Two Cost Analyses in Resource Economics
The Public Service Costs of Alternative Land Settlement Patterns and Effluent Allowance Trading in Long Island Sound

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(ABSTRACT)

This study offers two cost analyses to inform public policy decisions on the use of land and water resources. The first presents some public service costs associated with different spatial forms of land development. The second cost analysis presents costs associated with three different policy options for meeting water quality goals in Long Island Sound.

The objective the first analysis is to determine the cost to local governments of providing water distribution and wastewater collection services to alternative spatial forms of residential development. Components of spatial form are explicitly defined in terms of lot size, distance and tract dispersion. An engineering cost model is used to determine the water and sewer costs to three sets of hypothetical land settlement scenarios. Each set shows the effect of one component of spatial form on cost.

The results show that smaller lots, shorter distances between existing centers and less tract dispersion reduce public water and sewer costs. Lot size is found to have the most pronounced effect on water and sewer cost. Some policy options for reducing the public service costs associated with development are considered.

The objective of the second cost analysis is to analyze the cost implications of a nitrogen allowance trading system for wastewater treatment plants in Connecticut. Effluent allowance trading involves the transfer of pollution control responsibility between pollution sources. Effluent allowances are the right to discharge a given quantity of waste into the environment over a given time period. Allowance trading has been proposed as a way of reducing pollution control costs, encouraging innovative pollution prevention techniques and more quickly achieving water quality goals.

Long Island Sound, a major estuary in the northeastern United States, experiences chronically low dissolved oxygen levels. Excessive nitrogen loads from anthropogenic activities in the Sound watershed have been identified as the cause of the oxygen problem. The state of Connecticut is examining the possibility of introducing an effluent allowance trading system in order to reduce the cost of achieving required reductions in nitrogen discharge.

A linear programming model is used to predict trading outcomes and allowance prices. The total cost of achieving a nitrogen load cap is calculated under three administrative approaches. The first approach is a uniform reduction requirement where all plants are required to reduce discharge by the same proportion. The second approach is an administrative reallocation of waste load where a regulatory agency assigns control responsibility based on the agency's understanding of relative costs. The third approach is a flexible effluent allowance trading system. The results will show that a trading program offers cost savings over traditional regulatory approaches, demonstrate the potential for further cost savings from pollution prevention activities and estimate the cost savings that would result from including nonpoint sources in the overall nitrogen reduction strategy.

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Chapter 1. Introduction

This study offers two cost analyses to inform public policy decisions on the use of land and water resources. Environmental and resource policy-making can be viewed as a multistage process. First, scientists, managers and the public must decide what environmental quality goals are desired by society. Second, scientists and engineers determine what options are available to meet these goals. Third, managers must choose which options to use in achieving environmental goals.

Economic analysis can aid in the environmental policy-making process. One way is to conduct empirical cost analyses of the available options for meeting environmental quality objectives. Such cost analysis takes environmental goals as given and offers criteria for selecting the favored policy option, namely the least-cost option. This study offers two such cost analyses. Chapter two identifies the public water distribution and wastewater collection costs of alternative spatial patterns of land development. Chapter three identifies the cost of alternative policy options to control nitrogen pollution in Long Island Sound. The two situations differ in the precision of the policy goals. Land use planning often has multiple objectives, such as increasing the tax base, improving quality of life, minimizing traffic disruptions and minimizing public service costs. The costs estimated in this study, therefore, will not be the only criteria considered when deciding on policy. By contrast, the state of Connecticut has set specific nitrogen effluent goals that it believes are achievable. Minimizing the cost of compliance with these goals will be a major factor in deciding which policy option will be implemented.

The second way economic analysis can aid in the policy-making process is to inform the design of policy options so that they create institutions and incentive structures to encourage desired behavior and meet objectives. One example of this occurs at the end of chapter one. In order to reduce public service costs due to more costly settlement forms, local governments are advised to shift infrastructure costs to private developers and landowners and institute marginal cost pricing to more effectively recover costs. Another example of how economic analysis can inform policy design occurs in the second chapter where an effluent allowance trading program that creates incentives to reduce discharge and minimize costs pollution control costs is described.

Chapter 2. Isolating the Effects of the Spatial Form of Residential Land Settlement Patterns on Public Water and Sewer Costs

Section 1. Problem Statement

I. Introduction

"Urban sprawl" is a term frequently used to describe the spatial pattern of contemporary residential growth. Many proposed definitions generally characterize sprawl as spread out, low density development. There is concern about "sprawl" on many levels. It has been asserted that this type of development can degrade air and water quality, destroy open space and prime farmland, and contribute to the deterioration of urban centers (Burchell and Listokin 1995). A particularly pressing concern is the effect of sprawl development on the fiscal costs to local governments. It has been widely asserted in the economics and planning literature that sprawl costs local governments more in terms of infrastructure and public service expenditures than more compact forms of growth (Transportation Research Board 1998). This report will focus on the service costs from a local government perspective.

Discussion of the effects of sprawl is a debate about what spatial form growth should take. Spatial form is how development is arranged across the landscape. The relationship between spatial form and public service costs has received considerable attention. Most of the studies on the public costs of alternative land settlement patterns have been fairly consistent in reporting that more compact, contiguous forms of development are less costly to serve. *The Costs of Sprawl* report (Real Estate Research Corporation 1974), one of the most influential studies, analyzed various spatial arrangements of hypothetical developments, holding population constant. As developments increased in density, the study reported significant fiscal and infrastructure cost savings in every category of public service cost analyzed (RERC 1974). Burchell and Listokin (1995) synthesize the costs calculated in the three most widely cited recent studies, Duncan et al (1989), Frank (1989) and Burchell et al (1992b), and find significant capital savings associated with compact, contiguous development when compared to scattered, low-density, non-contiguous development.

The effect of spatial form on public costs has been analyzed for many services including roads, water, wastewater, parks, education, solid waste disposal, fire protection and police protection (Transportation Research Board 1998). According to the literature on the public service costs of alternative development patterns, each of these costs are affected by the spatial form of development to a different degree. Furthermore, disaggregated components of these costs may also be affected differently by the spatial form of development.

School costs are by far the largest component of local government costs. Based on a review of the literature, however, overall education costs appear to be relatively insensitive to the spatial arrangement of development. Duncan (1989) reports a 7 percent savings associated with compact contiguous forms of development relative to more spread out patterns. Frank (1989) and Burchell et al (1992b) report even smaller savings of 1 percent and 3 percent respectively. This insensitivity to spatial form is because the largest portion of education expenditures is in-school: capital facilities, teacher salaries, administration. These services do not need to be distributed across the landscape, but rather are located in relatively large, centralized facilities. As a result in-school expenditures are a function of student population rather than spatial form. While instructional or administrative costs may not be greatly affected, busing costs would seem to be much more sensitive to spatial form. More dispersed development requires longer bus routes and more children that need bus service (Esseks et al 1999).

Roads appear highly sensitive to spatial patterns. The synthesis by Burchell and Listokin reports a 25 percent savings associated with compact, contiguous forms of development relative to more spread out patterns. The reason for the greater sensitivity of road costs to the spatial form of development is easy to see intuitively. More spread out development requires more lane-miles of road to connect highly separated population, employment, retail and government centers. Roads are not always a local government expenditure, however, and this study aims to analyze costs from a local government perspective.

Water and wastewater services do appear to be significantly affected by the spatial arrangement of land settlement. Duncan et al (1989) and Frank (1989) find that compact, contiguous forms of development have water and sewer costs that are 60% and 66%, respectively, of spread out forms. Downing and Gustely (1977) look at the cost effects of locating settlements at various distances from existing centers. That study examines police, fire, solid waste disposal, school, water supply, storm drainage and sanitary sewer costs. Water supply was determined to be the most expensive service to provide on a per mile basis at $21,560 (1973 dollars). Sanitary sewers were found to be sensitive to spatial form, costing $12,179 per mile. It would seem that water and sewer distribution and collection system costs are more sensitive to spatial form than storage and treatment if per capital water consumption is constant across spatial forms. Distribution and collection systems in more compact development forms require shorter lengths of pipe to serve all houses. Treatment and storage facilities, however, are centrally located and sized on the basis of population and water consumption rather than spatial form. If, however, per capita consumption varies with the spatial form of development, then total treatment and storage costs will change with spatial form.

Nonetheless, previous empirical and non-empirical tests of the hypothesis that low density, spread-out forms of residential development are more costly to serve are not convincing for three reasons. First, the concept of the spatial form of development is often inadequately defined or measured. Second, methods of accounting for public service costs have often confused the spatial form of development with other factors such as population change and standards of service. Service standards are the type or quality of resources or materials used to deliver a service. For example, two communities have different service standards if one uses concrete sewer pipe and the other uses PVC sewer pipe. Third, operating costs are often neglected as only capital costs are reported in many studies.

The objective of this paper is to determine the cost to local governments of providing water distribution and wastewater collection services to alternative spatial forms of residential development. Components of spatial form are explicitly defined and isolated in the study design. Population and service standards are held constant over all spatial forms. Full cost accounting including operating and maintenance costs is performed.

II. Measuring Spatial Form

The term "sprawl" dominates the discussion of spatial form, yet it is rarely clearly defined. *The Costs of Sprawl* (RERC 1974), perhaps the most famous attempt to analyze the effects of alternative development patterns, never actually defines "sprawl." In fact, later interviews with investigators involved in the report reveal that the term "sprawl" was used only in the title as an afterthought (TRB 1998). A recent report by the Transportation Research Board (1998), entitled "The Costs of Sprawl – Revisited," states that the definition of sprawl has several components. Those components include: low density growth that is noncontiguous to the urban core, predominantly single family residential development, spatial segregation of land uses, consumption of large quantities of land (including good farmland and environmentally sensitive areas) and reliance on the automobile as the sole mode of transportation (TRB 1998). The Sierra Club report "The Dark Side of the American Dream: The Costs and Consequences of Suburban Sprawl" gives the following definition

> Sprawl is low-density development beyond the edge of service and employment, which separates where people live from where they shop, work, recreate, and educate – thus requiring cars to move between zones (Sierra Club 1998).

Another observer defines sprawl as "the spread-out, skipped-over development that characterizes the non-central city metropolitan areas of the United States" (Ewing 1997)

Definitions of "sprawl" are often vague and subjective. In fact, "even the most current literature on sprawl tends to *describe* its attributes rather than *quantify* them [emphasis in original]" (TRB 1998, p. 17). Spatial form is defined here as how development is located and arranged across a landscape. As the definitions of sprawl discussed above suggest, the spatial form of residential settlement has many different components that are not always clearly distinguished.

A. Qualitative assessments of spatial form

Many studies use qualitative assessments to indicate spatial form. The simplest grouping of settlement patterns exists in a group of reports by the Center for Urban Policy Research at Rutgers University (CUPR-Rutgers, see Burchell et al 1992a and 1992b). These documents compare the costs of "TREND" or "traditional" development with the cost of "PLAN" development or "managed growth." Trend or traditional development is so named because it has been the predominant pattern of land settlement since World War II. It is characterized by residential subdivision development on open space outside of incorporated municipal areas and strip commercial development along major highways. Trend development is often at low density (0.33-1.0 acre lots) and is not contiguous to existing municipalities and service areas. Planned development is contained within or around existing population centers. It is typified by higher densities and sometimes mixed uses (Burchell and Listokin 1995).

Esseks et al (1999) analyze what they refer to as scatter development. Scatter development, according to this study, is characterized by either large lot sizes (one or more acres) or smaller lots separated by at least one-half mile of undeveloped land (Esseks et al 1999). The report characterizes its three study sites as early scatter, maturing scatter or transitional scatter. Early scatter is typical of residential development on the exurban fringe. The site chosen as representative of early scatter in the Esseks et al report had low population density and was identified by the local planning department "as being at risk for substantial scatter type development." Maturing scatter patterns have densities that are still low, but higher than in early scatter sites. Maturing scatter sizes have been developed for a longer period of time relative to early scatter. Developments are widely spaced. Transitional scatter patterns have smaller average lot size, but low overall population density. Density may increase over time, but areas of this pattern have yet to reach full build-out. Also, some undeveloped land separates developments in the transitional scatter pattern. Aerial photographs were used to aid in the classification of the sites and the report uses visual imagery to describe the patterns (Esseks et al 1999).

Duncan et al's report (1989) contains a more detailed scheme of qualitatively indicating the spatial arrangement of land settlements. This scheme identifies five development patterns, or "urban development forms:" scattered, contiguous, linear, satellite, and compact. Each urban development form "characterizes the spatial relationship and structural order, or patterns of developed areas." Duncan et al use land use, population density, development intensity, parcel size, transportation linkages, employment concentration, and distance from service and employment centers to place each of the eight study sites into one of the five following categories.

- *Scattered development* is characterized by low-density growth that is separated from urban centers and other developed areas by undeveloped land. The study uses the term "leapfrog" development to describe this pattern. Scattered development is generally far from service and employment centers, has lower levels of service and is primarily residential in nature. Scattered development is defined by separation from existing centers, other development tracts and individual houses.

- *Contiguous development* is located next to urban areas and is developed at moderate densities. Mixed land uses and adequate levels of public services also characterize this pattern. Contiguous development is arranged with very little separation from existing centers and other development. Moderate density indicates intermediate levels of separation between houses. Duncan does not explicitly define moderate density, but the study sites in the report indicate less than one-acre lot sizes.

- *Linear development* is a low-density, mixed-use form of growth that spreads outward from urban areas along transportation corridors. Heavy automobile dependence is typical of this form.

- *Satellite development* is typified by moderate- to high-density, mixed-use development located in nodes that are separate from an urban center. These developments are physically separated from, but retain a cultural and economic relationship with, a major city. This type of development has high levels of separation between new development tracts and between new development and existing centers. Separation between individual dwelling units and commercial entities is low (i.e. density is high).

- *Compact development* patterns are characterized by high intensity development within an urban center. Separation between houses, between new development and existing centers and between individual new development tracts is minimized in this case.

The qualitative assessments of spatial form discussed above attempt to incorporate components of spatial form. Sprawl, as the above discussion suggests, can be discussed as a spatial form (or forms) that incorporates certain components of separation. Duncan et al (1989) and Esseks et al (1999) in particular, implicitly describe sprawl or alternative land settlement patterns in terms of the separation between houses, between new developments and existing centers and between new development tracts. The literature does not, however, use the three components to analyze growth patterns or define spatial form in a systematic way.

B. Quantitative indicators of spatial form

Spatial form is how development is arranged across a landscape. Some indicator or measure of spatial form must be used in order to isolate and identify the effects of the spatial form of development. Once such indicators are developed investigators can identify the effects of different dimensions of space on local government costs. Spatial form is essentially the relationship between the locations of different settlement parcels. Settlement parcels may be individual lots, existing centers or new development tracts. Two main quantitative indicators of spatial form have been discussed in the literature on local government costs: density and distance.

II.B.1 Density

Density measures the dwelling units or population per unit area, generally an acre. It is a measure of the relationship between individual lots. A review of the literature on public service costs by the Chesapeake Bay Program (CBP 1993) differentiates between gross and net density. Gross density is the number of dwelling units (or population) divided by the total area of the development. Total area includes all private lots, open space, streets and right of ways, undevelopable areas and all public facilities. According to the CBP review, "the significance of gross density was that it indicated the average distribution or spacing of dwelling units within an area…, although not necessarily the spacing between individual dwelling units" (CBP 1993, p. 2-20). Gross density reflects lot sizes plus the amount of space dedicated to public facilities.

Net density is the number of dwelling units (or population) divided by the privately developed land. Public areas and undeveloped land are excluded, thus this measure reflects only lot size. According to the CBP review, net density measures the "concentration of demand" for services and thus the amount of infrastructure needed to serve the dwelling units (CBP 1993, p. 2-20). Some studies use lot size as a measure of density. Since often these studies give an area measurement for the land under consideration, lot size is equivalent to net density.

Smaller scale studies such as Wheaton and Schussheim (1955), Duncan et al (1989) and *The Costs of Sprawl* (RERC 1974) calculate density at a subdivision or neighborhood level, several hundred acres or so. Often these are net density measurements. Wheaton and Schussheim (1955) vary the lot sizes while holding other factors constant at two sites in their study. They compare the costs associated with 20,000 square-foot lots with 110-foot frontages and 10,000 square-foot lots with 70-foot frontages at one site. The study also compares the costs associated with 30,000 square-foot lots with 150-foot frontages and 10,000 square-foot lots with 80-foot frontages at the other site.

The threshold for what researchers are willing to refer to as low-density development seems to be three dwelling units per acre. Frank (1989) and Esseks et al (1999) both cite this density. Frank calls 3 dwelling units per acre low-density. Esseks et al calls it “the threshold of scatter-type densities” based on comments by Burchell who includes residential development of lot sizes from .33 acres to 1 acre in his definition of “traditional” or “sprawl” development (Burchell 1996).

II.B.2 Distance

The literature also uses the distance between development and some central point as an indicator of spatial form. The central point may be a major city, employment centers, commercial centers or centralized public service providers. The report by Downing and Gustely (1977) in particular emphasizes the differences in fiscal costs due to locating development at different distances from existing centers. The report analyzed police, fire, sanitation, schools, water supply, storm drainage and sanitary sewer costs according to how far the development is located from employment centers, sewage plants, water plants or a receiving body of water. The Esseks et al (1999) study also classifies types of scatter development in part by how far from other development they are.

II.B.3 Indicators of spatial form in the present study

Attempts in the literature to quantify spatial form can be distilled into measures of lot size/density and distance. Lot size and net density measure separation between houses while distance can be used to measure separation between existing centers and new development and between different new development tracts. While some existing studies acknowledge that the concept of spatial form is multi-dimensional, these dimensions are frequently not clearly specified and their effects on local government costs are not individually explored. This study will describe the spatial form of development explicitly in terms of three types of separation: (1) separation between houses, measured as lot size or density; (2) separation from existing service or economic centers, measured as distance; and (3) separation between development tracts, which will be measured here as tract dispersion.

