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Project Summary

Procedures for Estimating Dry Weather Sewage In-Line Pollutant Deposition Phase II

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Planners, engineers, and municipal managers are given generalized procedures/equations to estimate the amount of pollutants deposited in combined sewer systems during dry weather so they can make intelligent decisions about sewer flushing programs and other combined sewer management controls.

The predictive equations relate the total daily mass of accumulated pollutants deposited within a collection system to the physical characteristics of collection systems such as per capita waste rate, service area, total pipe length, average pipe slope, average diameter, and other more complicated parameters that derive from analysis of pipe slope characteristics. Several other predictive equations that can be used with different available data and user resources are given. Pollutant parameters include suspended solids, volatile suspended solids, biochemical oxygen demand, chemical oxygen demand, total organic nitrogen, and total phosphorous.

The equations were developed from data assembled from three major sewage systems in eastern Massachusetts and from a portion of the combined sewer system in the eastern district of Cleveland. This study was an extension of earlier work; broader data was used here to prepare the predictive relationships.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Summary of Results

Results using the augmented data base are summarized. Various predictive models are described, relating total suspended solids deposition within a collection system with independent variables under the assumption of clean pipe conditions. These relationships therefore apply to situations in which the sewer piping system is properly maintained.

Statistical Summary of Regression Data

In Table 1 are found the means and standard deviations of the independent variables used in this regression analysis.

L, A, and $\bar{D}$ measurements for the augmented data base increased over those of the prior data base. By including data from the relatively flat Cleveland collection systems, the average slope parameters ($\bar{S}$, S_{PD}, and $S_{PD/4}$) all decreased.

The average collection-system deposition rate computed over all four per capita waste discharge levels (260, 190, 110, 40 gpcd, respectively) is 1.94 lb/day/acre of service area. The average and standard deviation of the rates computed for a per capita waste rate of 260 gpcd are 1.07 and 1.64 lb/day/acre of service area, respectively. The average

Table 1. Means and Standard Deviations of the Independent Variables Used in the Regression

	A*		B†	
Variable‡	*Mean*	*Standard Deviation*	*Mean*	*Standard Deviation*
L (ft)	13702.	22867.	14720.	20044.
A (acre)	76.	102.	106.9	110.8
$\bar{S}$ *(ft/ft)*	0.0210	0.0126	0.0166	0.0130
$\bar{D}$ *(in.)*	11.5	2.0	16.9	6.1
S_{PD} *(ft/ft)*	0.0101	0.0093	0.0067	0.0072
$S_{PD/4}$ *(ft/ft)*	0.0037	0.0033	0.0034	0.0029

**A = the prior data base, i.e., 75 collection systems from the three major sewerage systems in eastern Massachusetts;*

†B = all data, the augmented data base, i.e., the previous 75 plus 28 collection systems located within the eastern district of Cleveland combined sewer system;

‡L = total length of all pipe in the sewer shed, in ft;

A = the collection system area, in acres;

$\bar{D}$ = average diameter of pipe in the collection system, in in.,

$\bar{S}$ = the average collection-system pipe slope, in ft/ft;

S_{PD} = the slope corresponding to PL_D, in ft/ft (PL_D = the percentage of pipe length corresponding to where 80 percent of the solids deposit in the collection system);

$S_{PD/4}$ = the slope corresponding to $PL_{D/4}$, in ft/ft ($PL_{D/4}$ = one-fourth of the percentage of pipe length where 80 percent of the solids deposit).

deposition rates for per capita waste rates of 190, 110, and 40 gpcd are 1.35, 1.91, and 3.42 lb/day/acre of service area, respectively.

Alternative Equation Selections

Two regression equations are presented and recommended for user application; the alternative forms reflect the availability of data, or user resources, or both. The simple form requires few data and has the least predictive reliability; whereas the more elaborate equation, requiring greater user resources and data availability, provides estimates with extremely high reliability.

The Elaborate Equation

The highest multiple correlation coefficient, R = 0.970 (variance explained, $R^2 = 0.940$) was obtained using this equation:

$$TS = 0.00108\ L^{0.948} \bar{S}^{-0.323}\ S_{PD}^{-0.519}\ S_{PD/4}^{-0.148}\ q^{-0.518}$$

where:

TS = deposited solids loading in lb/day

q = per capita waste rate, in gpcd

The value PL_D (the percentage of pipe length corresponding to 80% of the loads depositing in the collection system) is derived from the extensive computer analyses. A discussion involving estimation of S_{PD} and $S_{PD/4}$ are contained in USEPA report numbers EPA-600/2-77-120 (NTIS No. PB 270 695) and EPA-600/2-79-133 (NTIS No. PB 80-118-524), respectively. The probability of the pipe slopes can either be derived from histograms computed from local pipe slope data, or it can be defined with reasonable approximation from the mean pipe slope, $\bar{S}$ only. If the pipe slopes are not available, a regression relationship of mean ground slope and mean pipe slope can be used to estimate mean pipe slope.

