Return to Users Guide

Return to Catalog

ESTIMATING COSTS FOR WASTEWATER COLLECTION AND TREATMENT UNDER VARIOUS GROWTH SCENARIOS

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Abstract

The New Jersey Office of State Planning (OSP) has developed a spreadsheet-based computer model that allocates municipal growth projections, estimates future incomes and housing needs for municipalities, and then evaluates the impacts of this future growth on several infrastructure systems. This paper describes the sewer impact portion of the model and presents sample results.

The sewer model is based on detailed information about local conditions principally gleaned from the Annual EPA Needs survey (A copy of the questionnaire is attached), which in New Jersey must be completed by every operator of a licensed sewer system. OSP also collected sewer service area maps and obtained information about water quality conditions for all streams into which treated sewerage is discharged. If the model determined the need for a new treatment plant, the cost for the new plant reflects both treatment capacity and the proper level of treatment to ensure compliance with the Clean Water Act. OSP also developed several interesting subroutines including one that calculates the likelihood for nonsewered areas to install sewers and another one that estimates future collector costs as a function of development density and pipe size. (Yes, it's another cost of sprawl data set!)

Results from the model have produced interesting policy discussions. Because most municipalities are connected to regional treatment facilities, growth elsewhere in the same sewer shed can increase cost in slower growing municipalities, or inhibit growth due to declines in treatment capacity. In the older urbanized areas, local officials are concerned that the high costs to rehabilitate existing facilities to meet Clean Water standards could inhibit revitalization efforts.

Introduction

Since 1988 the New Jersey Office of State Planning (OSP) has been developing computer models to estimate both future demographic and economic conditions and various trend and regional planning scenarios. This paper describes that portion of the OSP computer modeling designed to estimate the public sector capital costs associated the construction of wastewater collection and treatment plants needed to service future populations and jobs.

The model described in this paper is a modified version of the third model constructed for OSP's use. The initial sewer cost model was developed in the Spring of 1987 by Office of State Planning consultants Wallace, Roberts and Todd (WRT) and Hammer, Siler, George Associates (HSGA). The model consisted of a single spreadsheet in which two types of residential flows (single family and multifamily) and three types of employment based flows (commercial, office and industrial) for each municipality were calculated using per household

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and per employee factors unique to each of the Tiers in the Draft State Plan. (Tiers were defined as land areas with similar characteristics, such as density, percentage sewered, etc.). The sum of residential and employment-based flows was multiplied by a fixed operation cost ($.90 per 1000 gallons) and a fixed capital cost ($2.50 per gallon per day) to yield total municipal system costs.

There were several problems with this method. It lacked information about existing conditions and service levels. It also assumed that all development would have new sewers.

The next sewer cost model was based on the "Comparable Cities" method developed by Burchell and Listokin (Burchell and Listokin 1987). This method uses multipliers, developed from a national sample of cities, to adjust municipal budgets to reflect changes in population and shifts in the rate of growth. One of the activity costs estimated by this model was "Public Works," which could include public sector costs for wastewater treatment and collection.

The "Comparable Cities" method was abandoned in response to criticism that it relied on parameters derived from 1972 national information. OSP decided to develop fiscal impact techniques using more recent and more New Jersey-specific information.

The model described in this paper utilizes extensive data sets, maintained in New Jersey by the Department of Environmental Protection and Energy (DEPE), the agency that administers the EPA Annual Needs Survey. In this survey each public sewer operator must annually describe his system in detail, identifying existing and proposed service areas, and the number of households in the service area connected (and not connected) to the system. In addition, the operator must identify and provide cost estimates of capital improvements needed to bring the system up to current Federal standards as well as provide cost estimates for improvements needed to meeting the forecast year (20 year horizon) system demands. The survey requires that engineered cost estimates be identified. Where local sewer companies have estimated improvement costs or where future need is noted but future costs are not identified, the Needs Survey personnel use several cost curves to verify cost projections. These costing formulas were developed by Weston Engineers under contract to the EPA. The main engine that runs this version of the OSP sewer model is the EPA cost estimating methodologies fueled by the detailed systems descriptive data found in the 1988 EPA Needs Survey.

