knowing that this region requires at least 5 centers, one can repeat this analysis for all other regions in the State and determine a "threshold" number of centers for the entire State.

Another key lesson from this feasibility assessment is that increasing the number of centers can realize significant benefits in terms of reduced distance and travel costs, but that these benefits also follow a function of diminishing returns. For example, using Figure 14 suggests that it may be beneficial for the number of centers in the Upper Coastal Plain Council of Government to be increased from one to two, but probably should not be increased much above 5 or 6 centers.

These models can be applied to any region or any State in the United States. Ideally, cost models would be incorporated with the optimization models to minimize total start-up and operations costs of creating and running centers of shared management. These models would minimize total costs instead of minimizing the number of centers or the total distance, which are proxies for cost. Finally, these models assume that all small water systems would partake in the shared management initiative. If the State does not require that all small water systems need to regionalize their management and operations, and some systems are either opted in or forced to participate, while others are not, the number of centers and their optimal locations and water system assignments are likely to change. While the models may be modified to account for some of these changes, the method of assessing the feasibility of initiating a shared management regionalization program remains the same.

References

Aqua North Carolina (2006). *Annual Water Quality Reports*. Retrieved November 20, 2006, from Aqua North Carolina: http://www.aquanorthcarolina.com

Beecher, J., J. Higbee, A. Menzel, and R. Dooley (1996). "The Regionalization of Water Utilities: Perspectives, Literature Review and Annotated Bibliography." National Regulatory Research Institute Report 96-21. The National Regulatory Research Institute; Columbus, OH.

Castillo, E., S. Keefe, R. Raucher, and S. Rubin (1997). "Feasibility of Small System Restructuring to Facilitate SDWA Compliance." Project #185. Prepared for the American Water Works Association Research Foundation; Denver, CO.

Cowan C., A. Mescher, J. Miller, K. Pettway, and B. Pink (2005). "A Framework for Evaluating Water System Ownership and Management Alternatives." A Group Project report for the University of California; Santa Barbara, CA.

de Melo, J. J., and A. S. Camara (1994). "Models for the Optimization of Regional Wastewater Treatment Systems." *European Journal of Operational Research*, 73 (1), 1-16.

Dziegielewski, B., R. Beck, and T. Bik (2000). "Benchmarking Investigation of Small Public Water Systems Economics." Project Completion report for the Midwest Technology Assistance Center. Southern Illinois University; Carbondale, IL.

Dziegielewski, B., and T. Bik (2004). "Technical Assistance Needs and Research Priorities for Small Community Water Systems." Universities Council on Water Resources *Journal of Contemporary Water Research & Education*. June 2004, 128: 13-20.

Environmental Finance Center at the University of North Carolina (2006). Database of primary and secondary data on water utilities system characteristics, rates, rate structures, finances, and Census data in North Carolina. Chapel Hill, NC. Analysis performed by the author.

Garcia, K.,T. Younos, and C. Thompson (1999). "Restructuring Strategies for Small Water Systems: Virginia Small Water Systems Co-operative." Special Report SR15-1999. Virginia Water Resources Research Center; Blacksburg, VA.

Keuhl, D., J. Randolph, and T. Younos (1999). "The Virginia Small Water Systems Survey: An Assessment of Public Health Performance Appraisals." Special Report SR16-1999. Virginia Water Resources Research Center; Blacksburg, VA.

Lohr, S. (1999). *Sampling: Design and Analysis*. Brooks/Cole Publishing Company, Pacific Grove, CA.

Manning, P., A. Barefield, and J. Mays (undated-a). "Consolidation Efforts: Pros, Cons, Options and Perceptions." Report by the Community Resource Development, Mississippi State University Extension Service; Mississippi State, MS.

Manning, P., A. Barefield, and J. Mays (undated-b). "Mississippi Water Association: Financial Indicators Study." Report by the Community Resource Development, Mississippi State University Extension Service; Mississippi State, MS.

National Research Council (1997). *Safe Water From Every Tap: Improving Water Service to Small Communities*. Committee on Small Water Supply Systems. National Academy Press; Washington, DC.

NC Center for Geographic Information and Analysis (2008). Free Statewide Shapefiles. Accessed from http://www.nconemap.com/default.aspx?tabid=286 on March 2, 2008.