The Simple Equation

The highest R^2 value that can be obtained with the least number of independent variables is given by the relatively simple regression equation:

$$TS = 0.0088\ L^{1.065}\ (\bar{S})^{-0.433}\ q^{-0.539}\quad (R^2 = 0.880)$$

The exponents of the independent variables and the multiplicative constant of the equation changed only slightly in comparison with the equation derived from eastern Massachusetts collection system data. The degree of fit is high (R^2=0.0880) and superior to that of the prior fit for eastern Massachusetts data (R^2=0.845).

Estimation of Total Pipe Length

The total pipe length of the system, L, and its corresponding collection area, A, are generally assumed to be known. In cases where this information is not known and where crude estimates will suffice, the total pipe length can be estimated from the total basin area, using the expressions:

$L = 220.9\ A^{0.847}$ (R^2=0.804) - low population density (10-20 people/acre)

$L = 238.0\ A^{0.847}$ (R^2=0.804) - moderate-high population density (30-60 people/acre)

These equations were developed from a least squares analysis of the augmented data base.

Estimation of Pipe Slope

If data on pipe slope are not available, an approximate estimate of average collection-system pipe slope can be obtained by computing a mean value for the ground slope and then using this equation:

$$\bar{S} = 0.320\ (\bar{S}_G)^{0.790}\ (R^2 = 0.850,$$

where:

S_G = mean ground slope, in ft/ft.

The above equation resulted from a regression of mean ground and mean pipe slope for all 103 collection systems. The procedure used in estimating ground slope data for the Cleveland collection systems was similar to the method used in the earlier study of eastern Massachusetts collection systems and is included in the project report.

Discussion of Prior and New Results

Table 2 presents an overview of the predictive equations prepared from the original and the new combined data set appended to the original data. The R^2 for the two elaborate equations are very similar. All three collection-system slope parameters ($\bar{S}$, S_{PD} and $S_{PD/4}$) entered the regression equation at a high significance level (Student's t values exceeding 4.0) for the combined data set; whereas, only S_{PD} and $S_{PD/4}$ entered the elaborate equation for the original set. This ifference is due, in part, to the limited range of average collection-system pipe slopes, $\bar{S}$, for the three sewerage systems comprising the original data set. The range of the average pipe slopes computed for the collection systems within each of the three sewerage systems in eastern Massachusetts was from 0.0175 to 0.0254 and for the 28 systems in Cleveland, 0.0028 to 0.0178.

The inclusion of flatter pipe slope data from the Cleveland sewerage system increased the overall range of average collection system variable, $\bar{S}$, by an order of magnitude. The average collection-system pipe slope, $\bar{S}$, for the combined set of data assumed a more dominant role as an explanatory variable in describing the variance of estimated deposition solids loadings per collection system. A visual scanning of the average collection-system pipe slope for the entire data set revealed a fairly reasonable spread of observations along the entire range, thereby minimizing the concern of spurious correlation created by data clustering at opposite ends of the range. The results for the simple equations shown in Table 2 are similar and confirm the above discussion in that the R^2 is 4.5 percent higher for the combined data set.

As a side note, the original equations (derived from eastern Massachusetts data) were used to estimate daily deposits for the 28 Cleveland collection systems. The resulting R^2 values for the Cleveland data, using the equations generated from eastern Massachusetts data, are 0.717 and 0.811 for the elaborate and simple equations, respectively. The modified equations (derived for the combined data set) were then used to estimate daily deposits for the 75 eastern Massachusetts collection systems. The R^2 values for the eastern Massachusetts data, using the equations generated from the combined data base, are 0.821 and 0.867 for elaborate and simple equations, respectively. In these numerical sensitivity experiments, note that the degree of fits was superior, in a predictive sense, for the simple equations in comparison with those of the elaborate.

The more favorable R^2 results for the simple equations suggest that the elaborate equations are too specific and sensitive to changes in data input. In addition, the simple equations require comparatively little input data compared with that needed for the elaborate. The user needs only prepare estimates of the total collection-system pipe length, L; the average collection-system pipe slope, $\bar{S}$; and an estimate of the per capita waste rate, q, to use the simple equations.

The simple equations are therefore preferred. Since the exponents of the independent variables and the multiplicative constant of the simple equation for eastern Massachusetts differ only slightly from those of the combined (eastern Massachusetts and Cleveland) data, the equation derived from the combined data, based on a broader base, is recommended.

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Table 2. *Comparison of Deposition Predictive Equations*

Equation	*Data Source*	*R^2*	*Explanatory Variables*
Elaborate	*E. Mass.*	*.949*	$L, S_{PD}, S_{PD/4}, q$
Elaborate	*Combined*	*.940*	$L, S_{PD}, S_{PD/4}, \bar{S}, q$
Simple	*E. Mass.*	*.845*	$L, \bar{S}, q$
Simple	*Combined*	*.880*	$L, \bar{S}, q$

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***Richard Field** is the EPA Project Officer (see below).*
The complete report, entitled "Procedures for Estimating Dry Weather Sewage In-Line Pollutant Deposition: Phase II," (Order No. PB 84-141 480; Cost: $8.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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