The new work performed by OSP was to program the mainframe EPA model to run on a microcomputer. In addition, OSP modified the program to include a stochastic model capable of estimating the degree to which a municipality might be sewered in the future, and an equation used to modify the estimation of collector costs that would result from sub-municipal design changes, such as the development of compact centers as recommended in the New Jersey State Development and Redevelopment Plan.

Model Description

The sewer model consists of four major elements as illustrated in table 1.

table 1
The Major Elements of the Sewer Model

Given: Municipal Population and Employment Projections

Step 1: Estimate the Percentage of Households and Jobs Served by Sewers in the Future
Step 2: Estimate the Total Flow From Each Municipality
Step 3: Assign Municipal Flows to the Correct Treatment Facility

Step 4: Compare the Existing System Capacities to the Estimated Future Demand
Estimate Improvement Costs
Step 5: Assign Collection Treatment Costs to Municipalities

The model accepts alternative municipal estimates of population and employment, and estimates the costs for the public sewerage treatment and collection agencies to provide service that meets the requirements of the Clean Water Act. Because the model utilizes very detailed information about each sewer system, it produces a wealth of specific costs including capital costs for: secondary treatment; advanced treatment; correction of infiltration and overflow problems; replacement and rehabilitation of the existing collection system; new collectors; new interceptors; and, finally costs to correct problems resulting from combined sewer overflows.

However, the model does not generate the total costs of public sewerage systems since it does not evaluate operational or non-capital intensive maintenance costs. The model also does not include an estimate of *total* capital costs, since it does not address costs for privately owned treatment facilities including the cost for homes to be equipped with on-site septic systems.

Despite the model's shortcomings, we feel it is an appropriate public policy tool for regional planning. The purpose of the model is to generate future public capital costs so that the potential costs of providing sewer services can be considered in evaluating alternative land development scenarios.

Step 1: Estimate the Percentage of Households and Jobs Served by Sewers

Data about wastewater treatment and/or collection facilities were analyzed to determine which municipalities were serviced. At least one public provider was identified for each of the State's 567 municipalities. Typically, the role of this provider was wastewater collection. Even in municipalities where no service was provided, the DEPE records identified a public agency ultimately responsible to provide for collection of sewage.

To determine the number of persons within the service area who are to receive collection and treatment service, the user selects one of the three viable service conditions.

- o 1988 Constant - Records provided by DEPE, based on the Needs Survey, list the number of persons receiving collection and not receiving collection for each wastewater provider. If the user selects this option then the 1988 percent of the total population and employment receiving collection is used to determine the number of persons receiving collection in the future.
- o 2008 Constant - The DEPE data displays the number of persons proposed to receive collection in 2008 and the number not receiving collection in 2008. If this variable is chosen, the percentage receiving collection in 2008 is multiplied by the total future population and employment.
- o OSP Estimate - Several municipalities are not receiving any wastewater collection today nor is any forecast for the future. In most cases this is due to low growth estimates. Another problem is that growth might exceed the expectations of the local company and might result in the need for higher levels of service than those proposed in the 1988 or 2008 constants.

The OSP methodology uses DEPE datasets to establish a relationship between municipal population and percent-sewered. Once such a relationship is quantified, the percentage of residents on collectors can be projected at any level.

First, we calculated municipal population density for the year 2008[1], using the 208 plan data set provided by DEPE. This same dataset also provided an estimate of the ratio of persons on collectors to total population, by municipality, for the year 2008.

When graphed, the relationship between municipal population density and percent-sewered appears to follow a pattern (see figure 1). with large concentrations of municipalities at 0% and 100%, however, the relationship depicted in figure 1 does not lend itself to modeling using standard parametric techniques. Instead, a probability table was used to model the relationship.