NC Department of Environment and Natural Resources. (2007). Record of Water System Standards Violations from the State Drinking Water Information System State Version (SDWIS). Provided to authors upon request in September 2007. Raleigh, NC.

NC Department of Environment and Natural Resources. (2008). State Drinking Water Information System State Version (SDWIS). Provided to authors upon request in July 2008. Raleigh, NC.

NC State Water Infrastructure Commission (2007). "Regional Infrastructure Collaborations and Partnerships" Annual Report and Recommendations to the Governor and Members of the General Assembly of North Carolina. November 1, 2007.

Ottem, T., R. Jones, and R. Raucher (2003). "Consolidation Potential for Small Water Systems: Differences between Urban and Rural Systems." White Paper for the National Rural Water Association; Duncan, OK.

Paxson, M. (1995). "Increasing Survey Response Rates: Practical Instructions from the Total-Design Method." *Cornell Hotel and Restaurant Administration Quarterly*. August 1995, 66-73.

Raucher, R., M. Harrod, and M. Hagenstad (2004). "Consolidation of Small Water Systems: What are the Pros and Cons?" White Paper for the National Rural Water Association; Duncan, OK.

Rubin, S. (2001). "Economic Characteristics of Small Systems." White Paper for the National Rural Water Association; Duncan, OK.

Shih, J., W. Harrington, W. Pizer, and K. Gillingham (2004). "Economies of Scale and Technical Efficiency in Community Water Systems." Discussion Paper 04–15. Resources for the Future; Washington, DC.

US Environmental Protection Agency (2002). "System Partnership Solutions to Improve Public Health Protection." Report No. EPA-816-R-02-022, September 2002. Washington, DC.

US Environmental Protection Agency Office of Inspector General (2006). "Much Effort and Resources Needed to Help Small Drinking Water Systems Overcome Challenges." Evaluation Report No. 2006-P-00026, May 30 2006. Washington, DC.

US Environmental Protection Agency. (2007, January). State Drinking Water Information System Federal Version (SDWIS/FED). Washington, DC.

US Environmental Protection Agency. (2007). "Restructuring and Consolidation of Small Drinking Water Systems: A Compendium of State Authorities, Statutes, and Regulations." EPA 816-B-07-001, Office of Water (4606M), Washington, DC.

US Environmental Protection Agency. (2008). State Drinking Water Information System Federal Version (SDWIS/FED). Washington, DC.

APPENDIX A

Methods and Optimization Models Used in "Enhancing Performance of Small Water Systems through Shared Management"

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Management and Operations Model

Small water systems (SWS) are scattered across the state. In this paper, we are studying an initiative where groups of neighboring small water systems are to be managed and operated by regional management and operations teams. Managers and operators will be headquartered in centers of operations (henceforth "centers"), running and managing a group of small water systems that are assigned to their center. Each small water system is to be assigned to one, and only one, center. Operators would be required to drive from the center to the location of the small water systems that are managed by their center.

We developed a methodology to determine the number and location of centers required, and the assignment of small water systems to each center, under various conditions.

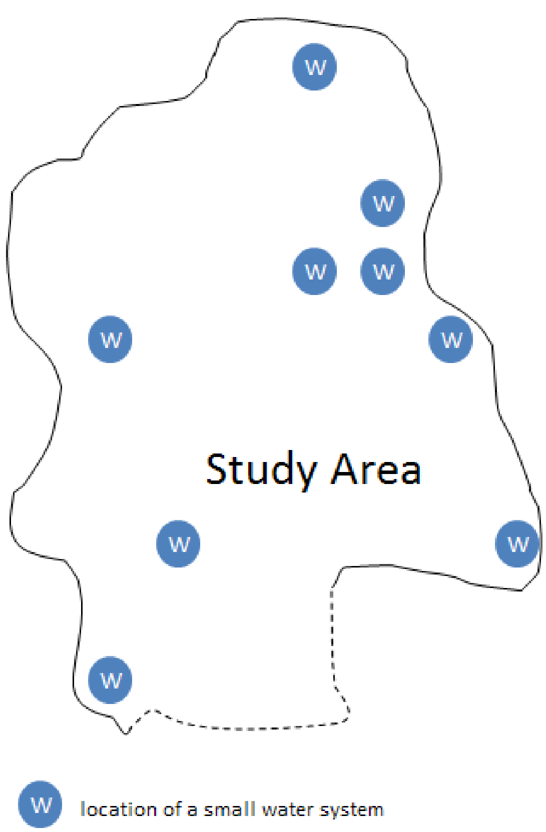
We selected a specific study area to develop our methodology and conduct our analysis.