Each component of separation will influence the cost of provisioning public water and sewer costs. Larger lots will require more infrastructure to connect individual dwelling units to water and sewer mains. Greater distance between new development and existing centers increases costs because longer water and sewer main extensions will be required to transmit water to and remove wastewater from new development tracts. Locating new developments far away from each other (high tract dispersion) may increase costs by increasing the number of pipelines required for service.

III. Isolating Spatial Form from Other Determinants of Cost

The spatial form of residential land development is only one factor that affects public service costs. Overall population, land use, demographics and service standards all affect cost (CBP 1993). Population size and service standards in particular affect water and sewer costs. Higher populations require a greater quantity of services. The CBP review notes that labor-intensive services are particularly affected by population size. In addition water and sewer costs will be affected because greater population generates higher flows requiring treatment. Service standards, the type or quality of resources used, also affect costs. For example, installing smaller diameter or lower grade material utility pipe and requiring private septic fields will reduce public costs. It is therefore essential that other cost influencing factors be held constant if the effects of spatial form are to be isolated.

The failure to separate spatial form from other factors is a common feature of cost studies. Windsor (1979) suggests that savings *The Costs of Sprawl* (RERC 1974) attributes to higher density are actually due to different population size, types of housing and demographic assumptions used to compare different developments. Windsor recomputes *The Costs of Sprawl* figures and suggests that any savings are negligible. Windsor also asserts, "low density development may be a form of growth management rather than unplanned sprawl. Such development may control public costs and environmental impacts by holding down population growth." These findings indicate that varying assumptions and therefore failing to account for other cost-influencing factors can alter a study's results. In order to isolate the cost effects of spatial form sufficiently other cost-influencing factors must be held constant.

The use of gross density is an example of how changes in population can be confused with the spatial arrangement of new growth. A study by Ladd (1992) calculates density at the county level. Density, as defined by the Ladd study, is county population divided by county area. Although Ladd never differentiates between gross and net density, clearly this is a gross density measure since all land in the county is considered. This confuses different population sizes with the spatial arrangement of development. The study purports to find that fiscal costs increase as density increases. However, since density is calculated over a large area, the results show only that per capita costs increase as overall *population* increases.

To isolate the effects of spatial form other determinants of costs, such as population and service standards should be held constant. In designing a study comparing the effects of developments with different spatial forms, new development increments should include the same or a similar number of people. This way portions of the service cost that are determined by population size, such as storage and treatment costs for water, will not change across scenarios. Also, the standard of service delivered to the new developments should be similar. For example, in designing a water distribution system pipes should be of the same material and quality if possible.

IV. Capital vs. Operating Expenses

A complete treatment of the costs of new development should consider both capital and operation and maintenance. Some studies do consider both, although capital costs seem to be given more weight. Frank (1989), for example, reviews several studies that include operation and maintenance costs, but synthesizes and draws conclusions using only capital costs. Knowing the operating costs associated with new land development would seem to be essential to local governments for two reasons. First, the increased use of proffer charges and impact fees pass public capital costs on to the property owner while local governments assume maintenance responsibilities (CBP 1993). Second, infrastructure costs are small in comparison to other costs in municipal budgets (Burchell et al 1992b).

V. Objectives

The objective of this study is to identify the effects of spatial form on the cost to local governments of providing water and wastewater service. Specifically this study will isolate how three components of separation of a new residential population -- (1) separation between houses (lot size), (2) separation from existing service or economic centers (distance), and (3) separation between development tracts (tract dispersion) -- will influence the total cost of providing public water and sewer service.

It is hypothesized that each of the three components of spatial form has a specific effect on public water and sewer costs. Larger lots may increase public water and sewer costs because greater lengths of distribution water mains and collector sewer mains will be required to serve new development. More distance between new development and existing centers may increase costs because longer pipeline extensions will be required to transmit water to and remove wastewater from new development tracts. Locating new developments far away from each other (high tract dispersion) may increase costs by increasing the number of pipelines required for service.

VI. Procedure

A spreadsheet-based simulation model is developed and used to estimate the cost of publicly provided water distribution and sewer collection facilities for a fixed number of residents in a hypothetical town. The residents will be settled in hypothetical development scenarios and costs will be calculated for each. The three components of spatial form, lot size, distance and tract dispersion, are varied over all scenarios. Other cost influencing factors, including total population size and service standards, are held constant over all scenarios. The results of the simulations will be analyzed and differences in the three dimensions of spatial form will be used to explain differences in cost between scenarios. The scenarios are not designed to mimic likely development patterns or growth possibilities, but rather to isolate the components of spatial form and determine their effects on cost.

Section 2. Methods

I. Introduction

The present study will determine the effects of the three components of spatial form on the cost of providing public water and sewer service. Conditions for a medium sized town of 25,000 to 30,000 people are simulated. Over a thirty-year period, population of the municipality is assumed to grow by 3,000 single-family, detached houses occupied by an average of 3.5 people each. This represents 300 new households per year and is a not unreasonable forecast for such a town (Town of Blacksburg 1996). The area is assumed to have basically flat topography.

A key aspect of this analysis is that other factors that influence the cost of public water and sewer service are held constant. Several scenarios are constructed so that spatial form changes while other factors do not. Changes in population are constant in all scenarios. The standard of service in all scenarios is also the same as similar materials and similar rules of thumb rules of thumb for locating fire hydrants and manholes are used. Three sets of cost scenarios are constructed. Each scenario represents a different layout of 3,000 homes. Each set shows the effect on cost of one component of spatial form: lot size, distance or tract dispersion.

Water distribution and sewer collection costs are calculated for each scenario using an engineering cost model. Length of pipe, number of valves, hydrants and manholes, number of booster pumps and pump energy and maintenance requirements are determined according to the layout of each scenario modeled. These infrastructure requirements are used in conjunction with unit cost data from generally accepted industry sources to calculate costs. The system is designed as if planners have perfect foresight about where new development will occur. That is, all infrastructure components are sized to serve only the development considered here and not over-sized to accommodate potential future growth beyond the planning time horizon.

II. Determining the effects of spatial form on public water and sewer costs

II.A Constructing spatial form scenarios

Several development scenarios are laid out so that a single component of spatial form is allowed to vary across all scenarios while two components of spatial form are held constant. An engineering cost model then calculates water and sewer costs for each scenario and the results are plotted on a graph. The effect of one component of spatial form can be seen by examining how costs change across each scenario.

II.A.1 Lot size

Separation between houses will be measured as lot size. Lot size determines the length of frontage for each lot. The length of frontage affects the amount of distribution and collector main piping required to serve subdivisions. There are 43,560 square feet per acre. If the lots are square shaped 210-foot frontages for a one-acre lot result. It is more likely, however, that lots are rectangular. Lots arranged in a 1:3 ratio, meaning every one foot of frontage corresponds to three feet of depth, is a fairly typical layout (NJOSP 1996, p. 62). This type of lot configuration is used for all lots in all scenarios. A one-acre lot, therefore, has 120 feet of frontage[1].

Four sets of lot size scenarios are constructed to demonstrate the effect of lot size on water and sewer costs. Lot size may take on four different values: 0.25 acres, 0.5 acres, 0.75 acres and 1 acre. In the first cost curve distance is held constant at 0.25 miles and the number of housing tracts is held constant at one. In the second cost curve distance is five miles and the number of tracts is one. In the third curve distance is 0.25 miles and the number of tracts is four. In the fourth curve distance is five miles and the number of tracts is one. Table 2.2-1 presents the values of the components of spatial form for all points plotted in each of the four cost curves.

[1] Recall that the area of a rectangle is equal to its length times its width: A = L*W. In the case of a 1:3 ratio the width is equal to 3 times the length, so 43560 = 3L*L. Solving for L gives L = 120.5.

Table 2.2-1 Components of spatial form for scenarios showing effect of lot size on cost.

Effect of Lot Size 1: near distance, low tract dispersion			Effect of Lot Size 2: far distance, low tract dispersion		
lot size (acres)	distance (miles)	tracts	*lot size (acres)*	distance (miles)	tracts
0.25	0.25	1	*0.25*	5	1
0.5	0.25	1	*0.5*	5	1
0.75	0.25	1	*0.75*	5	1
1	0.25	1	*1*	5	1

Effect of Lot Size 3: near distance, high tract dispersion			Effect of Lot Size 4: far distance, high tract dispersion		
lot size (acres)	distance (miles)	tracts	*lot size (acres)*	distance (miles)	tracts
0.25	0.25	4	*0.25*	5	4
0.5	0.25	4	*0.5*	5	4
0.75	0.25	4	*0.75*	5	4
1	0.25	4	*1*	5	4

II.A.2 Distance

Separation between new development and existing centers will be measured as distance. In all scenarios the existing center contains water and wastewater treatment plants. The distance from the center, therefore, is the length of water and sewer main extensions required to serve the new development. Tracts located five miles from the center, for example, require five-mile water and sewer main extensions.

Four sets of scenarios are constructed to demonstrate the effect of distance on water and sewer costs. Distance will take on seven different values in each cost curve:

0.25, 0.5, 1, 2, 3, 4 and 5 miles. In the first cost curve lot size is held constant at 0.2 acres and the number of tracts is held constant at one. In the second curve lot size is held constant at one acre and the number of tracts is one. In the third cost curve lot size is 0.2 acres and the number of tracts is four. In the fourth curve lot size is one acre and the number of tracts is four. Table 2.2-2 shows the values of the components of spatial form for all points plotted in each of the four cost curves demonstrating the effect of distance on cost.

Table 2.2-2 Components of spatial form for scenarios showing effect of distance on cost.

Effect of Distance 1: small lot, low tract dispersion			Effect of Distance 2: large lot, low tract dispersion		
lot size (acres)	*distance (miles)*	tracts	lot size (acres)	*distance (miles)*	tracts
0.2	*0.25*	1	1	*0.25*	1
0.2	*0.5*	1	1	*0.5*	1
0.2	*1*	1	1	*1*	1
0.2	*2*	1	1	*2*	1
0.2	*3*	1	1	*3*	1
0.2	*4*	1	1	*4*	1
0.2	*5*	1	1	*5*	1

Table 2.2-2 Components of spatial form for scenarios showing effect of distance on cost –continued.

Effect of Distance 3: small lot, high tract dispersion			Effect of Distance 4: large lot, high tract dispersion		
lot size (acres)	*distance (miles)*	tracts	lot size (acres)	*distance (miles)*	tracts
0.2	*0.25*	4	1	*0.25*	4
0.2	*0.5*	4	1	*0.5*	4
0.2	*1*	4	1	*1*	4
0.2	*2*	4	1	*2*	4
0.2	*3*	4	1	*3*	4
0.2	*4*	4	1	*4*	4
0.2	*5*	4	1	*5*	4

II.A.3 Tract dispersion

Separation between individual new development tracts will be measured as tract dispersion. Tract dispersion measures how far development tracts are located to each other. Development may be clustered close together to form a single large development tract of 3,000 homes or developed as smaller subdivisions in separate locations. In scenarios with higher tract dispersion, development tracts are located far away from each other. Higher tract dispersion scenarios require more water and sewer main extensions. In a scenario where 4 tracts exist, for example, four separate water and sewer mains, one for each tract, are needed. In scenarios with low tract dispersion, the development occurs as a single tract of 3,000 houses. Scenarios with low tract dispersion require only one water and sewer main extension. Note that tract dispersion does not measure the distance between tracts quantitatively. Instead, the number of tracts that require new water and sewer main extensions is used. The number of new water and sewer mains is the aspect of tract dispersion that is of interest when considering the effect of spatial form on cost.

Figure 2.2-1 consists of four development layouts and shows the levels of tract dispersions analyzed. The solid rectangle in the center of each layout represents the existing center, water and sewage treatment plants in this case. The hollow rectangles surrounding the centers represent development tracts. The numbers inside the development tracts are the number of households in each. In the first layout 3,000 households are settled in a single development tract. Moving from left to right, the development tracts become more dispersed as the number of development tracts increases. Note that the development tracts are separated from other tracts by enough space so that each tract requires its own water transmission and sewer interceptor mains.

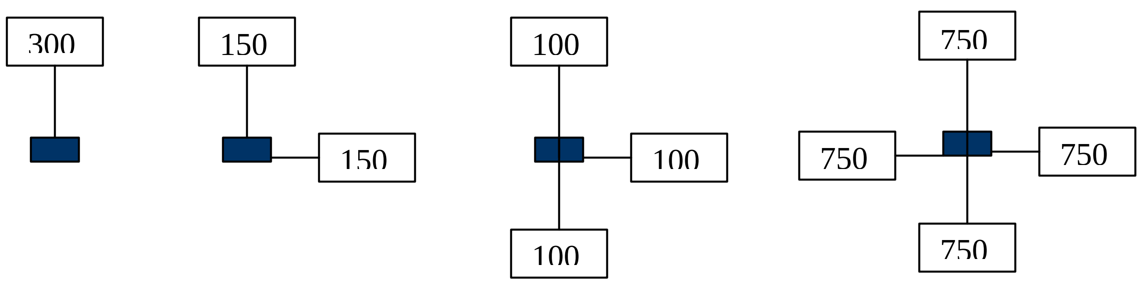


Figure 2.2-1. Levels of tract dispersion.

Four sets of scenarios are constructed to demonstrate the effect of tract dispersion on water and sewer costs. There will be one, two, three or four development tracts in each scenario. In the first cost curve lot size is held constant at 0.2 acres and the distance is held constant at 0.25 miles. In the second curve lot size is held constant at one acre and the distance is 0.25 miles. In the third cost curve lot size is 0.2 acres and the distance is 5 miles. In the fourth curve lot size is one acre and the distance is 5 miles. Table 2.2-3 shows the values of the components of spatial form for all points plotted in each of the four cost curves demonstrating the effect of tract dispersion on cost.

Table 2.2-3 Components of spatial form for scenarios showing effect of tract dispersion on cost.

Effect of Tract Dispersion 1: small lot, near distance			Effect of Tract Dispersion 2: large lot, near distance		
lot size (acres)	distance (miles)	*tracts*	lot size (acres)	distance (miles)	*tracts*
0.2	0.25	*1*	1	0.25	*1*
0.2	0.25	*2*	1	0.25	*2*
0.2	0.25	*3*	1	0.25	*3*
0.2	0.25	*4*	1	0.25	*4*

Effect of Tract Dispersion 3: small lot, near distance			Effect of Tract Dispersion 4: large lot, near distance		
lot size (acres)	distance (miles)	*tracts*	lot size (acres)	distance (miles)	*tracts*
0.2	5	*1*	1	5	*1*
0.2	5	*2*	1	5	*2*
0.2	5	*3*	1	5	*3*
0.2	5	*4*	1	5	*4*

Note that within each chart one component of spatial form is varied while the other two are held constant across all scenarios plotted. Differences in cost between scenarios can be attributed to differences in spatial form because of this layout. Because population and service standards are held constant, differences in lot size distance from existing centers, and the dispersion of tracts can be used to compare scenarios and determine the source of cost differences.

II.B Water Usage

Total water use for each household is initially held constant. All 3,000 units are assumed to be single-family residential homes. Each unit is assigned 3.5 people per household. Each person is assumed to consume 100 gallons of water per day (gpd). This consumption estimate is believed to be reasonable. The USGS estimates that the average person uses 80-100 gpd in the home (USGS 1999), while the Blacksburg-Christiansburg-VPI Water Authority (Virginia) reports that the average person uses 125 gallons per day (Blacksburg-Christiansburg-VPI Water Authority 1999) and other estimates range from 60 to 200 gpd (Jim Reilly, personal communication, August 1999). A 100 gpd per person assumption implies a need for 1.05 million gallons per day under each scenario. In the cost curves described above the potential need for new water treatment and storage capacity is not considered because when per capita water consumption is constant across all development patterns, the size and cost of these facilities is a function of population rather than spatial form. Since population increases by the same amount in every layout constructed additional treatment and storage costs do not need to be considered.

An alternative situation in which water demand increases with lot size is also considered. Large lots may encourage greater water consumption because of lawn watering (Hammer 1975). Water service costs if per capita demand is 125 gpd, a 25 percent increase over the above-mentioned case, are calculated for the large lot scenarios (5-8). The magnitude of the relationship between lot size and water use is difficult to isolate, but the 25 percent estimate is considered conservative (Hammer 1975). In this case lot size, one component of spatial form, does affect per capita water consumption. In this case, therefore, treatment and storage costs would be functions of spatial form.

III. Cost Model Structure

III.A. Overview of model structure

A spreadsheet-based simulation model is used to calculate water and sewer costs for each of the eight scenarios described above. The model assumes certain service standards for water and sewer infrastructure, calculates the amount of infrastructure needed based on the spatial characteristics of each scenario and uses unit cost information to determine total cost. The model does allow the user to specify spatial characteristics, physical characteristics and unit costs. Both present value and annualized costs are calculated. The discount rate and time horizon may also be specified by the user.

Water and sewer infrastructure are the two basic components of the model and are calculated separately. Spatial characteristics such as lot size, distance from existing center and dispersion of development tracts are inputs to the model as well as unit cost information. Information on service standards, such as pipeline diameter, is taken from readily available sources based on population and spatial characteristics.

III.B. Water transmission and distribution infrastructure

Providing water service entails three basic activities: acquisition, treatment and distribution. This model considers spatial arrangement as it predicts the cost of publicly provided water service. If per capita water use does not vary with spatial form, then acquisition and treatment are not as spatially sensitive because the amount of service required depends on the size of the population served rather than the spatial form of development. In the case where per capita water consumption is the same for all lot sizes, the cost of acquiring and treating water is not and considered and the model is only concerned with the distribution system. The model has five components: transmission mains, distribution mains, fire hydrants, valves and booster pumping.

III.B.1 Transmission and distribution mains

Transmission mains are large diameter pipelines that carry water from the treatment facility to a relatively large geographic area. Once the water arrives at its destination it flows into a distribution main network that distributes water to individual houses (ASCE 1992, p. 67). They are a distance related cost since the cost of the pipeline is directly related to the distance from the settlement to the center.