To accomplish this analysis, the 555 municipalities (out of a total of 567 municipalities) for which there was percent-sewered data were divided into ten population density classes of 55 or 56 each. The probability distribution of municipalities in each density class was calculated across seven classes of percent-sewered. The seven classes were: NOT SEWERED, 1 to 20% sewered, 20 to 40% sewered, 40 to 60% sewered, 60 to 80% sewered, 80 to 99% sewered and 100% sewered. Next, the cumulative probability distribution was calculated for the municipalities in each class. To utilize this information in the program, a lookup table was constructed using these cumulative probabilities. The table returns percent-sewered given a municipality's future population density and a computer generated random number. The percentages returned by the table are restricted to 0%, 100% and the midpoints of the other five classes (i.e., 10%, 30%, 50%, 70% and 90%).

Figure 2 shows that this simulation technique replicates the relationship shown in figure 1 reasonably well.

figure 1

Percent of Population on Collectors as a Function of Log(Population Density)

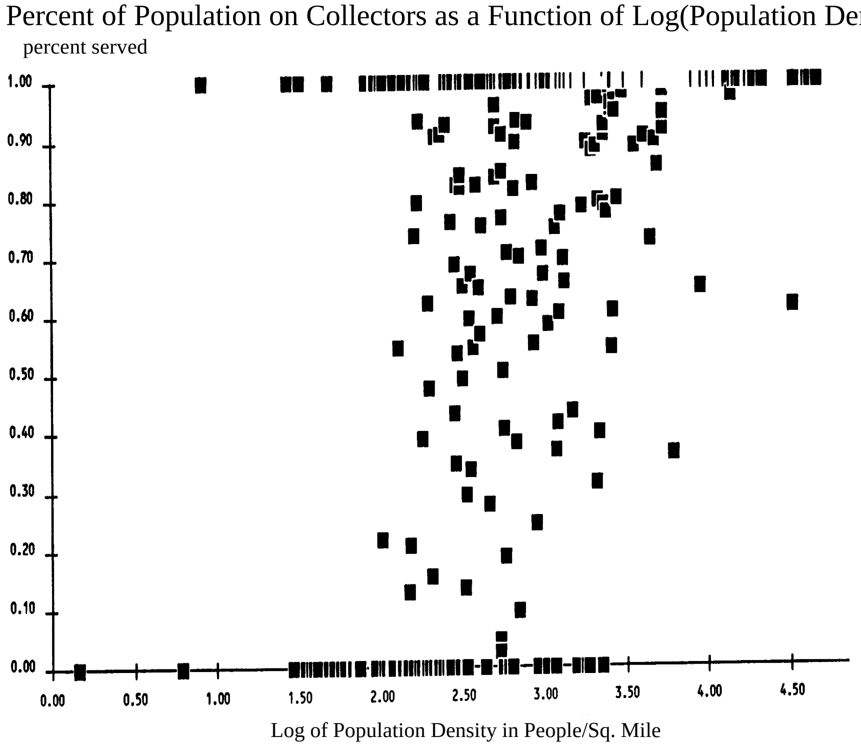
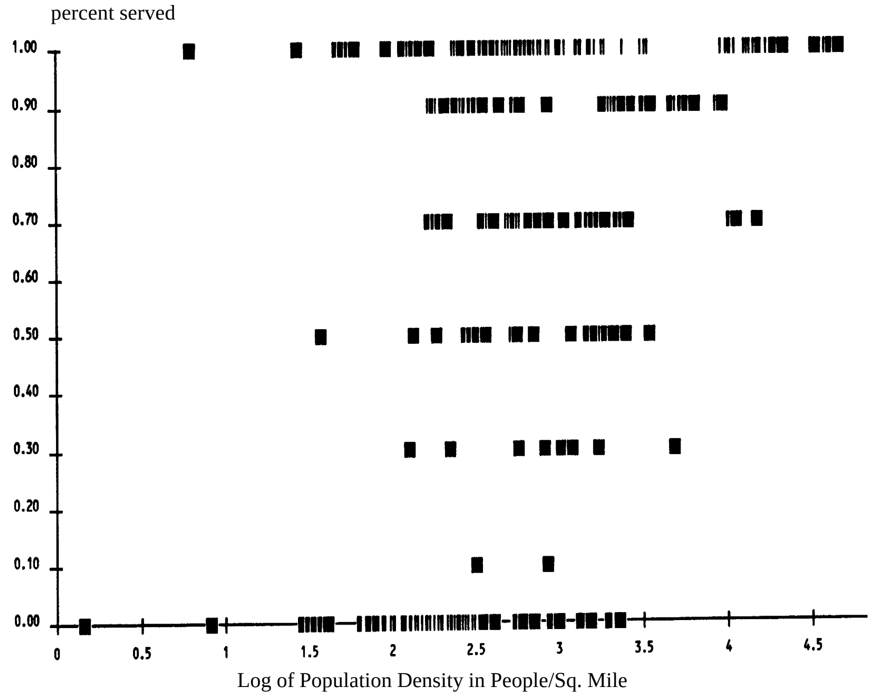