Step 1: Identifying the Location of Small Water Systems in the Study Area

The Division of Water Quality (DWQ) at the North Carolina Department of Environment and Natural Resources (NCDENR) maintains geospatial data on the location of water intakes for the State of North Carolina, and has provided me with their data. Since almost all small water systems that withdraw raw water are groundwater systems, their intake points identify the location of water wells. In many cases, a water system may have more than one well, and all wells are included in this dataset. We used ArcGIS to calculate the centroid of each water system by determining the "center point" between all the water intake points that belong to one system. This produced a single location for each water system that is included in the DWQ dataset. Since much of the operations-related work includes duties performed at the site of the water well, the location of the water well (or the centroid of all water wells) is a good determinant of the location of the system to which an operator must drive to starting from their center.

Purchase water systems are excluded from the DWQ water intake points dataset since they do not withdraw raw water. Locations for these systems within the study area will be obtained using other data sources with locational data. One of these sources may include another dataset from NCDENR called the Safe Drinking Water Infrastructure System (SDWIS), which contains some locational data of facilities and infrastructure of water systems. Where GPS-verified data are absent for entire water systems, we will approximate the location using Google Earth, street addresses and other known service area locations. Each small water system will be allocated one location point within the study area, as shown in a hypothetical example in Figure 1.

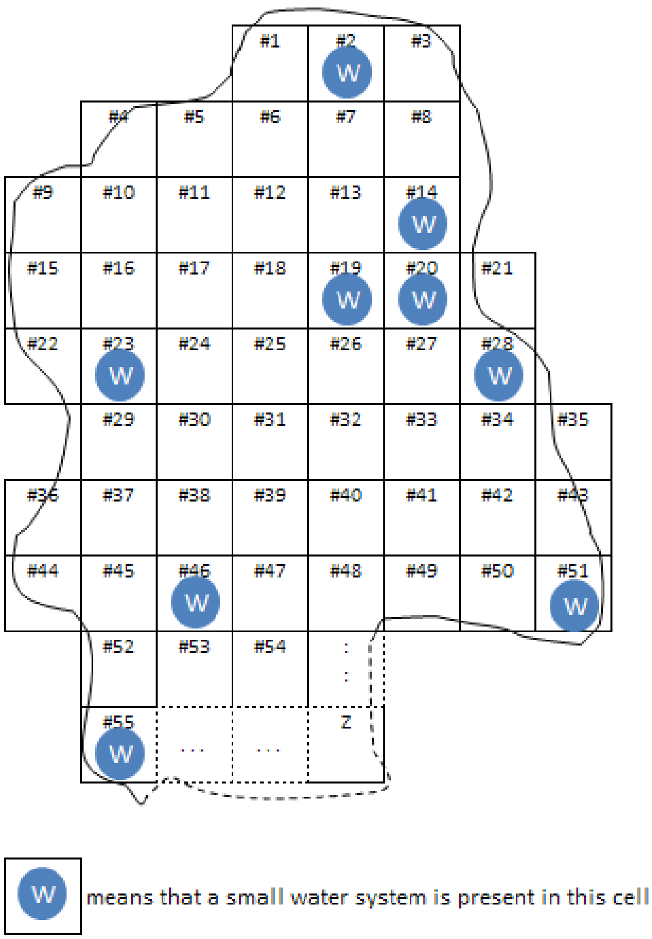
Fig. 1 Example of the Location of Small Water Systems within the Study Area



Step 2: Study Area Delineation

The study area will then be divided into a grid of Z uniquely-numbered cells. The grid's resolution will be as large as possible, but sufficiently small in order to locate only one small water system in any given cell. This is illustrated in Figure 2, continuing on the example from above.