Distribution mains are smaller diameter pipes that receive water from transmission mains and distribute it to individual houses. Distribution mains are density related costs because the length of pipe, and thus total cost, is determined by the frontage length. Length of pipe and cost per linear foot are inputs to the model. Total length of pipe is determined by multiplying average frontage by the number of households served by the main.

Costs for transmission and distribution mains are calculated the same way. Materials, labor and equipment cost per foot and excavation cost per foot are multiplied by the total length of the water pipe. The two are added to produce total capital costs in current dollars, which is then converted to an annual payment.

III.B.2 Fire hydrants

Fire hydrants are required for public safety. They are also used for flushing water mains and sewers, filling tank trucks for street washing or spraying and providing a temporary water source for construction projects (AWWA 1996, p. 155). Municipalities have their own standards and guidelines for locating hydrants. The number of hydrants required is determined by dividing total length of pipe by the municipality's minimum distance between hydrants. The number of hydrants is then multiplied by the cost per hydrant.

III.B.3 Valves

Valves in a water distribution system are used to keep the flow of water under control. They help maintain pressure, prevent backflow, conserve water and isolate segments of pipeline for maintenance and construction (Public Works Magazine 1998b). The cost of the valve depends on its diameter. Municipalities have standards and guidelines for locating valves. To determine the number of valves required the total length of pipe of each diameter is divided by the minimum distance between valves. The cost per valve for each diameter is multiplied by the number of valves required for each diameter to get total valve costs.

III.B.4 Pumping Costs

Pump stations are required to ensure that adequate water pressure is available at all homes. It is assumed that each development tract requires a new pump station. Cost curves for booster pumping stations given in Sanks (1998, p. 859, Figure 29-7) are used to determine pump station costs in this model. Pumps must be sized according to flow for use in this model.

Friction head loss, pressure lost due to friction between moving water and the interior surface of the pipe, is calculated based on flow, pipe material and length of pipe using the Hazen-Williams equation (see appendix C). Friction loss is added to the boost in pressure needed to provide adequate service to obtain total discharge head. Power requirements can be calculated using engineering formulas once flow and total discharge head are known (see appendix C). Power requirements can be converted to energy costs using the motor horsepower and the number of hours the pump is working (Hauser 1996).

General maintenance costs for water booster pumping stations are relatively low and fairly constant over all pump sizes. (Johnny Beane, Town of Blacksburg, personal communication and Sanks 1998). General maintenance is therefore insensitive to the spatial form of development and is not included in this model.

III.C Sewer collection infrastructure

Sanitary sewer infrastructure is essentially the reverse of the water supply system. Wastewater is collected from individual households, conveyed to a centralized facility, treated and returned to some waterway. Again, the size and location of treatment facilities are believed to be insensitive to the spatial arrangement of population across the landscape. The model is therefore concerned only with the collection system. The model has three parts: collector lines, interceptor mains and manholes. Sewage pumping costs are not considered in this model because their placement and cost is mainly a function of topography.

III.C.1 Collector and interceptor mains

Sewer collector mains are pipes that convey wastewater from individual households to larger mains. Collector lines are analogous to distribution mains in the water supply system. Collectors are density-related costs. The length of pipe and unit cost information are inputs to the model. Length of pipe is determined by multiplying average frontage by the number of households served by the main.

Interceptor sewer lines receive wastewater from collector lines and convey it to the treatment facility. They generally rely on gravity to draw wastewater toward its destination, but interceptors may be pressurized if topographic conditions warrant it. The use of pressurized sewer pipes (force mains) is not considered in this model. Use of force mains to move sewage through the collection system is determined based on topographic and soil conditions in the area. It is difficult to incorporate decisions about to sewage pumping into a generalized model such as this one. Interceptors are similar to transmission water mains and can be thought of as a distance related cost since cost varies directly with the distance of the settlement from the central facility.

The model considers the materials, labor and equipment costs and the excavation and bedding costs of laying water pipe. Materials, labor and equipment costs are based on the diameter and type of pipe used. Excavation costs depend on the depth and width of the trench and the type of equipment used to excavate. Materials, labor and equipment costs and excavation costs per foot are multiplied by the total length of the sewer mains. The two are added to produce total capital costs in current dollars.

III.C.2 Manholes

Manholes are used to access underground sewer pipeline networks. Access is required for inspection, maintenance, cleaning, repair and flow monitoring of the sewer system (Public Works 1998a). Municipalities have their own standards and guidelines for locating manholes along the collection system. The number of manholes required is determined by dividing total length of pipe by the municipality's minimum distance between manholes. The number of manholes is then multiplied by the cost per manhole.

IV. System Specifications

This section describes the data and sources used to estimate the total cost of providing water and sewer service for each of the eight development scenarios. Infrastructure design requirements were taken from engineering handbooks and personal interviews with public works employees. Most unit cost information was taken from a cost-estimating handbook in general use in the construction industry (R.S. Means Company, Inc. 1999). All unit costs and infrastructure requirements for each scenario are presented in tables in appendix E.

Both present costs and annualized costs are calculated. The discount rate for annualized cost is seven percent and the planning horizon is 30 years. It is important to note that the estimation of costs in each scenario is insensitive to the timing of the development in each scenario. Construction of the systems is not staged. The model in essence assumes a hypothetical town manager knows the dimensions of the water and sewer system at the beginning of a 30-year planning period and builds the entire system in the first year. The model then calculates the annual payments necessary to pay for the project over the next 30 years.

IV.A Water Transmission and Distribution System Design

IV.A.1 Transmission and distribution mains

The length of pipe and cost per linear foot are inputs to the model for both transmission and distribution mains. Capital costs for pipe installation include materials, labor and equipment costs and excavation costs. Per foot materials, labor and equipment costs depend on the pipe material, type of joint (mechanical or push-on) and diameter.

Class 50, cement-lined ductile iron pipe using push-on joints and purchased in 18-foot sections is assumed. Pipe diameters for transmission mains will change across scenarios and are approximated from a table equating daily average flow to appropriate pipe size. The table is reproduced in appendix A. Pipe diameter is always 8 inches for distribution mains, a generally accepted standard (Johnny Beane, personal communication). Materials labor and equipment costs per foot are taken from *Means Site Work and Landscape Cost 1999* (p. 86, section 026 666).

Excavation and bedding costs depend on the depth and width of the trench. Trench depth is 3 feet of cover above the top of the pipe for transmission mains (AWWA 1996, p. 92). Trench width is no more than 1 to 2 feet wider than the outside diameter of the pipe. Trench width values are taken from a table for ductile-iron mains (AWWA 1996, p. 94 table 4-1). Cost is based on the width and depth of the trench. Linear foot costs for excavating utility trenches is given in *Means Site Work and Landscape Cost Data 1999* (p. 432, section 12.3-110).

Pipe bedding costs are based on the width of the pipe being laid. Compacted sand is laid in the bottom of the trench and over the pipe. Linear foot costs for excavating utility trenches is given in *Means Site Work and Landscape Cost Data 1999* (p. 435, section 12.3-310).

Transmission mains are 5 miles long for distant settlements and 0.25 miles long for near settlements. Average frontage for large lots (1 acre) is 120 feet. Average frontage for small lots (0.2 acre) is 55 feet. Distribution main lengths are determined by multiplying the number of houses by the average frontage.

IV.A.2 Fire hydrants

Communities have their own standards for locating fire hydrants. This simulation places a hydrant every 800 feet along water mains, the rule used by the Town of Blacksburg, Virginia (Johnny Beane, personal communication). To calculate the capital cost of fire hydrants, the total distribution main length is divided by 800 and the result multiplied by the per unit cost of a hydrant. All hydrants are assumed to be three-way with 4.5-inch valve and 4 feet deep. Hydrant costs are given *in Means Site Work and Landscape Cost Data 1999* (p. 442, section 12.3-922).

IV.A.3 Valves

Valves in this model are placed every 800 feet along the transmission and distribution system, a generally acceptable engineering practice (Public Works 1998b). Although there are situations that commonly require a much shorter interval between valves, the 800-foot interval is appropriate for a generalized model. Valve costs are determined by the diameter of the valve. Per unit costs for nonrising-stem, post type gate valves are reported in *Means Site Work and Landscape Cost Data 1999* (p. 91, section 026 690). Means does not report cost for 18- or 20-inch valves. To obtain a figure for these valves reported prices are extrapolated so that an 18-inch valve costs $4,020 and a 20-inch valve costs $4,625.

IV.A.4 Water pump capital and operating costs

Sanks (1998) develops pump station capital cost curves based on data from 1966 through 1987. Sanks uses the Engineering News-Record Construction Cost Index (ENRCCI) to standardize costs at 1988 price levels. The ENRCCI is a price index published by a trade magazine, Engineering News-Record, and commonly used in the building and construction industry. To further update the cost curves for use in the present study, pump station costs are corrected to the September 1999 price level using an ENRCCI value of 6117 (ENR 1999).

According to Sanks (1998), the capital cost (equipment and installation) of water pumping stations is a function of the flow in gallons per minute (gpm). Other factors, including number of pumps, variable or constant speed drivers, presence of standby power, high or low head and soil conditions, were found to be insignificant in determining cost. To determine the flow to be used in costing pumps, average flow in gallons per minute is multiplied by a peaking factor to find the flow per minute under peak demand conditions. A minimum fire flow requirement is added to the peak flow in order to ensure that the pump is able to provide adequate water to fight fire and meet peak demand conditions. The sum of the peak flow and fire flow is used to determine pump cost (Sanks 1998, p. 563).

Pumps may serve 750 households or 3,000 households, depending on the level of tract dispersion. Average flow for development tracts in the scenarios are either 182 gpm for 750 households or 726 gpm for 3,000 households. Each average flow is multiplied by a peaking factor of 2.5 and then added to a required minimum fire flow of 500 gpm (from Sanks 1998, p. 563) to obtain the appropriate flow for sizing the pump station (see appendix B for detailed calculations).

Pump energy costs are calculated using the average flow (in gallons per minute) and the total discharge head. It is assumed that in-line booster pumps operate 18 hours per day, which equates to 6570 hours per year (Gary Robertson, personal communication, Johnny Beane, personal communication). Energy costs are assumed to be $0.039 per kilowatt-hour, the average electricity rate paid by the Roanoke County Utility Department (Gary Robertson, personal communication). It is assumed that all pump stations are operated with electric power.

IV.B Sewer collection infrastructure

IV.B.1 Collector and interceptor mains

Materials, labor and equipment costs for sewer mains are from *Means Site Work and Landscape Cost Data 1999* (p. 106, section 027 168 for PVC pipes and p. 102 section 027 162 for concrete pipes). Per foot materials, labor and equipment costs depend on the pipe material and diameter. Schedule 35 PVC pipeline is used for distribution mains, which are 8 inches in diameter (Johnny Beane, personal communication). Reinforced concrete is used for transmission mains. Transmission main diameter is determined based on flow using a table based on the Manning formula for pipe flow (Bouthillier 1981, Table 14, p. 57 see appendix D for details).

Excavation costs depend on the depth and width of the trench and the type of equipment used to excavate. Trench depth is an average of 3 feet above the top of the pipe. Trench width is no more than 1 to 2 feet wider than the outside diameter of the pipe. Trench width values are taken from a table (AWWA 1996, p. 95 table 4-3). Linear foot costs are determined as described above for water mains.

IV.B.2 Manholes

This model places a manhole every 400 feet along distribution mains, the rule used by the Town of Blacksburg, Virginia (Johnny Beane, personal communication). To calculate the capital cost of manholes, the total length of sewer pipe is divided by 400 and the result multiplied by the per unit cost of installing a manhole. Manholes with a 4-foot inside diameter are used on sewers up to 24 inches in diameter. Manholes with a 5-foot inside diameter are used on sewers larger than 24 inches. Unit costs for manholes are reported in *Means Site Work and Landscape Cost Data 1999* (p. 437, section 12.3-710).

Section 3. Results

I. Introduction

The spatial form of residential land settlement has three components, all related to separation: (1) separation between houses within a tract (lot size), (2) separation between new development and existing centers (distance) and (3) separation between new development tracts (tract dispersion). Each component has a specific effect on service costs. The following results report the total costs to provide water and sewer service and plot those costs to graphically illustrate the relationship between three components of spatial form and cost. The relative contribution of each component of separation to the total cost of providing the service is identified.

II. Scenario Costs

II.A Effect of lot size on cost

The results presented in Tables 2.3-1 through 2.3-4 and in Figure 2.3-1 clearly show that lot size has an effect on the cost of providing public water and sewer service. In all cases smaller lots cost less to serve than larger lots when distance and the number of tracts are held constant. These savings are due to shorter lengths of distribution main required for small lots. Friction head losses are also less with shorter lengths of pipe. As lot size is increased from 0.25 acres to 1 acre (at 0.25 acre increments) costs increase at a decreasing rate. The last column in Tables 2.3-1 through 2.3-4 gives the increase in cost due to increasing lot size by one-quarter of an acre.

In all cases the increase in cost is smaller than the preceding increase. Because a 1:3 frontage to depth ratio of lots used in the study, as lots increase in area by one-quarter of an acre, the length of frontage increases in a non-linear fashion. Frontage lengths are 60, 85, 105 and 120 feet for 0.25, 0.5, 0.75 and 1 acre lots, respectively. When the increase in frontage is less than the preceding difference, as in this case, the increase in cost will also be less.

Table 2.3-1. Effect of Lot Size on annual cost 1: near distance, low tract dispersion

lot size (acres)	distance (miles)	tracts	water costs	sewer costs	total costs	increase in costs
0.25	0.25	1	$ 482,757	$ 253,114	$ 735,871	
0.5	0.25	1	668,776	358,418	1,027,194	$ 291,323
0.75	0.25	1	817,522	441,451	1,258,973	231,779
1	0.25	1	928,992	503,662	1,432,654	173,681

Table 2.3-2. Effect of Lot Size on annual cost 2: far distance, low tract dispersion

lot size (acres)	distance (miles)	tracts	water costs	sewer costs	total costs	increase in costs
0.25	5	1	$ 643,617	$ 327,700	$ 971,317	
0.5	5	1	829,636	460,583	1,290,219	$ 318,902
0.75	5	1	978,381	543,616	1,521,997	231,778
1	5	1	1,089,852	613,550	1,703,402	181,405

Table 2.3-3. Effect of Lot Size on annual cost 3: near distance, high tract dispersion

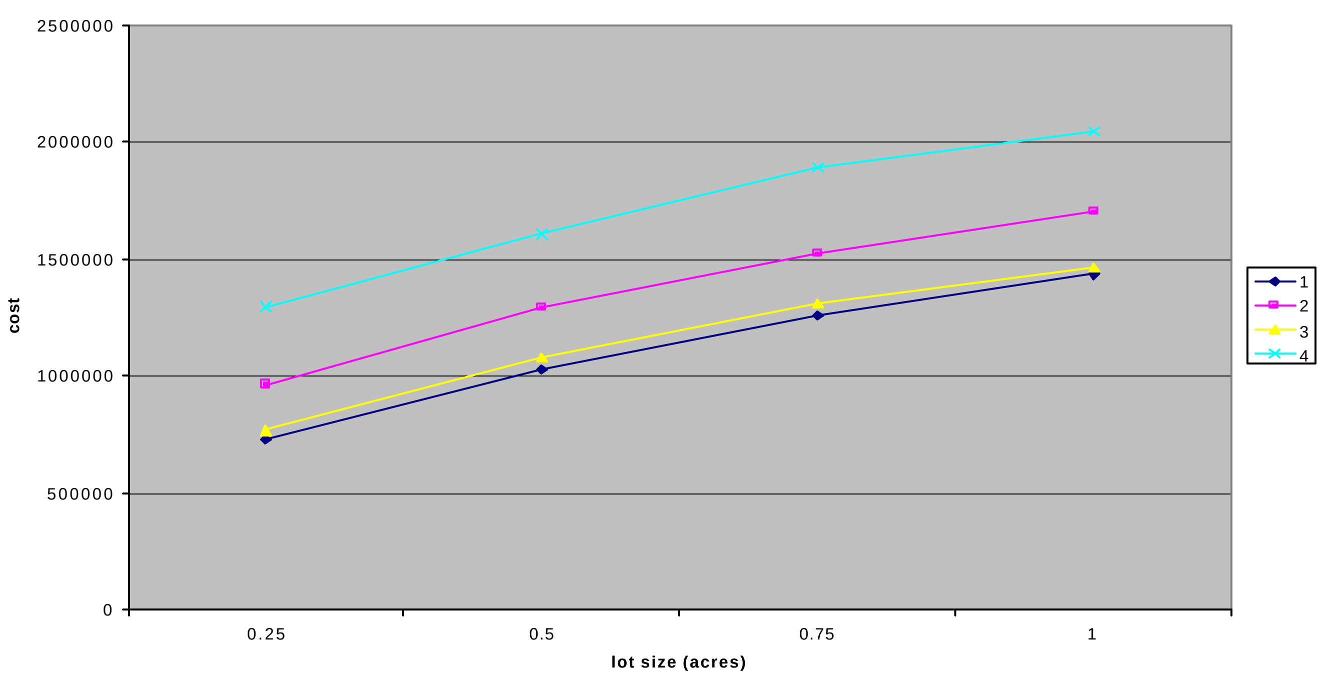
lot size (acres)	distance (miles)	tracts	water costs	sewer costs	total costs	increase in costs
0.25	0.25	4	$ 510,047	$ 260,550	$ 770,597	
0.5	0.25	4	694,294	364,402	1,058,696	$ 288,099
0.75	0.25	4	841,621	447,435	1,289,056	230,360
1	0.25	4	952,030	512,348	1,464,378	175,322

Table 2.3-4. Effect of Lot Size on annual cost 4: far distance, high tract dispersion

lot size (acres)	distance (miles)	tracts	water costs	sewer costs	total costs	increase in costs
0.25	5	4	$ 823,843	$ 476,038	$ 1,299,881	
0.5	5	4	1,008,089	578,829	1,586,918	$ 287,037
0.75	5	4	1,155,417	717,262	1,872,679	285,761
1	5	4	1,265,826	779,474	2,045,300	172,621

Figure 2.3-1 plots the total costs reported in Tables 2.3-1 through 2.3-4. The graphs show that total costs increase in decreasing increments as lot size increases by 0.25 acres. Each curve represents one of the tables presented above (2.3-1 through 2.3-4). The legend to the right of the graph identifies each curve. Curve 1 represents the effect of lot size on annual cost, the case where distance is held constant as near (0.25 miles) and tract dispersion is held constant as low (one development tract).