figure 2
OSP Simulation of Population on Collectors as a Function of Log(Population Density)



The final result of Step 1 is the identification of people and employees receiving collection for each municipality-based collection provider and the total number of persons and employers served by each treatment plant.

Step 2: Estimate the Total Flow from Each Municipality

Total wastewater flows, expressed in millions of gallons per day (MGD), are used during the next step as major input to cost estimating formulas. The general formulas used in the model are:

$$\text{Residential MGD} = \text{TPS} \times (\text{GPCD} \times (1-\text{CW}))/1{,}000{,}000 \quad (1)$$
$$\text{Employment MGD} = \text{TES} \times (\text{GPED} \times (1-\text{CW}))/1{,}000{,}000$$

TPS = Total Population Served
TES = Total Employees Served
GPCD = Gallons per Capita per day
GPED = Gallons per Employee per day
CW = % water saved by conservation methods

To a larger degree, the formulae for flows are derived from the EPA cost estimation methods. OSP added the water conservation element, since some type of water conservation methods will likely to implemented in the future. Three of the formula elements are user-selected variables.

1. Gallons Per Capita a Day - three alternatives are presented:

- o 1988 Constant - The DEPE data records 1988 flows as gallons per capita per day. This number is derived by taking total flow, subtracting industrial flow and dividing the remainder by the number of persons receiving collection and/or treatment. This facility-specific 1988 GPCD is used as a constant if this alternative is selected.
- o 2008 Constant - The constant in all equations is the facility-specific GPCD reported in the Needs Survey for 2008.
- o EPA numbers - EPA recommends 95 GPCD to serve populations of less than 5,000; 105 GPCD to serve populations greater than 5,000 and less than 10,000; and 115 GPCD to serve populations greater than 10,000 individuals.

2. Wastewater per employee per day - This factor represents the total industrial flow sent to public collection and/or treatment facilities divided by the number of employers served by the facility. It does not represent total industrial wastewater discharged in a service area. Much industrial wastewater is treated and discharged by business itself. Options available for selection by the user range from 30 gallons per day per employee (GPED) to 90 GPED, in increments of ten.

3. Water saved through conservation - Many parts of New Jersey already use more water than that provided by locally available sources. Northeastern New Jersey is dependent on water from the Delaware River. Parts of Southern New Jersey are exhausting groundwater supplies to such an extent that the water table (piezometric level) has dropped as much as 50 feet. Therefore, the implementation of water conservation techniques is likely to be commonplace in the near future. Such reductions in water consumption also result in reductions to wastewater flows. User-selected variables to simulate this phenomenon are expressed as percentage reductions to the wastewater flow ranging from 0% reduction to 20% reduction.

Step 3: Assign Municipal Flows to the Correct Treatment Facility

Two alternative structures were plausible. First, wastewater collection agencies could operate their own treatment plant. Alternatively, they could be grouped into service areas and provided with a single regional treatment plant designed to treat the collective wastewater of its constituent collection agencies.