Fig. 2 Study Area Delineation



Each cell will be given a value x_i, where

$$x_i = \begin{cases} 1, & if\ a\ SWS\ is\ located\ in\ cell\ i \\ 0, & otherwise \end{cases} \qquad [1]$$

The total number of small water systems within the study area, N, which is known, is

$$N = \sum_{i=1}^{Z} x_i \qquad [2]$$

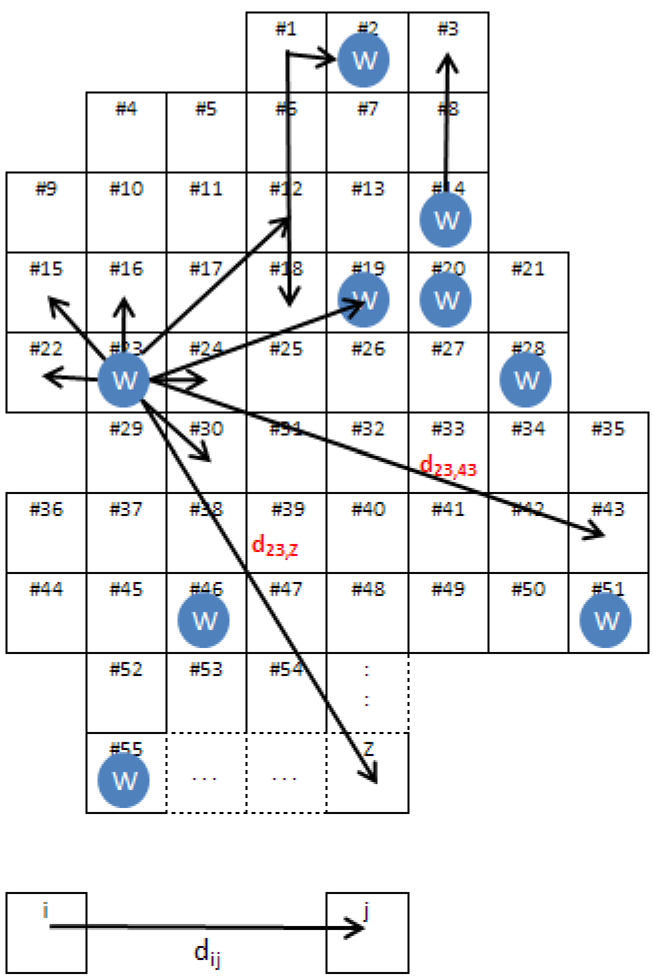
We will identify the array of the system-occupied cells as **W**, and $x_w = 1$ for
In this example, **W** = {2, 14, 19, 20, 23, 28, 46, 51, 55}.

Step 3: Calculating Distances between Cells

The one-way driving distance between all cells in the study area will be calculated using ArcGIS. Driving distances will be estimated between the centers of the cells, using established models in calculating approximate driving distances between two location points on a GIS map. The driving distance within one's own cell will be assumed to be half the distance between the edge and the center of the cell.

The driving distance from cell i to cell j will be designated as d_{ij}, where i = {1,2,...,Z} and j = {1,2,...,Z}. We will determine the distances in a symmetrical Z x Z matrix. One-way driving distance between a water system and any other cell in the study area is designated as d_{wj}, where , j = {1,2,...,Z}.

Fig. 3 Calculating Distances between Cells in the Study Area



Step 4: Locating Centers and Identifying Small Water System-Center Assignments

The 0-1 integer programming models described below will attempt to locate C centers in some of the cells in the study area grid, such that:

$$y_j = \begin{cases} 1, & \text{if a Center is to be located in cell } j \\ 0, & \text{otherwise} \end{cases} \quad \forall\, j \qquad [3]$$

where

$$C = \sum_{j=1}^{z} y_j \qquad [4]$$

Therefore, each cell in the study area has two binary values: x_i indicating whether or not a water system is present in the cell (given), and y_j indicating whether or not a center is to be located in the cell (decision variable). A similar methodology was developed for determining the optimal location of vaccination centers in rural China (Kim, 2007), but must be modified to fit the context of this research study.

Set Covering Model

We will select, as an input, a maximum distance, d, between centers and small water systems. The set covering model determines the minimum number of C centers required, C^*, and their locations, to ensure that all of the small water systems are within the specified maximum distance from at least one center. The maximum distance will be selected based on requirements of emergency response times or other best practices regarding how quickly an operator must be able to reach his/her system. The set covering model will then be run for a range of feasible distances.