Figure 2.3-1. Effect of lot size on cost



II.B Effect of distance on cost

The annual costs of providing water and sewer service when development is located at various distances are presented in Tables 2.3-6 through 2.3-9 and in Figure 2.3-2. These results show that distance affects the cost of providing public water and sewer cost. The tables and graph indicate that when lot size and the number of development tracts are constant, water and sewer costs increase each time the distance of development from the center increases. The change in cost per unit of distance reported in the last column of each table is roughly constant within each table. This indicates a linear relationship between distance and the total cost of water and sewer service. An exception to this occurs as distance is increased from 4 miles to 5 miles with small lots and one development tract. Total cost increases by over $78,000. This is a substantial jump in the rate of increase of approximately $49,000 per mile reported in other scenarios within the same table. This greater than normal increase in cost occurs because a larger sewer interceptor pipe is required when distance is increased from 4 to 5 miles. Sewer pipe diameter is in part a function of length of pipe because longer lengths receive more infiltration and inflow (see appendix D for details).

The increase in cost is substantially higher when there are four tracts. This is because distance related costs, transmission and interceptor mains and associated valves and fire hydrants, are a higher percentage of costs when there are more development tracts. Each development tract requires separate transmission water and interceptor sewer lines.

Table 2.3-5. Effect of Distance on annual cost 1: small lot, low tract dispersion

lot size (acres)	*distance (miles)*	tracts	water costs	sewer costs	total costs	increase in costs
0.2	*0.25*	1	$ 445,556	$ 232,418	$ 677,974	
0.2	*0.5*	1	454,244	236,311	690,555	$ 12,581
0.2	*1*	1	471,019	244,219	715,238	24,683

0.2	*2*	1	505,168	259,914	765,082	49,844
0.2	*3*	1	538,994	275,607	814,601	49,519
0.2	*4*	1	572,868	291,302	864,170	49,569
0.2	*5*	1	606,692	336,035	942,727	78,557

Table 2.3-6. Effect of Distance on annual cost 2: large lot, low tract dispersion

lot size (acres)	*distance (miles)*	tracts	water costs	sewer costs	total costs	increase in costs
1	*0.25*	1	$ 928,992	$ 503,662	$ 1,432,654	
1	*0.5*	1	937,681	509,008	1,446,689	$ 14,035
1	*1*	1	954,455	519,821	1,474,276	27,587
1	*2*	1	988,604	541,325	1,529,929	55,653
1	*3*	1	1,022,153	567,462	1,589,615	59,686
1	*4*	1	1,056,304	590,509	1,646,813	57,198
1	*5*	1	1,089,852	613,551	1,703,403	56,590

Table 2.3-7. Effect of Distance on annual cost 3: small lot, high tract dispersion

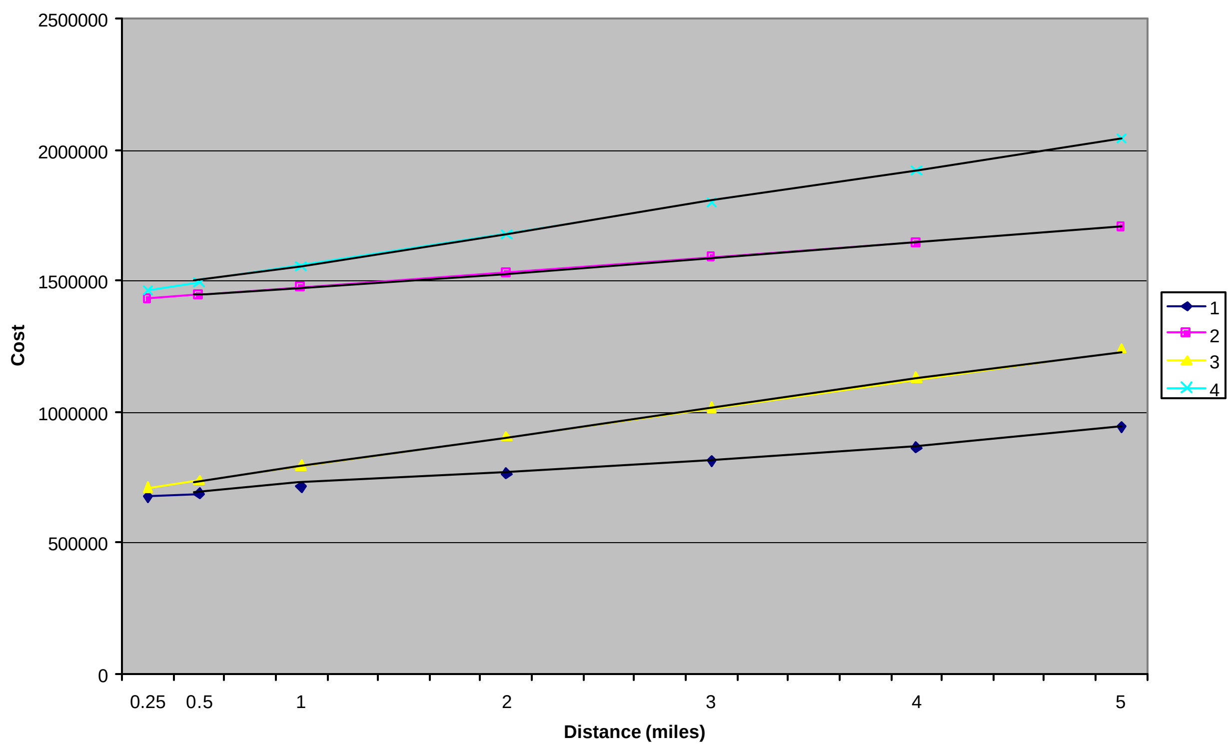
lot size (acres)	*distance (miles)*	tracts	water costs	sewer costs	total costs	increase in costs
0.2	*0.25*	4	$ 473,200	$ 239,854	$ 713,054	
0.2	*0.5*	4	489,879	251,184	741,063	$ 28,009
0.2	*1*	4	522,849	273,841	796,690	55,627
0.2	*2*	4	589,064	319,281	908,345	111,655
0.2	*3*	4	655,116	364,719	1,019,835	111,490
0.2	*4*	4	721,057	410,158	1,131,215	111,380
0.2	*5*	4	787,272	455,467	1,242,739	111,524

Table 2.3-8. Effect of Distance on annual cost 4: large lot, high tract dispersion

lot size (acres)	*distance (miles)*	tracts	water costs	sewer costs	total costs	increase in costs
1	*0.25*	4	$ 952,030	$ 512,369	$ 1,464,399	
1	*0.5*	4	968,709	526,422	1,495,131	$ 30,732
1	*1*	4	1,001,679	554,526	1,556,205	61,074
1	*2*	4	1,067,618	610,858	1,678,476	122,271
1	*3*	4	1,133,946	667,490	1,801,436	122,960
1	*4*	4	1,199,887	723,522	1,923,409	121,973
1	*5*	4	1,265,826	779,723	2,045,549	122,140

Figure 2.3-2 plots the total costs reported in Tables 2.3-5 through 2.3-8. Each curve represents one of the tables presented above (2.3-1 through 2.3-4). The legend to the right of the graph identifies each curve. Curve 1, for example, represents the effect of distance on annual cost 1, the case where lot size is held constant as small (0.2 acre) and tract dispersion is held constant as low (one development tract). The graph illustrates that costs are more sensitive to changes in distance when tract dispersion is high (cases 3 and 4, reported in Tables 2.3-8 and 2.3-9) than when tract dispersion is low (cases 1 and 2, reported in Tables 2.3-6 and 2.3-7).

Figure 2.3-2. Effect of Distance on Cost



II.C. Effect of tract dispersion on cost

The annual costs of providing water and sewer service when tract dispersion is varied are presented in Tables 2.3-10 through 2.3-13 and in Figure 2.3-3. These results show that number of development tracts requiring affects the cost of providing public water and sewer cost. In all cases increasing the number of development tracts, and thus the number of new water and sewer lines, results in higher costs. The magnitude of the increase in cost is differs between and within the tables. For instance, when lot size is small and distance is near, the increase in costs increases at a roughly constant rate as more tracts are developed (see Table 2.3-10). When lot size is small and distance is far, however, the increase in costs decreases as more tracts are developed (see Table 2.3-12). Increases in cost are not constant because more tracts are developed, fewer households are settled in each tract. The per foot cost of water mains is therefore less since pipes need to carry less flow and are sized smaller. Also note that when the distance is held constant at 0.25 miles, as in Tables 2.3-10 and 2.3-11, differences in cost among scenarios with different numbers of tracts are quite small.

Table 2.3-9. Effect of Tract Dispersion on annual cost 1: small lot, near distance

lot size (acres)	distance (miles)	*tracts*	water costs	sewer costs	total costs	increase in costs
0.2	0.25	*1*	$ 441,044	$ 232,418	$ 673,462	
0.2	0.25	*2*	448,769	235,941	684,710	$ 11,248
0.2	0.25	*3*	460,715	236,928	697,643	12,933
0.2	0.25	*4*	472,074	239,854	711,928	14,284

Table 2.3-10. Effect of Tract Dispersion on annual cost 2: large lot, near distance

lot size (acres)	distance (miles)	*tracts*	water costs	sewer costs	total costs	increase in costs
1	0.25	*1*	$ 919,146	$ 503,662	$ 1,422,808	
1	0.25	*2*	926,471	505,733	1,432,204	$ 9,396
1	0.25	*3*	938,006	508,763	1,446,769	14,565
1	0.25	*4*	949,572	509,646	1,459,218	12,449

Table 2.3-11. Effect of Tract Dispersion on annual cost 3: small lot, far distance

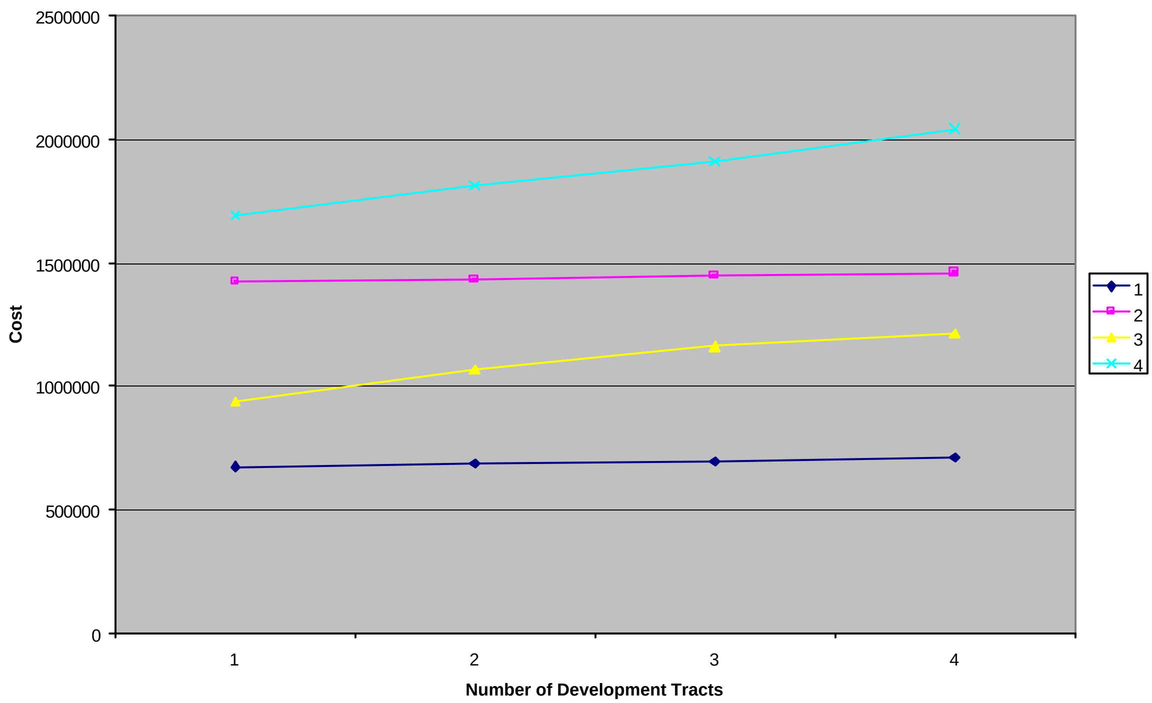
lot size (acres)	distance (miles)	tracts	water costs	sewer costs	total costs	increase in costs
0.2	5	1	$ 602,180	$ 335,911	$ 938,091	
0.2	5	2	687,294	378,062	1,065,356	$ 127,265
0.2	5	3	721,458	439,420	1,160,878	95,522
0.2	5	4	786,145	425,342	1,211,487	50,610

Table 2.3-12. Effect of Tract Dispersion on annual cost 4: large lot, far distance

lot size (acres)	distance (miles)	tracts	water costs	sewer costs	total costs	increase in costs
1	5	1	$ 1,080,005	$ 613,551	$ 1,693,556	
1	5	2	1,164,718	647,979	1,812,697	$ 119,141
1	5	3	1,198,748	709,341	1,908,089	95,392
1	5	4	1,263,368	779,723	2,043,091	135,002

Figure 2.3-2 plots the total costs reported in Tables 2.3-9 through 2.3-12. The legend to the right of the graph identifies each curve. Curve 1, for example, represents the effect of tract dispersion on annual cost 1, the case where lot size is held constant as small (0.2 acre) and distance is held constant as near (0.25). The graphs show that when distance is near (cases 1 and 2, reported in Tables 2.3-9 and 2.3-10) the increase in costs as tract dispersion increases is small. The graph also illustrates that when distance is far (cases 3 and 4, reported in Tables 2.3-11 and 2.3-12) the increase in costs as tract dispersion increases are substantially larger.

Figure 2.3-3. Effect of Tract Dispersion on Cost



II.D Comparing the magnitude of the effects of components of spatial form

Lot size seems to have a greater effect on total cost. The reason total costs are most sensitive to changes in lot size is that distribution water mains and collector sewer mains are the two largest items considered in this cost analysis. Table 2.3-13 shows each infrastructure item as a proportion of total costs. The figures in this table are the average of all scenarios constructed to determine the effects of each component of spatial form. Results presented in Table 2.3-13 show that, together, these two items make up the large majority of costs. Distribution and collector mains are density-related costs. They are directly related to how close together houses are or lot size. Changes in density-related costs will have a large impact on total cost. Note that each infrastructure item's proportion of total cost can vary widely according to spatial form. For example, when there is a greater number of tracts and a greater distance, transmission and interceptor mains' proportions of total cost increase greatly. Therefore, each infrastructure item's proportion can be different from the average by a large amount in a given scenario.

Table 2.3-13 Proportion of total costs.

scenarios	distribution mains	transmission mains	valves	hydrants	pump station	pump energy
lot size	43%	7%	2%	8%	3%	1%
distance	42%	8%	2%	8%	3%	1%
tract dispersion	42%	8%	2%	8%	3%	< 1%
average	42.3%	7.7%	2%	8%	3%	1%

Table 2-3.13 Proportion of total costs – continued.

scenarios	collector mains	interceptor mains	manholes
lot size	23%	5%	7%
distance	22%	6%	7%
tract dispersion	22%	6%	7%
average	22.3%	5.7%	7%

II.E. Per dwelling unit costs

The annualized costs per dwelling unit for water and sewer are shown in table 2.3-14 through 2.3-25. The per capita cost numbers in the table are obtained by dividing annual costs, as reported in Tables 2.3-2 through 2.3-13, by 3,000 houses. Monthly costs are also reported in Tables 2.3-14 through 2.3-25 and are roughly comparable to the monthly payment by each household required to finance the system. Annualized monthly costs per dwelling unit vary widely as the values range from $18.71 to $56.82. Increasing lot size, distance and tract dispersion increases the monthly cost in all cases.