We assigned municipal flows to the treatment plant intended to serve these areas in the future, in accordance with the current 208 and 201 plans submitted by local agencies to DEPE.. Where a municipality was served by more than one facility, the proportion of the municipality served by each agency in 1988 was assumed to continue. For example, if 20% of Anyplace Township is served by Someplace Sewer Company and the rest of Anytown is served by Noplace Sewer Company, then 20% of the future population and employment is assigned to the Someplace Sewer Company and the rest of Anyplace's population and employment is assigned to the Noplace Sewer Company.

To perform this assignment process OSP used named formulas to link municipal flows to treatment facilities. This results in a program that works, but which is very difficult to check or to make corrections or change. It would be better to use a database program to store these relationships and then to link the database to the sewer program using DDE methods.

Step 4: Estimating Improvement Costs

In developing this portion of the model, several Rules had to be incorporated into the program to decide when and how to use the cost estimates produced by the local companies as opposed to using costs projected by OSP or EPA methodologies. First, if future municipal flows were equal to or less than the 1988 wastewater flows, then no costs were added to meet future needs. Second, if future needs exceeded the 1988 flows, but were equal to or less than the 2008 estimated flows, then the local agency estimates could be used. One of the data sets provided by DEPE indicates a basis upon which these locally produced costs were estimated. If these costs were the products of engineering studies, the costs were directly used in the model. If the costs were based on the EPA cost-estimating equations, then new costs were generated using the EPA equations and the exact new flow requirements. Third, if future flows exceeded the 2008 Needs Survey flow estimates and the 2008 costs were locally engineered, these engineered costs were used up to their design capacities then the EPA cost equations were used to cost out the residual. Where the 2008 costs were not engineered, all growth costs were estimated using the EPA cost equations.

Backlog Costs. All Needs survey identified costs intended to alleviate existing "backlog" problems were included in all cost estimates reported by the model.

Collector Costs. Collector costs are estimated using the following equation provided by the EPA.

$$\text{(Future Collected - Existing Collected) x 16 ft. x \$59 x CDA x } (RCA^2) \qquad (2)$$

where:

CDA = constant dollar adjustment from the EPA base year of 1985
RCA = Regional Cost Adjustment

The model assumes 16 feet of pipe per person and that the pipe costs $59 per foot. It became evident to us that the constant of 16 feet of collector pipe per person had to incorporated a constant assumption about residential density. To make the collector cost model more robust (and more sensitive to the clustering policies included in the Plan), we undertook a statistical analysis in order to identify the relationship between density/design on the one hand, and per unit road requirements on the other. It was assumed that most collectors are built beneath or parallel to local roads, as are some other infrastructure systems, especially water distribution lines.

The general approach was to generate a large and diverse sample of residential development patterns using 1986 aerial photoquads at 1:24,000 scale. To measure the development we used clear plastic sheet sheets with 20-acre grids, each then subdivided into 16 squares of 1.25 acres each. the twenty-acre grids were placed on the photoquads. Center-line road lengths (in linear feet) within each grid were calculated using an electric digital curvimeter (naturally, driveways were excluded). The number of housing units in each subsquare was counted and recorded, along with the photoquad number, sample number, and road length. (The number of units divided by the 20 acres in each grid resulted in gross density.

Samples were chosen based on clarity and recognition as single-family housing developments. The intent of this exercise was to count housing units, not industrial, commercial, or office uses. since no field work was conducted, it was necessary to restrict the sample to single-family residential developments, which are easy to identify in aerial photos. One must therefore exercise caution before extending the results of this analysis to developments containing mixed-use or multi-family structures (even though intuitively, multi-family developments could be expected to increase infrastructure cost-efficiencies).

Approximately three 20 acre observations were taken from each photoquad. Exceptions to this occurred in cases where the photoquad only showed a small amount of New Jersey land. Eventually, 368 observations were collected.

In addition to density and road length, the variables COVER was estiamted. COVER, is the percentage of subsquares in each sample that contain any development. Holding density constant, the COVER variable clearly serves as a measure of cluster[3].

Linear regression was used to analyze per-unit length of road (dependent variable) and the various measures of density and cluster (independent variables). the coefficient on DENSITY is hypothesized to be negative; and COVER, positive.