The set covering model is formulated as:

$$\underset{y_j}{\text{Minimize}}\; C = \sum_{j=1}^{z} y_j \qquad [5]$$

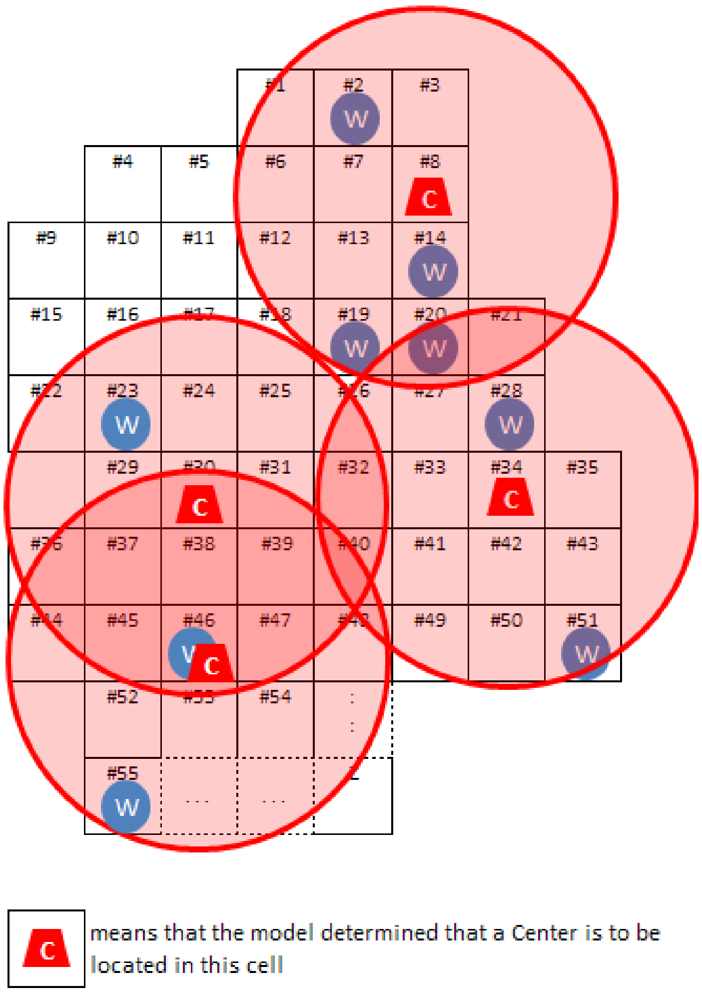
$$\textit{subject to} \sum_{j=1}^{z} G_{wj}\, y_j \geq 1, \quad \forall\, w \in \boldsymbol{W} \qquad [6]$$

$$\textit{where} \quad G_{wj} = \begin{cases} 1, & \textit{if } d_{wj} \leq d \\ 0, & \textit{if } d_{wj} > d \end{cases} \quad \forall\, w \in \boldsymbol{W}, j = \{1,2, \qquad [7]$$

Equation [7] qualifies G_{wj} as equal to 1 if the small water system located in cell w is within the maximum distance d from a center to be built in cell j, and 0 otherwise. Equation [6], which is repeated N times, once for each cell that contains a small water system, ensures that each water system is within the maximum distance of at least one center.

The model is formulated as a 0-1 integer programming problem since the decision variable y_j is binary. The model can be solved by the branch-and-bound method, using specific software programs such as *What's Best*.

Fig. 4 Minimizing the Number of centers in a Set Covering Model, and Locating them to Ensure All Systems can be Assigned to at Least One center within a Maximum Distance Constraint



In the example shown on Figure 4, $C^* = 4$, and $y_j = 1$ for j = {8, 30, 34, 46}. As the maximum distance requirement is changed, the set covering model produces a finite set of optimal numbers of centers to be established. For example, as the maximum distance d is incrementally changed from 10 miles to 50 miles, the set covering model may determine optimal numbers of centers = {20, 16, 12, 4, 1}.

On Cost

The set covering model minimizes the number of centers to be established, ensuring that all systems are within a maximum driving distance from their center, as shown in Figure 4. The model essentially minimizes the total cost of startups attributable to the number of centers in the area. However, the model does not optimize location or assignments of the systems based total distance. There may be several feasible configurations of the same number of centers, all with different total distances between centers and their systems – the model computationally only selects one, and does not minimize distances. On Figure 4, the water system in cell 46 may be assigned to the center in cell 30, despite the presence of a center in its own cell. Hence, a second optimization model is required to minimize costs attributable to total distance between small water systems and their assigned centers.

p Median Model

Building on the set covering model, the p median model uses the number of centers to be established, C, as an input, and optimizes the location of the C centers and their water systems assignments to minimize the total distance between all centers and their assigned systems. The p median model will therefore locate the centers as close to the systems as possible, and assign each water system to the nearest available center. Since there is no maximum distance constraint, the p median model may assign centers centrally to more populated regions, and force a few outlying water systems to centers that are far from them in order to minimize total distance.