Table 2.3-14. Cost per dwelling unit: effect of Lot Size on annual cost 1: near distance, low tract dispersion

			cost per year			cost per month		
lot size (acres)	distance (miles)	tracts	water	sewer	total	water	sewer	total
0.25	0.25	1	$ 157.96	$ 84.37	$ 242.34	$ 13.16	$ 7.03	$ 20.19
0.5	0.25	1	222.93	119.47	342.40	18.58	9.96	28.53
0.75	0.25	1	272.51	147.15	419.66	22.71	12.26	34.97
1	0.25	1	309.66	167.89	477.55	25.81	13.99	39.80

Table 2.3-15. Cost per dwelling unit: effect of Lot Size on annual cost 2: far distance, low tract dispersion

			cost per year			cost per month		
lot size (acres)	distance (miles)	tracts	water	sewer	total	water	sewer	total
0.25	5	1	211.52	109.23	320.75	17.63	9.10	26.73
0.5	5	1	276.55	153.53	430.07	23.05	12.79	35.84
0.75	5	1	326.13	181.21	507.33	27.18	15.10	42.28
1	5	1	363.28	204.52	567.80	30.27	17.04	47.32

Table 2.3-16. Cost per dwelling unit: effect of Lot Size on annual cost 3: near distance, high tract dispersion

			cost per year			cost per month		
lot size (acres)	distance (miles)	tracts	water	sewer	total	water	sewer	total
0.25	0.25	4	168.48	86.85	255.33	14.04	7.24	21.28
0.5	0.25	4	236.64	121.47	358.11	19.72	10.12	29.84
0.75	0.25	4	286.22	149.15	435.37	23.85	12.43	36.28
1	0.25	4	317.34	170.78	488.13	26.45	14.23	40.68

Table 2.3-17. Cost per dwelling unit: effect of Lot Size on annual cost 4: far distance, high tract dispersion

			cost per year			cost per month		
lot size (acres)	distance (miles)	tracts	water	sewer	total	water	sewer	total
0.25	5	1	$ 272.99	$ 158.68	$ 431.67	$ 22.75	$ 13.22	$ 35.97
0.5	5	1	341.51	192.94	534.45	28.46	16.08	44.54
0.75	5	1	391.09	239.09	630.18	32.59	19.92	52.51
1	5	1	421.94	259.82	681.77	35.16	21.65	56.81

Table 2.3-18. Cost per dwelling unit: effect of Distance on annual cost 1: small lot, low tract dispersion

			costs per year			costs per month		
lot size (acres)	*distance (miles)*	tracts	water	sewer	total	water	sewer	total
0.2	*0.25*	1	$ 148.52	$ 77.47	$ 225.99	$ 12.38	$ 6.46	$ 18.83
0.2	*0.5*	1	151.41	78.77	230.19	12.62	6.56	19.18
0.2	*1*	1	157.01	81.41	238.41	13.08	6.78	19.87
0.2	*2*	1	168.39	86.64	255.03	14.03	7.22	21.25
0.2	*3*	1	179.66	91.87	271.53	14.97	7.66	22.63
0.2	*4*	1	190.96	97.10	288.06	15.91	8.09	24.00
0.2	*5*	1	202.23	112.01	314.24	16.85	9.33	26.19

Table 2.3-19. Cost per dwelling unit: effect of distance on annual cost 2: large lot, low tract dispersion

			costs per year			costs per month		
lot size (acres)	*distance (miles)*	tracts	water	sewer	total	water	sewer	total
1	*0.25*	1	$ 309.66	$ 167.89	$ 477.55	$ 25.81	$ 13.99	$ 39.80
1	*0.5*	1	312.56	169.67	482.23	26.05	14.14	40.19
1	*1*	1	318.15	173.27	491.43	26.51	14.44	40.95
1	*2*	1	329.53	180.44	509.98	27.46	15.04	42.50
1	*3*	1	340.72	189.15	529.87	28.39	15.76	44.16
1	*4*	1	352.10	196.84	548.94	29.34	16.40	45.74
1	*5*	1	363.28	204.52	567.80	30.27	17.04	47.32

Table 2.3-20. Cost per dwelling unit: effect of distance on annual cost 3: small lot, high tract dispersion

			costs per year			costs per month		
lot size (acres)	*distance (miles)*	tracts	water	sewer	total	water	sewer	total
0.2	*0.25*	4	$ 157.73	$ 79.95	$ 237.68	$ 13.14	$ 6.66	$ 19.81
0.2	*0.5*	4	163.29	83.73	247.02	13.61	6.98	20.59
0.2	*1*	4	174.28	91.28	265.56	14.52	7.61	22.13
0.2	*2*	4	196.35	106.43	302.78	16.36	8.87	25.23
0.2	*3*	4	218.37	121.57	339.95	18.20	10.13	28.33
0.2	*4*	4	240.35	136.72	377.07	20.03	11.39	31.42
0.2	*5*	4	262.42	151.82	414.25	21.87	12.65	34.52

Table 2.3-21. Cost per dwelling unit: effect of distance on annual cost 4: large lot, high tract dispersion

			costs per year			costs per month		
lot size (acres)	*distance (miles)*	tracts	water	sewer	total	water	sewer	total
1	*0.25*	4	$ 317.34	$ 170.79	$ 488.13	$ 26.45	$ 14.23	$ 40.68
1	*0.5*	4	322.90	175.47	498.38	26.91	14.62	41.53
1	*1*	4	333.89	184.84	518.74	27.82	15.40	43.23
1	*2*	4	355.87	203.62	559.49	29.66	16.97	46.62
1	*3*	4	377.98	222.50	600.48	31.50	18.54	50.04
1	*4*	4	399.96	241.17	641.14	33.33	20.10	53.43
1	*5*	4	421.94	259.91	681.85	35.16	21.66	56.82

Table 2.3-22. Cost per dwelling unit: effect of tract dispersion on annual cost 1: small lot, near distance

			costs per year			costs per month		
lot size (acres)	distance (miles)	*tracts*	water	sewer	total	water	sewer	total
0.2	0.25	*1*	$ 147.01	$ 77.47	$ 224.49	$ 12.25	$ 6.46	$ 18.71
0.2	0.25	*2*	149.59	78.65	228.24	12.47	6.55	19.02
0.2	0.25	*3*	153.57	78.98	232.55	12.80	6.58	19.38
0.2	0.25	*4*	157.36	79.95	237.31	13.11	6.66	19.78

Table 2.3-23. Cost per dwelling unit: effect of Tract Dispersion on annual cost 2: large lot, near distance

			costs per year			costs per month		
lot size (acres)	distance (miles)	*tracts*	water	sewer	total	water	sewer	total
1	0.25	*1*	$ 306.38	$ 167.89	$ 474.27	$ 25.53	$ 13.99	$ 39.52
1	0.25	*2*	308.82	168.58	477.40	25.74	14.05	39.78
1	0.25	*3*	312.67	169.59	482.26	26.06	14.13	40.19
1	0.25	*4*	316.52	169.88	486.41	26.38	14.16	40.53

Table 2.3-24. Cost per dwelling unit: effect of Tract Dispersion on annual cost 3: small lot, far distance

			costs per year			costs per month		
lot size (acres)	distance (miles)	*tracts*	water	sewer	total	water	sewer	total
0.2	5	*1*	200.73	111.97	312.70	16.73	9.33	26.06
0.2	5	*2*	229.10	126.02	355.12	19.09	10.50	29.59
0.2	5	*3*	240.49	146.47	386.96	20.04	12.21	32.25
0.2	5	*4*	262.05	141.78	403.83	21.84	11.82	33.65

Table 2.3-25. Cost per dwelling unit: effect of Tract Dispersion on annual cost 4: large lot, far distance

			costs per year			costs per month		
lot size (acres)	distance (miles)	*tracts*	water	sewer	total	water	sewer	total
1	5	*1*	$ 360.00	$ 204.52	$ 564.52	$ 30.00	$ 17.04	$ 47.04
1	5	*2*	388.24	215.99	604.23	32.35	18.00	50.35
1	5	*3*	399.58	236.45	636.03	33.30	19.70	53.00
1	5	*4*	421.12	259.91	681.03	35.09	21.66	56.75

IV. Effect of higher water consumption

It is possible that households on larger lots will consume more water, primarily for lawn and landscape watering. To account for this, costs for large lot scenarios are recalculated assuming that per capita water consumption is 125 gpd. This represents 262,500 gpd more water consumed than if average use is 100 gallons per capita per day (gpcd). Higher daily water usage should increase water distribution costs. Transmission mains and associated valves must be larger to accommodate higher flow rates. Pump stations must be sized to pump larger quantities of water, increasing capital costs, and energy costs will be higher. Collection costs in the sanitary sewer system should not be affected, as the increase in water use will be returned to groundwater. Changes in infrastructure requirements, such as pipe diameter, needed as per capita consumption increases can be noted by comparing system requirements under the different sets of assumptions about per capita water use. The impact of increased water use is examined by recalculating the cost of delivering water to four scenarios with large (one acre) lots.

The difference between water costs for 100 gpcd scenarios and 125 gpcd water use rates is slight. Costs differ by less than one percent when the distance between the developments and existing centers is small (0.25 mile), as in the first two rows of Table 2.3-14. The difference in costs is somewhat higher when the distance between the developments and existing centers is large (5 miles) because transmission mains are a larger proportion of the water costs. Costs are higher in the 125 gpd case mainly because transmission mains must be sized larger and are thus more costly per linear foot. Scenarios locating development far from existing centers and requiring longer transmission mains will therefore be more sensitive to changes in water consumption. This requires greater lengths of transmission mains, one of the pieces of infrastructure that is affected by greater water consumption.

Table 2.3-26. Effect of increased water consumption

lot size	distance	number of tracts	annual difference in cost	percent difference in cost
1 acre	0.25 mile	1	$7,393	0.8%
1 acre	0.25 mile	4	$8,231	0.9%
1 acre	5 miles	1	$26,615	2.4%
1 acre	5 miles	4	$51,921	3.9%

The comparison shows that increasing per capita water consumption by 25 gpd results in only a very small increase in water distribution costs. It should be noted, however, that this simulation does not include costs for treatment and storage of municipal water supply. Including such costs in the analysis may affect the magnitude of the differences in cost reported in Table 2-3.14.

Section 4. Implications and Conclusions

I. Summary and policy implications

The results show that smaller lots, shorter distances between existing centers and less tract dispersion reduce public water and sewer costs. These results fit with previous work on the costs of alternative land settlement patterns (including Burchell and Listokin 1992b, Frank 1989, Duncan et al 1989 and Esseks et al 1999). The present study, however, extends these works by explicitly defining three components of spatial form and isolating their effects on public costs.

Three components of spatial form are examined: 1) separation between houses (lot size), 2) separation between new development tracts and service centers (distance) and 3) separation between individual development tracts (tract dispersion). The results presented above show that all three components affect costs. Greater separation, of all three types, results in higher water and sewer costs. Water and sewer costs seem to be most sensitive to lot size. This is because density-related infrastructure (water distribution and sewer collector mains) makes up almost 65 percent of costs on average.

The results also show that distance and tract dispersion have a complimentary effect on costs. When tract dispersion is low (i.e., there is one distinct development tract) costs increase by about $50,000 per mile as distance is increased. When tract dispersion is high (i.e., there are four distinct development tracts) costs increase by between $111,000 and $122,000 per mile[2]. When distance is near (0.25 mile) costs increase by between $9,000 and $15,000 as the number of development tracts is increased by one. When distance is far (5 miles) cost increase by between $50,000 and $135,000 as the number of development tracts is increased by one. This indicates that a greater degree of separation between development tracts increases the sensitivity of costs to distance and a greater degree of separation between new development tracts and existing centers increases the sensitivity of costs to tract dispersion. This complimentary effect is due to

[2] Refer to Tables 2.3-6 through 2.3-9.

the fact that distance and tract dispersion affect the same types of infrastructure, namely transmission water lines, interceptor sewer lines and associated appurtenances.

The spatial form of development will affect the cost of water and sewer service in two ways. First, greater separation between houses, between development tracts and existing centers and between new development tracts increases the amount of infrastructure required to provide service. This effect has been demonstrated in this report and is shown in Tables 2.3-2 through 2.3-13. Second, larger lot sizes may result in greater per household water consumption because of increased landscape watering. Higher water consumption may increase distribution system costs by requiring larger water mains. The effect of increasing water consumption from 100 gpd to 125 gpd in l acre lots on distribution system costs has been demonstrated in this report. Results presented in Table 2.3-26 show that this effect is quite small. Higher water consumption may also increase overall water costs by increasing the amount of water that requires treatment and storage, an effect which has not been analyzed in this study.

Many public utilities are self-financing entities. They are required, legally in some cases, to recover the cost of service through fees. Most utilities charge a flat rate or base fees on water usage using average cost methodologies. If average cost pricing for water and sewer service is used to recover costs, some users in less compact spatial forms may pay less than the true cost of service, while users in more compact forms may pay more. The simulation estimates marginal costs. Costs are estimated for an increment of 3,000 new houses that are built in an existing community. Only expenditures required as a direct result of delivering water and sewer service to the new houses are considered. Tables 2.3-14 through 2.3-25 clearly show that per household costs for alternative spatial forms can be different even if consumption is held constant. If uniform, average cost-based rates are charged to all customers, irrespective of spatial form, some users may pay more than the cost of delivery while others may pay less. Users in developments with small lots, located close to existing centers and located close to other developments end up subsidizing water and sewer service for users in less compact forms.

One possible solution is to charge one-time fees to those whose service costs more to deliver. The results of this study indicate that most of the significant costs are for infrastructure costs that are incurred only once during construction. Another possibility is to shift construction and financial responsibility for infrastructure installation to the developer. As a new subdivison is built, the developer must install distribution and collector mains, valves, hydrants and manholes at his own expense. Infrastructure that is located within the subdivision is a large portion of the expenses. Requiring the developer to bear the cost of distribution and collector mains would shift about 65 percent of the total cost of new development away from the public sector (see Table 2.3-5).

Many public utilities currently use such strategies and thus use marginal cost pricing to recover costs. Roanoke County, Virginia, for example, charges developers a fee for extending transmission and interceptor mains to serve new development. Developers must install and pay for any infrastructure occurring within a subdivision, including distribution and collector lines. (Gary Robertson, personal communication).

Much opposition to less compact or “sprawl” development forms has been based on the premise that it is more costly to serve with public services such as water and sewer. The present analysis shows that such a premise is correct. Shifting costs, however, from the public to private developers and homeowners may be a relatively simple matter and may eliminate much of the disparity in public costs between spatial forms of development. If private parties are required to bear most of these costs, efforts by state and local governments to encourage more compact forms may be harder to justify on the basis of water and sewer costs.

II. Limitations and extensions of the present analysis

The most significant limitation of the present analysis is that is does not allow for the use of privately owned water and wastewater systems, i.e., wells and septic fields. Such systems are another way to shift costs from the public to private homeowners and will significantly reduce public costs.

A second limitation is that costs presented in the present study do not reflect the timing of development. This model is designed as if planners have perfect foresight of all new growth that will occur over a 30-year planning period. All infrastructure required to service new growth is then constructed in the first year of the period. This is not a realistic case, but the issue of the effect of timing on public service costs is outside the scope of the present study, which seeks to isolate the effects of components of spatial form.

Another limitation is the lack of detailed information on operating costs. As discussed above, increased use of proffer charges and other cost-shifting strategies make operating costs far more important from a local government standpoint. Pump energy costs are the only operating cost item considered here. Local government accounting methods make differentiating operating costs in such a way that differences in spatial form can be analyzed very difficult. There is a lack of detailed information on the relationship between the spatial for and operating costs.

Extensions of the present analysis might include the possibility of private water and sewer systems and operating costs. One way to do this may be to construct a statistical model using local government cost data from a broad cross-section of counties. Extensions might also better analyze the effect of higher water consumption on larger lots. Such a study would include the cost of water storage and treatment, including any possible economies of scale involved when larger quantities of water are treated and stored.

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Chapter 3. Cost Consequences of Effluent Allowance Trading in the Connecticut Portion of the Long Island Sound Watershed

Section 1. Problem Statement

I. Introduction

Effluent allowance trading involves the transfer of pollution control responsibility between pollution sources. Effluent allowances are the right to discharge a given quantity of waste into the environment over a given time period. Allowance trading has been proposed as a way of reducing pollution control costs, encouraging innovative pollution prevention techniques and more quickly achieving water quality goals. Trading programs for managing air and water pollution have been implemented in the United States and elsewhere.

Long Island Sound, a major estuary in the northeastern United States, experiences chronically low dissolved oxygen levels. Excessive nitrogen loads from anthropogenic activities in the Sound watershed have been identified as the cause of the oxygen problem. The state of Connecticut is examining the possibility of introducing an effluent allowance trading system in order to reduce the cost of achieving required reductions in nitrogen discharge.

The objective of the present study is to analyze the cost implications of a nitrogen allowance trading system for wastewater treatment plants in Connecticut. A linear programming model is used to predict trading outcomes and allowance prices. The total cost of achieving a nitrogen load cap is calculated under three administrative approaches. The first approach is a uniform reduction requirement where all plants are required to reduce discharge by the same proportion. The second approach is an administrative reallocation of waste load where a regulatory agency assigns control responsibility based on the agency's understanding of relative costs. The third approach is a flexible effluent allowance trading system. The results will show that a trading program offers cost savings over traditional regulatory approaches, demonstrate the potential for further cost savings from pollution prevention activities and estimate the cost savings that would result from including nonpoint sources in the overall nitrogen reduction strategy.

II. The Situation in Long Island Sound

II.A The Estuary and Long Island Sound Study

Long Island Sound is an estuary on the northeastern coast of the United States. It is 110 miles long and bounded by the state of Connecticut and Westchester County, New York to the north and Long Island to the south. The Sound is an unusual estuary in that it is open at both ends, at the East River to the west and the Race at the eastern end. Figure 3.1-1 shows a map of the LIS watershed and major sub-watersheds. The Long Island Sound watershed is 16,000 square miles including the entire state of Connecticut, part of New York (portions of Westchester, Nassau and Suffolk Counties and New York City), and extends as far north as Canada. The Connecticut, Housatonic and Thames are the major river systems that empty into the Sound (LISS 1994).