At the outset, it was recognized that density and cluster are likely to be highly collinear[4]. In some sense, whether a land use pattern is dense or highly clustered is simply a matter of scale. this problem has not been satisfactorily resolved in the analysis.

Plots of the data suggested using a log-log form for the regression equation. If one had to choose among the collinear independent variables, it appears that DENSITY provides the strongest confirmation of the hypothesis. some of the regression results are displayed in table 4.

table 4a
Regression of Density to Road Length
(Log-Log form)

Dependent Variable: Log of Per-Dwelling Unit Road Length
Independent Variables:

Parameter	Estimate	T-Statistic	PROB > |T|	S.E.
Intercept	4.66	259.48	0.0	.02
Log Density	-0.64	-39.40	0.0	.02

N = 367
F-VALUE: 1552.39
PR>F: 0.0
R-SQUARE: .809

table4b
Regression of Density and Cover to Road Length

Dependent Variable: Log of Per-Dwelling Unit Road Length
Independent Variables:

Parameter	Estimate	T-Statistic	PROB > |T|	S.E.
Intercept	4.61	113.77	0.0	.04
Log Density	-0.58	-12.92	0.0001	.04
Log Cover	-.010	-1.45	0.1496	.07

N = 367
F-VALUE: 1557.11
PR>F: 0.0
R-SQUARE: .810

Further analysis to control for colinearity between density and cover were made by dividing the sample into density classes. Regression analysis of COVER within each class to road length was made, holding density more or less constant. It was found that the effect of COVER on Road length was largely insignificant. Therefore, the relationship between road length and density was the basis for the OSP algorithm to calculate collector lengths.

Trend cost estimates are produced using the density to road length equation (table 4b) and the existing density of the municipality in lieu of using the EPA constant of 16 feet per person. If the user selects to test a Plan scenario, an additional dialog box prompts the user to estimate the extent to which development under Plan would be more (or less) dense than would the same development under a Trend growth scenario. This density factor than is multiplied with the mean density of each municipality to simulate the mean municipal density for new development under Plan.

Interceptor Costs. - To calculate interceptor costs a multi-step process is employed. First, total future flow is subtracted from total existing flow to yield total new flow due to growth. The model always assumes that this increased flow will be handled by constructing a new interceptor. This flow is then compared to an EPA generated table to determine the diameter of pipe needed to carry the flow. A second EPA table reveals the cost per foot of the selected diameter pipe. Finally, a third EPA table estimates the length of interceptor required based on the change in population served by the system.

Based on this information the following equation is used.

$$\text{Interceptor Cost} = \text{Length} \times \text{Cost/sq ft} \times (\text{CDA}) \times (\text{RCA}) \qquad (3)$$

Again, where engineered interceptor costs are provided, they are preferable to numbers generated by the EPA cost methods.

Treatment Plant Costs. The following briefly describes the EPA cost equations.

- Treatment Costs - These equations estimate capital costs of sewer treatment plants. The method uses separate cost equations for ten different types of plants, ranging from 'plain vanilla' secondary treatment facility to highly sophisticated advanced treatment plants. Data provided by DEPE identified which of the ten plant types would be needed for the plant to meet the requirements of the Clean Water Act, given the water quality of the discharge stream or river. In applying the EPA cost equations, OSP assumed that the "backlog" costs, if any, would bring the existing plants up to requirements. Therefore, the cost equation only estimated those plant improvements necessary to serve the added flow created by growth and the costs of improving treatment methods, if required. The EPA model also provides equations to "recover" costs to reflect efficiencies from re-using existing plant facilities. This cost-recovery method was not used in the OSP model, nor is it used by DEPE, due to the use of "backlog" costs to improve existing plant estimates.
- Plant Capacity Variable - Federal law stipulates that new treatment facilities should commence the design/build process when flows reach 80% of plant capacity. Many plants operate in violation of this requirement. This variable allows the user to select the operating level at which the cost of a new

facility is estimated. The range is 80% to 120%, with a default setting of 100 percent.

General Cost Adjustment Variable. For all cost estimates, resulting costs are adjusted by a user-selected variable to reflect local labor and materials price conditions. The cost adjustment variables differ from the Regional Cost Adjustments, in that the regional cost adjustments reflect cost differences that DEPE reported as a function of density, congestion, and the degree to which new improvements have to be installed into utility right-of-ways serving other systems, such as water or electric lines. The price adjustment variables are:

- o Constant = 1
- o New York Region = 1.52
- o Trenton Region = 1.09
- o Philadelphia Region = 1.21

Step 4: Reassignment of Costs to Municipalities

During this final step, all backlog and improvement costs are reassigned to the municipalities served by these systems. Costs are assigned proportionate to each municipality's percentage of total flow to the system. Multiple costs can accrue to any municipality. This cost aggregation allows for the cost of regional facilities, possibly primarily resulting from growth in another municipality, to be assigned to each municipality in the sewer service region.

Model Results and Findings

The sewer model has been used by OSP to evaluate various public policies, with interesting results. In addition, the model was adopted for use by the Rutgers University Center for Urban Policy Research, when they conducted the official evaluation of the New Jersey Development and Redevelopment Plan, as mandated by Act of the New Jersey Legislature.

Rutgers reported that the possible sewer capital cost savings that would accrue from implementing the State Plan would be $379 Million over a 20 years period. While this is a great deal of money, it is not as large as many might have anticipated. However, it is important to note that this result is primarily due to the relatively conservative population growth forecast which Rutgers used in their analysis.

The Rutgers finding also foreshadows some policy myths exposed by the model. It had been taken as an article of faith, by proponents of the State Plan that there were areas of the State with substantial excess capacity and that the concentration of new growth into these excess capacity areas and into areas already provided with existing service would result in substantial public cost savings. The spatial expression of these concepts was that new growth should be focused into the older urbanized portions of the State, which experienced population and employment declines (and therefore should have excess treatment capacities and the existing collectors and interceptors to support growth), into vacant land in suburbanizing areas served or designated to be served by sewer, and into existing towns and villages, presumed to have excess capacity so that only collectors and interceptors would have to be built.

Unfortunately, the model and its datasets demonstrated that for all practical purposes there was no excess capacity in New Jersey. The older urbanized areas typically had collector systems in need of substantial reconstruction and undersized plants providing very low levels of treatment. The costs to bring these areas into existing day conformance were so high that some of the counties feared that this information might act as a detriment to future development. It also became evident that adding capacity to these older systems might be more costly that building new systems in more rural areas of the State. Because of this result the utility underpinning of the Plan's urban policy was subtly changed to argue that new development should be allocated to these urbanized areas since major investment would be required in any case to service the existing residents and business.

Another political policy problem resulted from the concept of locating suburban growth into areas designated to be sewered. Earlier versions of the State Plan utilized sewer service boundaries to identify areas where future growth was to be encouraged. The sewer model dataset revealed that many municipalities had received funding from the Federal government to provide collectors into areas designated in their 208 Plans, but instead had used the money to provide service to areas where the market had directed growth. (In New Jersey there is no requirement that Master Plans and Zoning conform.) Because of the Federal grant, many municipalities now were obligated to sewer the 208 areas with their own money as a pre-condition to receiving any additional Federal sewer construction grants. Therefore, if growths were directed into many areas designated to be sewered, substantial local costs would be incurred. The policy resolution of this problem was the downgrading of the role of sewer service areas played to define areas where growth is desired. In addition, increased emphasis was place on the Plan's policies to require or encourage private developers to install sewer service.

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[1] Year 2008 data was used for this analysis because of its ready availability from DEPE. An alternative would be to use 1988 data. Since we are simulating for the years 1995 to 2010 in the model, one could imagine using either 1988 or 2008 as a standard, depending on whether the target year is early or late in the forecast.

[2] Three regional cost adjustments are provided and user selected: urban = 1.13; Suburban = .95; Rural = .80)

[3] A second varible representing the standard diviation of the number of units in each subsquare also was developed and explored. Results from this variable are not discussed in this paper.

[4] Pearson correlation coefficient of .759 between DENSITY and COVER in this sample.