In this model, the decision variable is G_{ij}, which is equal to 1 if cell i is assigned to cell j, and 0 otherwise, for all i,j = {1,2,…,Z}. Given that C is an input taken from the array of optimal number of centers determined by the set covering model, a p median model that minimizes total distances between systems and their assigned centers is:

$$\underset{G_{ij}}{\text{Minimize}} \sum_{i=1}^{Z} \sum_{j=1}^{Z} G_{ij} \cdot d_{ij} \cdot x_i \qquad [8]$$

$$\text{subject to} \sum_{j=1}^{Z} G_{ij} = 1 \quad \forall\, i = \{1,2,\dots,Z\} \qquad [9]$$

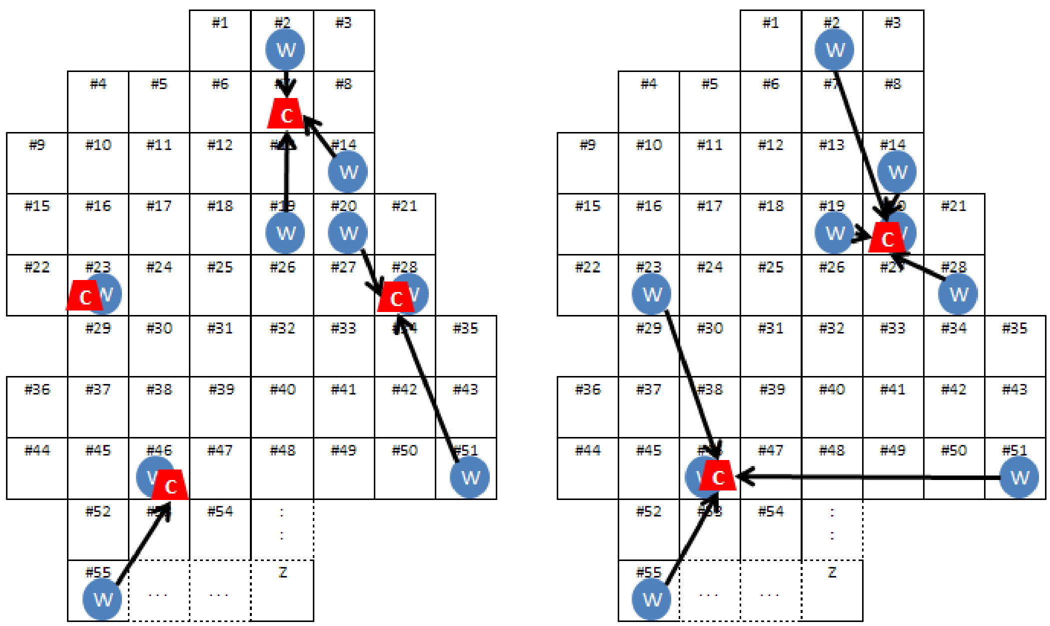
$$\sum_{j=1}^{Z} G_{jj} = C \qquad [10]$$

$$G_{ij} \le G_{jj}, \ \forall\, i, \forall\, j \qquad [11]$$

Equation [8] minimizes the cross product of all cell i to cell j assignments, with the distance between the cell pairing, and the value of x_i, which is equal to 1 only if a water system is present in cell i, and 0 otherwise. Equation [9] forces each cell to be assigned to one, and only one, cell in the study area. This prevents double-assigning water systems to more than one center. Since the model attempts to minimize total distances, if it selects cell j as a location for a center, the model will automatically self-assign the cell (any water system in that cell) to itself. This will then allow us to count the total number of cells that are selected as sites for centers, and this is forced to equal the pre-selected number of centers to be used in the p median model, in equation [10]. Equation [11] ensures that no cell i can be assigned to cell j, if cell j is not already assigned to itself (or in other words, if there is no center in cell j).