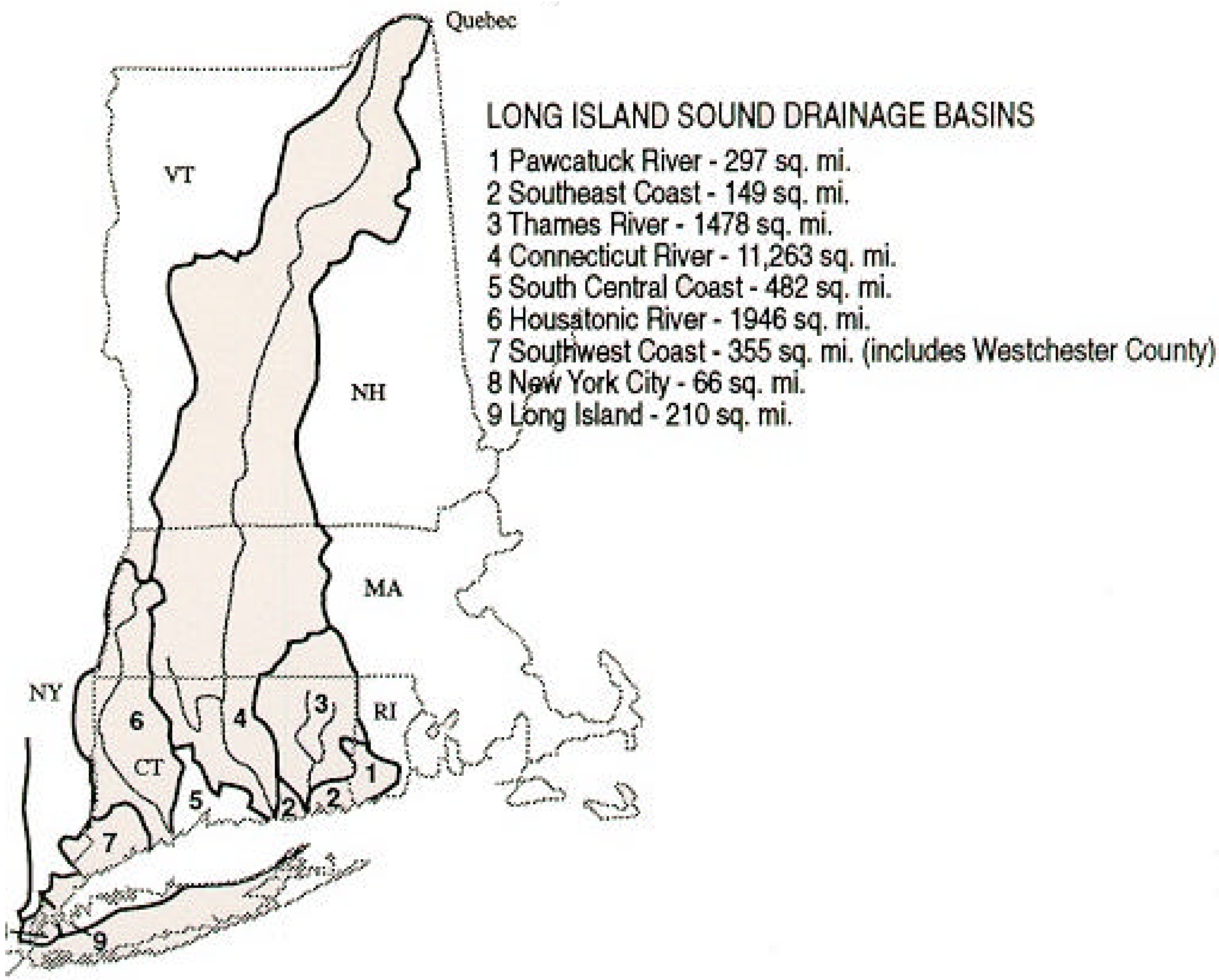

Figure 3. 1-1. Long Island Sound watershed (source LISS/EPA)

Long Island Sound drains one of the most highly urbanized areas in North America. Approximately 8.5 million people live in the watershed and anthropogenic impacts on the water body have been significant (Powers 1998). As a result, management of water quality in the Sound has intensified over the past 15 years. In 1985 the Long Island Sound Study (LISS) was begun as a cooperative effort between the U.S. Environmental Protection Agency and the states of Connecticut and New York. The Study's purpose is to "research, monitor, and assess the water quality of Long Island

Sound" (LISS 1994). In 1988 the Sound was designated an Estuary of National Significance under the National Estuary Program and the Management Conference for the Long Island Sound Study was created.

The Management Conference issued the Comprehensive Conservation and Management Plan (CCMP) in 1994. The plan's purpose was to provide a blueprint for "protecting and improving the health of Long Island Sound while ensuring compatible human uses within the Sound ecosystem" (LISS 1994). The CCMP lists six problems upon which the Management Conference will focus most of its attention: (1) low dissolved oxygen or hypoxia, (2) toxic contamination, (3) pathogen contamination, (4) floatable debris, (5) the impact of these water quality problems and habitat degradation and loss on the health of aquatic life, and (6) habitat loss and degraded water quality resulting from land use and development (LISS 1994). The LISS considers low dissolved oxygen levels to be the most significant problem.

II.B Nitrogen pollution and hypoxia

II.B.1 Description of the hypoxia problem

Hypoxia, low oxygen levels, is a serious problem in certain areas of Long Island Sound in the late summer. The maximum possible oxygen concentration in water at summer temperatures is 7.5 milligrams per liter (mg/L). Concentrations above 5.0 mg/L are satisfactory for aquatic life. Dissolved oxygen (DO) levels between 3.5 and 5.0 mg/L affect the most sensitive species, but are generally healthy. Concentrations below 3.5 mg/L are considered hypoxic and are unhealthy living conditions for marine life. The most severe effects on marine life occur when DO levels go below 2.0 mg/L (LISS 1996).

Hypoxic conditions occur in the late summer, when high water temperatures limit the amount of oxygen that can be dissolved in the water. Hypoxic conditions generally last between 40 to 80 days and can affect anywhere from 25 to 40 percent of the bottom area of the sound. The areas at the far western end of the sound are most impaired by hypoxic conditions. Dissolved oxygen levels in the late summer in this area regularly approach 1.5 mg/L and have been known to go much lower (LISS 1996). Figure 3.1-2 shows dissolved oxygen levels in the Sound. The LISS has set a goal of a minimum DO level of 3.5 mg/L at all times and in all portions of the sound.

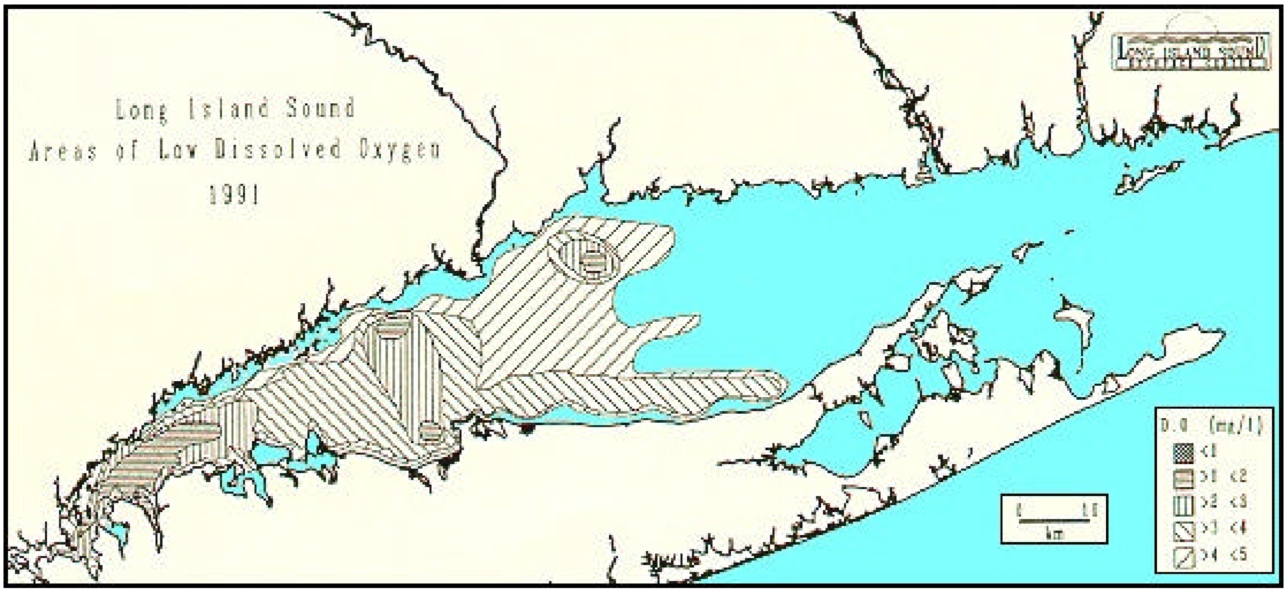

Figure 3. 2-2. Areas of low dissolved oxygen in Long Island Sound (source EPA/LISS)

<u>II.B.2 Cause of the hypoxia problem</u>

The root cause of low DO levels is excessive amounts of nitrogen deposited in Long Island Sound. Large amounts of nitrogen stimulate large algae blooms. When the blooms die off, bacteria decompose the plant matter in a process that requires oxygen. Such oxygen depletion results in hypoxia. It is estimated that 99,900 tons of nitrogen enter the Long Island Sound ecosystem each year (LISS 1997). Of that, 58,500 tons are a result of human activities. Discharge from wastewater treatment plants is the most significant source of anthropogenic nitrogen. Some runoff from nonpoint sources, especially urban stormwater, may also be a significant factor.

Discharged nitrogen has a different effect on the impaired areas of the Sound depending on where in the watershed it is released. Not all nitrogen discharge or runoff reaches the impaired portions of the sound. Nitrogen discharged farther north and east in the watershed has less of an effect on the impaired areas for two reasons. First, some nitrogen is assimilated through natural processes during river transport before it reaches the Sound. Second, once in the Sound, some nitrogen will drift out of the Sound through the Race or the East River without affecting the impaired areas. The unassimilated nitrogen that reaches the impaired areas of the Sound is referred to as the delivered load. Ratios expressing the relative impact of nitrogen discharge have been developed for both processes described above and used to translate end-of-pipe discharge in various areas of the watershed into delivered load.

The LISS management efforts focus on nitrogen from Connecticut and New York only, so amounts that enter the sound through the East River and the Race, from air deposition and from tributaries north of Connecticut are not subject to management measures. It is estimated that 40,800 tons of nitrogen originate within Connecticut and New York. It is this delivered load 40,800 tons that the LISS considers controllable. Watershed and hydrologic models indicate that to meet the dissolved oxygen level goal by 2015 the controllable load, nitrogen loads from human activities in Connecticut and New York, must be reduced by 58.5% to 23,800 tons per year. The majority of current nitrogen loads comes from point source discharges, most of which are municipal sewage treatment plants – or publicly owned treatment works (POTWs). Point sources account for 32,400 tons per year while nonpoint sources, primarily urban stormwater runoff, are responsible for 8,400 tons (LISS 1999).

II.B.3 Connecticut's management plan to reduce nitrogen loads

Nitrogen effluent allowance trading is of interest in to the state of Connecticut as it attempts to meet its reduction goal of 58.5 percent by 2015. Monitoring and enforcement are perceived to be easier for point sources than for nonpoint sources and thus Connecticut is proposing that wastewater treatment plants will be responsible for making most, if not all, of the required reductions. Connecticut Department of Environmental Protection (CTDEP) has determined that point sources in Connecticut must reduce delivered loads by approximately 70 percent from 1990 levels. Steps to achieve a 10 percent reduction in delivered nitrogen from nonpoint sources through voluntary measures will also be taken. Taken together, the mandatory point source reductions and the voluntary nonpoint source reductions would meet the overall 58.5 percent delivered load reduction goal.

CTDEP plans to require all POTWs to reduce end-of-pipe nitrogen loads by 70 percent regardless of their relative contribution to the impairment in Long Island Sound. CTDEP calculated the delivered load from Connecticut POTWs in 1990 to be 10,407,393 pounds. A 70 percent reduction is 7,951,185 pounds, which translates into a delivered load cap of 2,456,210 in 2015.

As mentioned above, the effect of a pound of nitrogen on the impaired areas of Long Island Sound is different depending on where in the watershed it is released. For example, 100 percent of nitrogen discharged at Stamford, located on the southwest coast of Connecticut, reaches impaired areas of the Sound. By contrast, only 9 percent of the nitrogen discharged at Killingly, located in the Thames River watershed in eastern Connecticut, reaches impaired areas of the Sound. Thus, treatment plants in the western portion of Connecticut must reduce discharge by a greater amount than plants in the northeastern portions of the state in order to achieve the same improvement in water quality.

The state of Connecticut has expressed interest in devising a program for point source dischargers that reallocates nitrogen effluent control among POTW's as a way to reduce the total cost of compliance. Because of the stringency of the reduction requirements and the different water quality consequences of each POTW, the uniform 70 percent discharge requirements for all plants may be prohibitively expensive, particularly for POTWs in eastern Connecticut. Instead of undertaking costly steps to reduce nitrogen flows, plants in eastern Connecticut could sponsor additional controls from POTWs in the west that are able to achieve the same reduction in delivered load at a much lower cost.

Expressing a desire to explore cost effective regulatory options, the LISS convened the Nitrogen Trading Discussion Group to examine the possibility of using an effluent allowance trading program to lower the cost of achieving stated water quality goals. CTDEP was an active member in these discussions and developed outlines of a draft trading policy (Shabman and Stephenson 1998). The Connecticut General Assembly later enacted a law instructing CTDEP to develop a trading program (Connecticut General Assembly 1999).

III. Objectives

The objective of the present study is to analyze the cost implications of a nitrogen allowance trading system for wastewater treatment plants in Connecticut. Specifically, the report will:

1. calculate the overall cost of meeting the nitrogen cap with uniform reduction requirements at point sources
2. calculate the least cost waste load allocation or, expressed differently, the least cost allocation of nitrogen discharge allowances and compare the overall nitrogen control cost associated with uniform reduction requirements, administrative allocation of waste load and an effluent allowance trading.
3. identify the sensitivity of total costs to reallocating some nitrogen control responsibility to nonpoint sources.

IV. Procedures

The conceptual basis for effluent allowance trading and the requirements of a well-designed market for nitrogen allowances are described in Section 2. In Section 3, a linear programming model is developed to calculate the least cost distribution of nitrogen allowances among Connecticut POTWs. This least cost solution simulates the outcome of a trading program under certain behavioral assumptions and given that nitrogen abatement costs are known. The model is then used to examine the nitrogen control cost of a uniform reduction requirement, administrative reallocation of control responsibility and an effluent allowance trading program. The cost consequences to POTWs of shifting control responsibility to nonpoint sources is also examined. Results are discussed in Section 4. Policy implications and conclusions are discussed in Section 5.

Section 2. Policy Options for Reducing Nitrogen Discharge

The state of Connecticut must reduce nitrogen loads to Long Island Sound in order to meet water quality objectives of the Long Island Sound Study. It has been determined that much of the reduction from wastewater treatment plants. Among the policy options being considered are uniform reduction requirements for each plant, an administrative allocation of nitrogen loads by regulatory authorities or a flexible effluent allowance trading system. The section below will describe the conventional regulatory approach to pollution control and some alternatives to it. The alternatives include administrative allocation of nitrogen loads and effluent allowance trading. The conceptual basis for allowance trading will also be discussed in detail.

I. Conventional pollution control regulation

Most water pollution control regulation is dealt with by the federal Clean Water Act (CWA). The CWA has established the protection of water quality for wildlife and recreational purposes as a goal. Most regulation under the CWA deals with point sources. The Environmental Protection Agency (EPA) sets effluent discharge standards for a list of pollutants, identified by the CWA or subsequent regulations. The standards are set based on the best technology available for controlling the pollutant and point source in question. Such standards are then used by the EPA and the states to write permits for point source dischargers. The permits establish conditions under which dischargers are allowed to operate including limitations on the amount of pollutant each source may emit. Point source discharge permits may also take into account water quality standards for a given body of water. If technology-based standards are not sufficient to ensure a mandated level of water quality, the permitting authority may set more stringent limitations on individual dischargers. Once a permit is issued to a party, the CWA prohibits issuance of future permits that would allow the point source to increase its assigned discharge.

The current system of water pollution control regulation has been criticized on at least three grounds. First, there is very limited flexibility to assign control responsibility according to cost. Standards are generally uniformly applied to all point sources even though the marginal cost of control is different for each discharger. Second, because regulators identify the technology that will be used to write discharge permits, there is little incentive for permitted parties to seek innovative ways of pollution control. Although dischargers are free to select any method of controlling discharge as long as it achieves the permitted standard, most point sources use the technology upon which the standard is based (Atcheson 1996). This is because regulators often write required technology into permits along with standards and because adopting other control methods carries substantial risk of exceeding the permitted limit (Stephenson, Shabman and Geyer 1999). Third, under a system of individual permits negotiated or assigned on a case-by-case basis there is no limit, or cap, on the overall amount of pollution discharged into the environment. This limits the ability of the permitting process to achieve overall water quality goals.

II. Other policy options for pollution control

Conventional uniform point source standards can be costly because they do not equalize the marginal cost of pollution control across all sources and do not provide dischargers with incentives to invest in new control methods. A goal of the Connecticut nitrogen program is to reduce the cost of achieving POTW load targets. This can be achieved in three ways: 1) improved (non-uniform) allocation of discharge control responsibility among POTWs, 2) creation of incentives for each POTW to develop new methods to reduce nitrogen discharge control costs, and 3) reallocation of discharge control responsibility between POTWs and nonpoint sources.

II.A. Administrative reallocation of waste load

One way to reduce the overall cost of a nitrogen reduction program is to improve the allocation of pollution control responsibility so that the marginal control costs are equalized for all effluent dischargers. Total control costs are minimized when marginal costs are equal. This can be done in two ways: an administrative reallocation or an effluent allowance trading program. In an administrative waste load reallocation a regulatory authority determines the least cost distribution of pollution control responsibility, based on the regulators' understanding of available options, and issues discharge permits accordingly. Sources that are able to reduce discharge most cheaply are required to make larger reductions. Assignment of waste load limits can be achieved using financing incentives such as generous cost share provisions for plants that are required to invest in capital upgrades or using more traditional regulatory measures such as legally binding discharge permits.

Although they distribute waste load reductions non-uniformly, administrative reallocations retain many features of conventional regulation. In particular, permitted discharge levels are often the result of negotiations between the regulator and the discharger. This negotiation process will often lead to higher levels of discharge than would be seen with a more flexible trading system. Dischargers have incentives to negotiate as high a level of discharge as possible in order to reduce costs and avoid the risk on non-compliance. Dischargers will therefore understate their ability to control effluent. Because regulators are unsure of the actual achievable performance, resulting permitted discharge levels will often be higher than what plants can actually achieve.

II.B. Effluent allowance trading

Effluent allowance trading is another way to reallocate pollution control responsibility according to marginal cost. Effluent allowance trading involves the transfer of pollution control responsibility between pollution sources. A regulating authority determines the overall level of discharge that is consistent with environmental goals, creates rights to discharge effluent based on the overall limit and distributes those rights, called allowances, to dischargers. Parties that hold allowances may use them to discharge effluent or sell extra allowances that are not used. When two POTWs face different marginal nitrogen abatement cost functions, the source that is able to reduce nitrogen discharge more cheaply (source 1) will do so and sell excess allowances to a source with higher marginal abatement costs (source 2). Trade will occur because source

1 is better off selling the allowances at a price higher than its marginal abatement cost while source 2 is better off purchasing allowances at a price lower than its marginal abatement cost. This type of trade is possible until the marginal abatement costs for the two dischargers are equal (Tietenberg 1998, p. 236).

Improved allocation of pollution control is the aspect most often emphasized when discussing trading as an improvement over conventional regulatory standard setting. Leading textbooks (Tietenberg 1998, p. 236; Field 1997, Pearce and Turner 1990, p. 110), as well as the Environmental Protection Agency's *Draft Framework for Watershed-Based Trading* (EPA 1996) explain the primary rationale for trading in terms of the equimarginal principal.

A more dynamic view of trading offers an important additional reason for cost savings. The pollution prevention argument for allowance trading recognizes that a centralized agency has limited ability to know all the pollution control alternatives for each individual discharge source. Instead, allowance trading advocates believe that individual dischargers, each with unique circumstances and possessing first-hand knowledge and experience of their particular systems, are in the best position to determine how to manage their waste stream. A positive price for effluent allowances then creates an incentive for individual dischargers to search for pollution prevention opportunities. Dischargers with high marginal abatement costs search for means to lower costs in order to avoid purchasing allowances. Dischargers with low initial costs also search for additional improvements because lowering costs would free a greater number of allowances for sale. These opportunities may arise through experimentation with new technology or changes in production or pollution control processes (Stephenson and Shabman 1996). This rationale views trading in a dynamic framework as marginal control cost functions are not known with certainty and can change rapidly with the discovery of new knowledge.

A trading program also differs from administrative reallocation in that there is no negotiation process for issuing permits. With a trading program, environmental quality goals are translated into an overall cap. The cap is then distributed to individual dischargers based on plant size or past history of discharge. The elimination of the permitting process removes dischargers' incentives to understate pollution control capabilities and creates incentives for innovative control, as described above.

III. Incorporating nonpoint source reductions

Expanding nitrogen control policy, especially trading programs, to include nonpoint sources can reduce costs by increasing the flexibility given to dischargers. Municipalities are often responsible for both point and nonpoint sources. For example, town governments in Connecticut operate POTWs and are responsible for controlling nonpoint source nitrogen runoff that results from urban stormwater discharges. When a cap is imposed, municipalities may find it less costly to shift control responsibility to nonpoint sources if point source dischargers face high marginal abatement costs. Including nonpoint sources will also increase the number of potential trading partners within the context of an effluent allowance trading program. This will result in lower transactions costs and perhaps greater demand and supply for allowances.

IV. Characteristics of effluent allowance trading systems

Allowance trading offers a way to reduce the cost of achieving water quality goals. Trading equalizes the marginal cost of pollution control across all dischargers. It also provides incentives for dischargers to discover innovative strategies for pollution control that reduce the marginal cost of control. In order for the goals of trading to be realized, the system must be well designed to encourage trades and innovation. The characteristics of well designed allowance markets are described below.

IV.A. General characteristics of effective markets: property rights

Effluent allowance trading systems create property rights (allowances) to discharge waste into the ambient environment. Creation of property rights is intended to encourage exchange of allowance and innovative pollution control methods. Property rights “specify both the proper relationships among people and the use of things and the penalties for violating those relationships” (Randall 1987, p. 157). In order for any market to be successful, property rights must have certain general characteristics. They must be exclusive, specific, transferable and enforceable (Randall 1987). Exclusivity ensures that only the owner has access to the property in question. Specificity of property rights ensures that the ways in which the owner is permitted to use the property are clearly and specifically defined. Transferability permits buying and selling of property rights and thus allows trade to be an effective way to resolve conflicts and allocate resources. Enforceability of property rights includes effective detection of violations and detainment and punishment of violators. If enforcement is not possible, then no property right exists because there is no way to prevent non-owners from using property.

The above characteristics of property rights must apply to commodities in any market system of exchange. Specific issues are associated with effluent allowance trading. These issues are important because effective trading systems offer strong incentives to reduce the cost of compliance with environmental goals. The following aspects should be considered in designing trading programs.

IV.B. Creating transferable property rights to discharge effluent

IV.B.1. Establishing water quality goals: capping watershed loads

Effluent allowance systems begin by establishing ambient water quality goals. Managers must first determine what ambient water quality levels are required to achieve environmental goals. The LISS, for example, determined that dissolved oxygen levels of 3.5 mg/L are required to sustain aquatic life such as fish. These ambient water quality levels must then be translated into load limits. Next, effluent loads must be capped at levels that are consistent with achievement of ambient water quality goals. The LISS and CTDEP determined that in order for DO levels of 3.5 mg/L to be maintained, nitrogen delivered to impaired areas of the Sound from Connecticut POTWs must not exceed 2,456,210 pounds per year.

After the overall cap is set allowances are distributed to participating sources. A discharge allowance is the right to discharge a unit of effluent over a specified period of time. For example, an allowance gives the owner authorization to discharge 1 pound of nitrogen during the calendar year. The total number of allowances issued is equal to the cap.

A source will generate surplus allowances if it discharges less than the allowances it receives in the initial allocation. It may then sell the surplus to other sources that are unable to discharge less than their allotted amount. Total discharge within the system cannot exceed the cap. Any new sources, or existing sources that want to expand, must buy allowances in order to begin operation (Powers 1998). Effluent allowance systems are often referred to as "cap-and-trade" because overall load is capped, distributed to participants and then traded among dischargers.

Trading systems can be open or closed (Stephenson and Shabman 1996). In a closed system no new discharge rights are created once the overall cap on discharges is established. Closed systems are cap and trade as described above. Open effluent trading systems differ from closed systems in that no overall cap is set in an open system. New sources of pollution may begin operation and participation in the trading system at any time, the only condition being compliance with a discharge permit. Trading occurs in open systems when a source that is unable to comply with its discharge permit in a cost-effective manner pays another to reduce emissions rather than undertake the reduction itself. This arrangement is often referred to as an "offset." Permitted discharge is generally based on available technology standards rather than ambient water quality goals (Powers 1998).

An effective effluent allowance trading system should be closed. A significant advantage of closed systems is that they allow for growth in the number of dischargers without increasing total pollutant loads in the environment. This is because new sources must buy into a closed system by purchasing existing allowances. By contrast, new sources may be included in open systems with the issuance of additional permits. No reduction by existing sources is required in an open system. Also, in closed systems permitted discharges are based on ambient water quality goals. In open systems permitted discharge levels are based on technologically achievable standards. Closed systems may therefore be better able to meet environmental quality goals (Stephenson and Shabman 1996).

IV.B.2. Compliance Flexibility

Effluent allowance trading systems allow dischargers to determine how they will meet regulatory requirements for pollution control. This ability of dischargers to choose their own strategy is referred to as compliance flexibility (Stephenson, Shabman and Geyer 1999). Compliance flexibility can be internal or external.

Internal compliance flexibility allows individual discharges to choose their own pollution control methods. No specific control technology is required. Such an arrangement encourages dischargers to search for innovative and cost-effective control processes. Effluent can be controlled either by installing pollution control equipment or by modifying production process to generate less waste. Internal flexibility allows dischargers to respond to financial incentives to reduce effluent flows, i.e. a positive price for allowances (Stephenson, Shabman and Geyer 1999).

The need for internal compliance flexibility is derived from the dynamic view of trading described above. In this dynamic view, trades need not occur in order for cost savings to be realized. Individual sources will actively try to discover new ways to cost-effectively reduce pollution internally because reduced discharge leads to the creation of assets, allowances, which have value. A trading system may be judged successful even when no trades occur if better control performance and lower control costs are observed. The possibility of obtaining a valuable asset, or being forced to pay for more allowances, puts pressure on POTWs to search for new, cost-effective ways to reduce discharge (Porter and van der Linde 1995).

External compliance flexibility is the discharger's ability to change its legal obligation to limit its effluent flow. It is the ability to trade allowances. External compliance flexibility ensures that the property right, allowances, is transferable. External flexibility is directly related to the number of opportunities to trade. An effective trading system would therefore minimize transactions costs involved with exchanging effluent allowances. To do this, a trading program should be designed with a minimum of restrictions on trades and provide participants with as much information as possible in order to find willing buyers and sellers and evaluate potential trades (Stavins 1995).

IV.B.3. Measurement, monitoring and enforcement

Effluent discharge and ownership of allowances, the right to discharge a given quantity of waste, must be measured, monitored and enforced in order for an emissions trading system to work. Treatment plants and regulators must devise ways of accurately measuring discharge. Once effluent can be measured, it must also be monitored by treatment plants and regulators to ensure that discharge agrees with the number of allowances held. If a plant is found to be in violation of the program by discharging more than the amount of allowances held, the program must be enforced with penalties that are severe enough to discourage cheating. Implementation of an effluent allowance trading system requires a shift in government activity from technology-based standard setting to monitoring and enforcement. The regulatory authority must keep track of allowances exchanged and measure each source’s discharge to ensure that it agrees with the number of allowances the source owns.

IV.B.4. Certainty

The rules of the trading system must remain stable if the system is to work properly. The notion that the rules governing the exchange and use of allowances should be stable is related to the requirement that property rights must be specific, as discussed above. In establishing a market for any asset, including effluent allowances, certainty about the rules governing the use of the asset is critical for investment in the asset. Uncertainty about the nature and value of allowances in the future will cause participants to be reluctant to trade or engage in innovative control strategies. For example, if dischargers demonstrate superior pollution control performance, previously granted allowances should not be revoked by the regulatory authority. "Anti-backsliding" language in the Clean Water Act may imply that such revocation is possible and is often cited as a barrier to the implementation of trading systems (Powers 1998; Stephenson, Shabman, and Geyer 1999). Also, it is important that the regulatory authorities not impose requirements on how effluent is to be controlled after allowances are distributed and traded.

Section 3. Model Description

I. Introduction

A linear programming model is used to simulate outcomes of potential waste load reallocation policies where nitrogen control technology and costs are known and not subject to change. Waste load allocation policies include a centrally directed administrative allocation and a competitive market for nitrogen discharge allowances. Waste load is allocated among municipal wastewater treatment plants in Connecticut. The objective function of the model is to minimize total compliance costs. The primary constraint is that goals for the amount of nitrogen delivered to impaired waters of Long Island Sound be met.

The model is used to determine the sensitivity of total control costs to: 1) assumptions about nitrogen control performance and 2) the total nitrogen cap level. Differences in total control costs to due to different assumptions about nitrogen control performance will demonstrate the potential savings achievable with an effluent allowance trading system that encourages innovative, cost-effective methods of nitrogen control. Differences in total control costs due to changes in the nitrogen cap level will demonstrate the potential cost savings achievable by incorporating nonpoint source reductions into nitrogen control policy. The model allocates nitrogen discharge among plants under assumptions on nitrogen control performance which are intended to reflect conditions in an administrative reallocation program and a cap and trade program. Total control costs are calculated for 60 percent and 70 percent reduction requirements.

A linear programming model such as this one will choose the least-cost method of distributing control responsibility. Achieving the distribution of control responsibility at the lowest cost is the goal of both administrative reallocation and cap and trade. Linear programming methods have been used frequently to simulate trading of discharge rights in other studies. Hecq and Kestemont (1991) estimate cost consequences of an emissions trading program in Belgium. O'Ryan (1996) uses linear programming to estimate total compliance costs for traditional regulatory approaches and trading with respect to particulate matter air pollution in Chile. Schleich, White and Stephenson (1996) use linear programming to calculate the cost of achieving phosphorus load reductions in the Fox-Wolf River watershed in Wisconsin. Hanley et al (1998) use linear programming methods to quantify cost consequences of a potential nutrient trading program in Scotland.

II. Data

All data is obtained from the Connecticut Department of Environmental Protection (CTDEP). Seventy-four wastewater treatment plants are included in this study. Attenuation factors, exchange ratios, the 1990 calculated discharge, the annual cost of potential process changes, the cost of low and high capital upgrades, the annual operation and maintenance costs and the projected future flow for each plant are presented in appendix F. Attenuation factors and exchange ratios have been estimated by the Long Island Sound Study.

II.A. Normalization rates

A stated goal of the Long Island Sound Study is to prevent dissolved oxygen levels from falling below that which causes severe harm to aquatic life. Most of the concern is for the most heavily impacted areas at the western end of the Sound. The effect of nitrogen on water quality in the areas of the Sound most affected by hypoxia is different depending on where in the watershed the effluent is discharged. Nitrogen from the northeast corner of Connecticut has less of an effect on impacted areas of the Sound than nitrogen from areas farther to the southwest.

To account for this spatial variability in the impact of nitrogen effluent, discharges are weighted according to their location within the watershed. The state of Connecticut is divided into 6 zones and 4 tiers. Zones are vertical bands that correspond to subwatersheds. Figure 3.3-1 shows the nitrogen control zones in the LIS watershed. Zones with lower numbers are farther to the east and have a lesser impact on water quality in the impacted areas. Zones 1-6 are in Connecticut and will be included in the present analysis. Tiers are horizontal bands across the state. Tiers with lower numbers are farther south (closer to the Sound) and have a greater impact on water quality in the impacted areas.

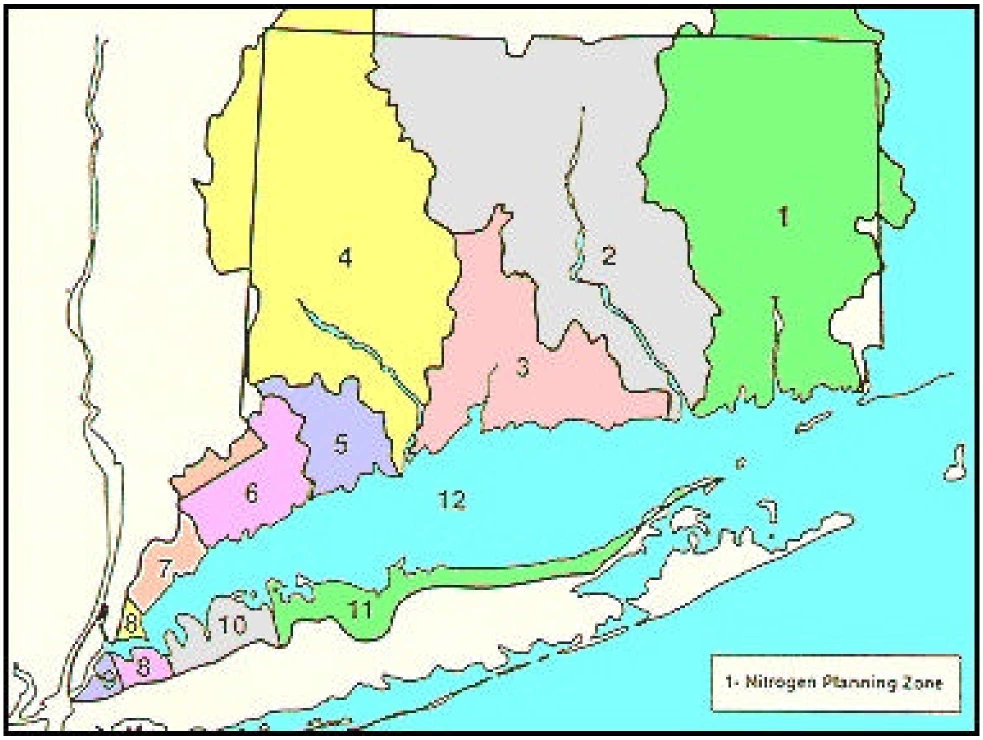

Figure 3.3-1 1. Nitrogen control zones in Long Island Sound watershed (source EPA/LISS)

Each zone is assigned an exchange ratio while each tier is assigned and attenuation factor. The attenuation factor and exchange ratio are multiplied to produce a normalization rate for a plant in a given zone and tier. Normalization rates for relevant zones and tiers are shown in Table 3.3-1. A plant's normalization rate is multiplied by the number of allowances it owns to determine the amount of discharge permitted. It should be noted that all data in the model are expressed in terms of normalized load, i.e., the amount of nitrogen delivered to impaired area of the sound.

Table 3.3-1. Normalization rates for relevant zones in Connecticut

	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6
tier 1	.182		.595	.671	.854	1
tier 2	.182	.1744	.476	.5368 – N .2416 – H		
tier 3	.0932 – Q .1165 – S	.1395		.1087		
tier 4		.1116				

N = Naugatuck River watershed, H = Housatonic River watershed, Q = Qinnebaug River watershed, S = Shetucket River watershed

II.B. Discharge levels and reduction costs

The 1990 calculated discharge is found by multiplying the 1990 wastewater flow by a nitrogen concentration of 18 mg/L (note, however, that discharge is given in pounds). The annual cost of process changes without capital upgrades is based on experience in the Tar-Pamlico basin in North Carolina (Owen Engineering and Management Consultants 1991). Costs for capital upgrades are estimated by CTDEP and annualized over 20 years at an interest rate of 6 percent, which reflects the cost to POTWs of borrowing to finance capital upgrades. Projected future flows are calculated by averaging wastewater flow to each plant from 1990 to 1996 and increasing that average by 20 percent at the end of 15 years. Effluent concentrations after capital upgrades were also estimated by CTDEP. High-grade upgrades should reduce nitrogen concentration to 3 – 4 mg/L, low-grade upgrades reduce concentration to 6 – 8 mg/L and no upgrade results in 18 mg/L.

III. Modeling nitrogen control costs and waste load allocation

The model results will be used to determine: (1) the difference in cost between uniform reduction requirements, administrative reallocation of waste load responsibility and a trading program and (2) the sensitivity of costs to changes in the overall nitrogen cap for point sources. Modeled results, including information on individual plant behavior, are presented in appendices G - L.

III.A. Difference in cost between policy options

III.A.1. Uniform discharge requirements

One policy option to reduce nitrogen discharge in Long Island Sound to the desired levels is to reduce the discharge of each POTW by 70 percent. Calculated 1990 discharge levels are multiplied by 30 percent to obtain the discharge limit for each plant. The appropriate control strategy (high-grade capital improvements, low-grade capital improvements and non-capital process changes) for each plant is chosen based on whether the technology is able to reduce discharge to the required level. If a plant is able to meet its discharge limit with more than one control strategy, then the lowest cost option is chosen. If the chosen technology is capable of exceeding the required reduction, then the plant reduces discharge by only the amount required to meet its discharge limit (i.e., plants do not "overcontrol"). If none of the nitrogen control strategies available to a plant is capable of achieving the discharge limit, then the plant chooses the high-grade capital improvement option and reduces as much as possible. This may be similar to the way permit levels are generally established under the conventional pollution control regulation system. Regulators and dischargers negotiate standards based on the abilities of known technologies and some sense of water quality goals. No binding overall cap on discharge is set, however.

III.A.2. Administrative reallocation and effluent allowance trading

III.A.2.i The linear programming model

Total nitrogen control costs and waste load allocation for an administrative reallocation program and a trading program are calculated using a linear programming model. The model solves the following problem:

Minimize: $\Sigma_{i=1}^{74} (C_i * N_i)$

where:

C = cost to control one normalized pound of nitrogen
N = total N controlled, in normalized pounds

i = POTW

subject to:

Total reduction ≥ total required reduction

The model allows each of seventy-four POTWs to select from a number of different nitrogen control options. For each control option the nitrogen removal effectiveness and the cost to achieve that reduction is specified in the model. There are six choice variables for each plant, each corresponding to a specific nitrogen reduction strategy. Three choice variables are for capital improvements (high-grade, low-grade or no capital investment). Capital costs are annualized over 20 years at 6 percent, the borrowing conditions for municipalities in Connecticut seeking wastewater treatment plant improvements. Three choice variables are the number of pounds of nitrogen, in normalized terms, to be controlled with each strategy. Constraints are set up so that the model may choose one capital upgrade and then must select the number of pounds reduced subject to the technological control limit for the chosen upgrade. Each pound reduced has an associated annual operating costs.

The model reports the control option and delivered nitrogen loads for each plant. The model selects the combination of control options to be implemented at each of the seventy-four plants. The selected combination minimizes the total cost of meeting the nitrogen cap for the Connecticut portion of the LIS watershed. The control option selected and the corresponding discharge levels simulate what each individual POTW would discharge at the end of a 15-year phase-in period under a trading system. For trading scenarios it is assumed that there are no transactions costs and all possible trades are made.

III.A.2.ii Nitrogen control performance assumptions

The administrative reallocation scenarios and the cap and trade scenarios differ in the assumed level of nitrogen control performance. The administrative reallocation scenarios assume an effluent nitrogen concentration of 3.5 mg/L for high-grade capital improvements, 7 mg/L for low-grade capital improvements and 14 mg/L for non-capital process changes. The allowance trading scenarios assume an effluent nitrogen concentration of 3 mg/L for high-grade capital improvements, 6 mg/L for low-grade capital improvements and 12 mg/L for non-capital process changes.

The nitrogen concentrations used when modeling the uniform reduction requirements and administrative waste load reallocation are the midpoints of CTDEP estimates of the effectiveness of each capital intensive nitrogen control strategy. The concentration associated with the non-capital process changes control option is based on experience in the Tar-Pamlico watershed (Hall and Howett 1995). These improvements in performance are likely to come through higher energy, labor or consultant fee costs (Owen Engineering and Management Consultant 1991). In an administrative reallocation program, permitted discharge levels are still based the ability of known technology. Table 3.3-2 shows the pollution control performance conditions for the uniform reduction requirements, administrative waste load reallocation and cap and trade policy alternatives.

Table 3.3-2. Achievable nitrogen concentrations assumed in different scenarios

	Nitrogen Concentration in the Waste Stream		
Pollution control performance conditions	*High Grade Capital Project*	*Low Grade Capital Project*	*Non-capital process changes*
Uniform reduction requirement	3.5 mg/l	7 mg/l	14 mg/l
Administrative waste load reallocation	3.5 mg/l	7 mg/l	14 mg/l
Capped effluent allowance trading system	3 mg/l	6 mg/l	12 mg/l

The nitrogen concentrations used when modeling the effluent allowance trading system are the most optimistic CTDEP estimates of the effectiveness of each capital intensive strategy. The concentration associated with the non-capital process changes control option is based on experience in the Tar-Pamlico watershed (Hall and Howett 1995; Owen Engineering and Management Consultant 1991).

Optimistic estimates of nitrogen control effectives are used when modeling trading for two reasons. First, allowance trading provides enhanced incentives to control nitrogen discharge that are created by a trading system will induce a high level of nitrogen control performance. This is consistent with the dynamic view of trading discussed in the previous sections. Second, under an allowance trading system, individual discharge permits are no longer issued. The elimination of permit negotiations removes incentives for dischargers to understate their ability to control effluent. It is quite conceivable that dischargers will be able to negotiate higher nitrogen concentration limits than what could actually be achieved. This is reflected by using higher nitrogen concentration assumptions in the administrative reallocation case.

III.A.2.iii Trades and allowance prices

The volume of allowance trades and the price of nitrogen allowances are also derived from model results for trading scenarios. Allowances are the right to discharge one pound of delivered nitrogen. Allowances are initially distributed such that each POTW receives an equal proportion of the delivered load cap. The model allocates pollution control responsibility so that costs are minimized. The results will show the final distribution of discharge reductions. The difference between the individual plant limit and the control level chosen by the model, therefore, is the number of allowances a plant would need to buy or sell.

Exchange prices for allowances are determined in part by the marginal cost of production. In this case the price at which plants buy and sell allowances should be equivalent to the cost to control the last units of discharge, the shadow price. Computing the shadow price is a three-step process. First the cap is decreased by one-tenth of one percent and the model is run again. Second, the difference in total cost is figured by subtracting the total cost calculated when the cap is decreased from the total cost calculated in initial simulation. Third, this difference in total cost is divided by the number of pounds by which the cap is increased to obtain a per pound difference in cost. The per pound difference in cost is the allowance price.

III.B Difference in cost between cap levels

The goal of Connecticut's point source reduction policy, whatever form it may take, is to reduce normalized nitrogen discharge from POTWs by 70 percent. The calculated delivered load to impaired areas of Long Island Sound from Connecticut wastewater treatment plants was 10,407,396 normalized pounds. A 70 reduction is 7,951,186 normalized pounds and would result in a cap of 2,456,210 normalized pounds. The present analysis will determine the cost effect of making the cap less stringent. Uniform reduction requirements, administrative waste load reallocation and effluent allowance trading outcomes will be recalculated as described above with a 60 percent reduction goal. The 60 percent reduction is 7,132,450 normalized pounds and would result in a cap of 3,274,946 normalized pounds.

Achieving the last (marginal) units of nitrogen discharge reduction will be more expensive than the first, as more high-cost POTWs are required to pay for reductions. Altering the cap will show the cost of achieving the final 819,000 normalized pounds with a 70 percent reduction. The difference in costs to POTWs between a 70 percent and 60 percent required reduction should be equal to what towns are willing to pay to get nitrogen reductions from some alternative source besides their treatment plants. Nonpoint sources, particularly nitrogen in urban stormwater runoff, are obvious alternatives. Solving for cases where a 60 percent reduction by point sources is required may show the cost effects of shifting some control responsibility to other nitrogen sources, such as nonpoint runoff which currently has a reduction target to be achieved by voluntary measures.

Section 4. Results

I. Introduction

The objective of the present study is to analyze the cost implications of three ways to attempt to meet nitrogen effluent discharge goals for wastewater treatment plants in Connecticut. The results presented below will: (1) compare the total compliance costs of uniform reduction requirements, an administrative reallocation of the nitrogen waste load, and a nitrogen effluent allowance trading program, (2) the cost savings of including nonpoint source reductions within the overall strategy. The results are presented in terms of costs per year at the end of a fifteen-year phase-in period.

II. Gains from allocating nitrogen waste load according to cost

The estimated total cost of making a 70 percent nitrogen discharge reduction at every plant is $63,095,146 per year. Also, given available information, a 70 percent reduction is not achievable for all plants. At 32 plants, construction of high-grade capital projects cannot result in a 70 percent reduction in delivered nitrogen loads. Reducing discharge by as much as possible (using the high-grade capital option) at those 32 plants and by 70 percent at the 42 other plants results in a total delivered load of 2,495,906 pounds per year. This exceeds the cap of 2,456,210 pounds by almost 40,000 pounds. Under uniform reduction requirements 73 plants chose the high-grade capital option and 1 plant chose the low-grade capital option.

The estimated cost of control under an administrative reallocation of the total nitrogen waste load is $48,120,608 per year. The administrative reallocation of nitrogen discharge results in savings of approximately 24 percent over uniform, 70 percent discharge reduction requirements, or almost $15 million annually. These cost savings are due to equalizing the marginal cost of nitrogen control across all dischargers. Just as important as the reduction in cost is the fact that administrative reallocation of nitrogen discharge and control responsibility allows the overall nitrogen reduction goal to be met.

Those plants that are able to do so are required to reduce nitrogen discharge beyond 70 percent of 1990 levels.

The total cost to POTWs of reducing nitrogen discharge under an effluent allowance trading system is $34,527,315 per year. This represents savings of about 28 percent ($13.6 million) annually over an administrative reallocation of nitrogen discharge and savings of 45 percent ($28.6 million) annually over uniform, 70 percent reduction requirements. The savings over an administrative reallocation program are due to better pollution control performance by all POTWs. The better performance would be stimulated by increased flexibility in using pollution control strategies and enhanced incentives to reduce nitrogen discharge. Table 3.4-1 shows total compliance costs and delivered load under each of the three nitrogen reduction policies.

Table 3.4-1. Compliance costs under different nitrogen waste load assignment policy.

Waste load assignment policy	Annual cost	Nitrogen load (normalized pounds)
Uniform Reduction Requirements	$63,095,146	2,495,906*
Administrative Waste Load Reallocation	$48,120,608	2,456,209
Effluent Allowance Trading	$34,527,315	2,456,209

* The effluent cap corresponding to a 70% reduction of delivered nitrogen is not met under uniform reduction requirements.

Allowance prices are the cost POTWs must pay to obtain the right to discharge additional units of nitrogen beyond their initial allocation. Allowance prices are estimated by finding the marginal cost of the last one-tenth of one percent of normalized pounds of nitrogen reduced. The effluent allowance trading program would result in an allowance price of $45.92 per normalized pound.

III. Nitrogen control costs for different cap levels

An alternative strategy is to include nonpoint sources in the overall nitrogen reduction program. This study examines the cost implications for POTWs of lowering the POTW reduction goal to require a 60 percent reduction in nitrogen discharge from wastewater treatment plants. Changing the reduction requirements increases to size of the POTW cap from 2.456 million pounds to 3.275 million pounds per year (see Table 3.4-2). Relaxing the reduction requirement for point source dischargers from 70 percent to 60 percent results in a nitrogen cap that is 818,737 normalized pounds per year higher.

Table 3.4-2. Reduction requirements for POTWs– normalized pounds of nitrogen per year

	70% reduction*	60% reduction*	difference
cap	2,456,210	3,274,946	818,737
required reduction	7,951,186	7,132,450	818,737

*from 1990 discharge levels.

The required reduction constraint is reduced by 818,737 pounds to reflect a 60 percent reduction by wastewater treatment plants. The costs savings associated with a higher overall discharge are significant, as shown in Table 3.4-3. Total costs are 40 and 35 percent lower under a 60 percent reduction requirement (2.866 million pound cap) for the administrative reallocation and a cap and trade program, respectively. Costs are virtually the same under the uniform discharge reduction requirement even though the more nitrogen is discharged under the 60 percent uniform reduction requirement. This is because under both caps, most treatment plants are required to invest in high-grade capital projects.

Table 3.4-3. Control costs under different reduction requirements

discharge concentration assumptions	70% reduction: 2.456 million pound goal	60% reduction: 2.866 million pound goal	difference in cost	difference per pound	percent difference in cost
Uniform discharge reduction requirements	$63,095,146	$63,081,458	$13,688	$0.02	.02
Administrative waste load reallocation	$48,120,608	$29,047,043	$19,073,565	$23.30	40
Effluent allowance trading	$34,527,315	$22,538,115	$11,989,200	$14.64	35

* The effluent goals corresponding to 70% and 60% reduction of delivered nitrogen are not met under uniform reduction requirements.

Section 5. Implications and Conclusions

Requiring each wastewater treatment plant in Connecticut to reduce nitrogen discharge by 70 percent will not achieve water quality goals. As reported above, even the most effective improvements will not achieve the required reduction at 32 out of 74 plants. The nitrogen waste load must be reallocated in order for water quality goals to be met. Allocating waste load based on the cost of nitrogen control allows water quality goals to be met and reduces overall costs. Administrative reallocation offers savings of 24 percent over uniform reduction requirements, according to the model presented here. These savings are achieved by assigning more control responsibility to those plants with lower control costs. An effluent allowance trading system is one way to further reduce the cost of achieving a nitrogen reduction goal in Connecticut. The results presented above show that a trading program that provides incentives to reduce discharge and exchange allowances offers savings of 45 percent over uniform discharge reduction requirements and savings of 28 percent over an administrative waste load reallocation. Part of these savings come from assigning more control responsibility to those plants with lower control costs, just as in the case of administrative reallocation. The additional savings come from better pollution control performance through eliminating the permit negotiation process and creating incentives to reduce discharge as much as possible.

Trading programs are a way to meet water quality goals at a reduced cost. The model presented here relies on trading to create incentives for individual wastewater treatment plants to seek out innovative pollution prevention techniques. The rationale for this option draws from the dynamic view of allowance trading as discussed in previous sections. A trading program allows dischargers to create valuable assets, allowances. The possibility of generating revenue through the sale of allowances, or having to pay for additional allowances if they are unable to reduce discharge, may spur treatment plants to discover previously unknown control methods that meet or exceed engineering projections.

Overall cost savings due to trading must be viewed in light of the additional costs that would be incurred by changing the regulatory system. It may be quite expensive to set up some sort of allowance exchange and monitoring and enforcement mechanisms. The results presented above demonstrate large cost savings are possible through effluent allowance trading. It is therefore likely that any administrative or regulatory costs incurred during the transition from the permit system will be offset by savings to dischargers.

If trading is to be considered, the trading system must be designed so that incentives exist and barriers to trade and innovation are low. Reducing the barriers to trade makes allowances more valuable. Few regulatory rules on allowable exchanges should be set in order to increase the number of possible trades. Also, it may be desirable to create some sort of exchange center to get buyers and sellers together. Such a center may operate like a commodities exchange or may use central authorities as brokers to help identify buyers and sellers. Another possibility is to allow for the banking of allowances for future use. Dischargers that are able to reduce effluent flows below their allowance holdings may use the surplus allowances, or some portion thereof, in the future. The discharger would be, in essence, trading with itself in the future.

There is some risk involved with relying on dynamic, innovative technologies to ensure the nitrogen cap is met. There is no way to model potential changes in control technology or processes within the context presented in the current study. The final outcome of innovative control cannot be known ahead of time. There is, however, evidence from other programs to support the dynamic view of the benefits of allowance trading. The sulfur-dioxide allowance trading program undertaken as a result of Title IV of the Clean Air Act amendments of 1990 is considered the most successful emissions trading program in the United States. The cost of compliance with mandated discharge reductions has been substantially less than was estimated before the trading program began. Few trades, however, have occurred. Cost reductions have come not from equalizing marginal cost through trade, but by individual firms taking advantage of the compliance flexibility offered to them. Dischargers have switched to low-sulfur coal and competitive pressures have resulted in more efficient and less costly sulfur scrubbing equipment (Burtraw 1996).

Another example of the potential for unanticipated cost savings through innovative control processes is the nutrient trading program in the Tar-Pamlico Basin in North Carolina. After implementation of a cap-and-trade program, POTWs in the watershed discovered that 80 percent of the required reduction could be met by optimizing existing treatment works rather than by more expensive capital upgrades. The cost of these procedural changes was only $40,000 for an engineering evaluation by a consultant (Hall and Howett 1995).

Another option to reduce the cost of meeting water quality goals is to make the point source reduction target less stringent. The results above show that a 60 percent reduction requirement, a 3.274 million normalized pound target would reduce costs for point source dischargers by about $19 million annually under an administrative reallocation (40 percent) or by about $12 million annually (35 percent) under a cap and trade program. This should reflect what towns are willing to pay to achieve a reduction of 818,737 pounds, the difference between a 60 and 70 percent reduction, from some another source.

Towns, as operators of municipal wastewater treatment facilities, are responsible for both point and nonpoint sources of nitrogen. A 35 – 40 percent cost savings associated with a 10 percent less restrictive cap on point sources suggests that including nonpoint sources may be a desirable option to reduce overall nitrogen control costs. The cost of the reducing the final 818,737 pounds of nitrogen under a 70 percent reduction requirement is $15 - $35 per pound, on average, and will be significantly higher for some plants. Some nonpoint source controls may remove nitrogen at lower cost. Planting forest and grass buffer zones along the edges of streams has been estimated to reduce nitrogen runoff at a cost of $8 and $20 per pound (Virginia DEQ 1995, p.68). This would suggest that towns have other low-cost options for reducing nitrogen discharge. Given incentives and a degree of flexibility, it is very likely that towns and treatment plants would devise ways to reduce nitrogen loads beyond current technological and institutional projections.

References – Chapter 3

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