Since water systems are only located in cells w, where , G_{ij} must equal to 0 where since there are no water systems in those cells to assign to centers. An example of an optimal solution where C = 4 and C =2 are pre-selected is shown in Figure 5.

Fig. 5 Minimizing the Total Distance Between centers and Assigned Systems in a p Median Model, Where Total Number of centers is Pre-Selected to be 4 or 2



The p median model might be solved through linear programming. However, all G_{ij} assignments must be binary. In the case that linear programming produces an optimal solution with fractional assignments; the branch-and-bound method can be used to select optimal integer solutions for a 0-1 integer programming problem instead.

On Cost

Since the number of centers is predetermined using the p median model, the startup costs associated with the construction of the centers is also predetermined. However, these costs have already been minimized using the set covering models to determine the minimum number of centers required for reasonable center-to-system distances. The daily distances traveled by operators between the center and their assigned systems varies, and the size of the center, as determined by the total number of operators and managers employed by each center, also varies depending on the system assignments. The model as formulated essentially minimizes the total daily travel costs by minimizing the total distances between centers and their systems. Since the total number of operators in a study area will be fixed, based on the total number of water systems in the area which is assumed to be constant, the total wages and benefits of the operators and managers will be constant in the study area, regardless of which center they are employed in. The marginal cost of expanding the construction of the center to accommodate larger staff sizes may vary by the size of the center, but these marginal costs are assumed to be negligible compared to the average cost of construction of each center, and the total annual cost of travel between centers and systems.

Simplifications to the Models

Ideally, we would be able to optimize the location of centers using the two models described above. Practically, this involves delineating a study area into hundreds, or thousands, of cells with small enough areas so as to locate only one water system in any given cell. This produces a large matrix of constraints and variables to consider in computing the optimization solutions. For example, if a study area is delineated into 1,000 cells, equation [11] describes 1,000,000 constraints. Computationally, and due to software limitations, these models are very difficult, or nearly impossible, to optimize as described, and require some adjustments to simplify computation based on logical assumptions.

The first adjustment that we will make is to enlarge the dimensions of the cells in order to reduce the total number of cells within a given study area. This will lead to grouping of a few small water systems within individual cells, as opposed to maintaining a one system per cell limit. In this case, it is assumed that all of the systems within a cell will be assigned to the same center that the cell is assigned to using the optimization models. As the cell size increases, a tradeoff clearly occurs between the optimization solution precision and the computational simplicity of the model. The smallest cell size will be used that can be feasibly computed by the optimization software, which has a limit on the number of variables and constraints one might use. The p median model needs to be adjusted to allow for appropriate weighting of each cell. The constraints remains the same, but x_i in the objective function – equation [8] – now represents the *total* number of small water systems in cell i.

The second adjustment that we will make is based on a logical assumption that centers will realistically be based in cells that already contain small water systems. For example, if the optimization model identifies that two or three cells of systems are to be assigned to a center, which is to be located in the empty cell adjacent to one of the cells containing small water systems, it would make practical sense to move the center to the cell with systems, even if it marginally increases total distances travelled to the other system-occupied cells. All centers must now be located in cells c where , and the p median model can be simplified to only include system-occupied cells and center-occupied cells that are now part of the **W** array:

$$\underset{G_{wc}}{\text{Minimize}} \sum_{w \in \boldsymbol{W}} \sum_{c \in \boldsymbol{W}} G_{wc} \cdot d_{wc} \cdot x_w \tag{12}$$

$$\text{subject to} \sum_{c \in \boldsymbol{W}} G_{wc} = 1 \quad \forall\, w \in \boldsymbol{W} \tag{13}$$

$$\sum_{c \in \boldsymbol{W}} G_{cc} = C \tag{14}$$

$$G_{wc} \leq G_{cc}, \ \ \forall\, w \in \boldsymbol{W}, \forall\, c \in \boldsymbol{W} \tag{15}$$

This practically-oriented assumption essentially drops all non-occupied cells from consideration in the model, and significantly simplifies computation, while marginally decreasing the accuracy of the results. However, by significantly reducing the numbers of cells to include in the model, reducing the number of variables and constraints in the model, we may now reduce the size of each cell to counteract the first adjustment made. This will help offset the loss of accuracy in the results.

Reference

Kim, Dohyeong (2007). "Strategy for Determining Vaccination User Fees and Locations: A Case Study in Rural China." Doctoral dissertation, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill.