EPA-R2-73-138
FEBRUARY 1973

Environmental Protection Technology Series

The Feasibility of Flow Smoothing Stations in Municipal Sewage Systems

Office of Research and Monitoring
U.S. Environmental Protection Agency
Washington, D.C. 20460

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Monitoring, Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA-R2-73-138
February 1973

THE FEASIBILITY OF FLOW SMOOTHING STATIONS IN MUNICIPAL SEWAGE SYSTEMS

by

C. N. Click

Project No. 11010 FDI
Contract No. 14-12-935

Project Officer

Harry E. Bostian
U.S. Environmental Protection Agency
National Environmental Research Center
Cincinnati, Ohio 45268

Prepared for

OFFICE OF RESEARCH AND MONITORING
U. S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Price $1.25 domestic postpaid or $1.00 GPO Bookstore

EPA Review Notice

ABSTRACT

Flow smoothing in sanitary sewers was studied to determine under what conditions the resulting higher flow capacities can be economically obtained. Conservative assumptions were made in this preliminary design and economics study to provide a severe test for the cost effectiveness of the concept. In many situations, flow smoothing is an attractive alternative when compared to relief pipe installation. Circumstances which favor flow smoothing are high interest rates, high peak-to-average flow ratios, low pipe slopes, small diameters, and low design depths of flow. Flow smoothing is strongly favored where earthen construction can be utilized.

This report was submitted by Research Triangle Institute, Research Triangle Park, N. C., in fulfillment of Contract Number 14-12-935, Project Number 11010 FDI under the sponsorship of the Office of Research and Monitoring, Environmental Protection Agency.

CONTENTS

FIGURES

TABLES

I. CONCLUSIONS

The following conclusions were drawn from this feasibility study of flow smoothing in municipal sanitary sewage systems.

1. Flow smoothing in sanitary systems may offer an economically attractive alternative to relief sewers in systems needing additional capacity.

2. Flow smoothing is attractive in most circumstances if outfall pipe length exceeds about 3 miles. For inexpensive basin construction, flow smoothing can be attractive if outfall pipe lengths exceed about 0.5 mile.

3. Flow smoothing is favored by increasing peak-to-average flow ratios and interest rates and by decreasing slopes, construction costs, pipe diameters, and design depth of flow.

4. Capacity increase by flow smoothing will result in a proportionate capacity increase in all downstream piping and equipment.

The conservative nature of the assumptions made in the analysis must be emphasized. Field experience should show an even wider potential range for application of flow smoothing than indicated above.

II. RECOMMENDATIONS

1. Full-scale demonstrations of flow smoothing stations should be undertaken to identify and solve technical problems and to provide more accurate design and cost data. The desirability of locating smoothing stations at various locations in existing systems should be considered, i.e., in the collection system and at treatment plants, wherever overloads may occur. Demonstrations would provide evidence to justify flow equalization for new sewerage systems and for upgrading existing systems.

2. Further feasibility studies should be made to consider additional possibilities for flow-equalization and to evaluate their economic attractiveness. Studies are needed to analyze sewer systems with multiple junctions and multiple smoothing stations and to identify and evaluate alternatives for smoothing at the treatment plant. The effects on both hydraulics and concentrations need to be examined. Computer modeling studies are recommended because these would permit examination of a greater number of alternatives than would be practical with experimental investigations. Broader investigation is needed to better determine the long range optimum applications for flow equalization.

III. INTRODUCTION

It is common knowledge that the flow in municipal sewage systems varies from day to night, being at its highest during the early daylight hours when there is increased demand for water and at its lowest in the middle of the night. Sewage systems are usually designed with sufficient capacity to carry the peak flows. Since these peak flows only occur for a fraction of the time, the sewage system operates at less than its design capacity during the remaining periods. As population grows and more load is placed on the normal municipal sewage system, the point will inevitably be reached at which the peak sewage flows exceed the design capacity of the sewage system and additional capacity is needed. One possible way to provide this additional capacity is to install flow smoothing basins at key locations within the sewage system. These basins would store sewage flow during the periods of high delivery and release sewage into the downstream piping at more nearly constant rates. The basin function would thus be to provide for better usage of existing sewage piping during the off-peak hours by releasing sewage which has been stored during the high demand period.

The purpose of this study has been to assess the feasibility of flow smoothing compared to the installation of additional piping as a method of increasing the capacity of existing sewage systems.

Toward this end, capital and operating costs have been estimated for flow smoothing basins of several different types and for a range of design conditions. These costs have been compared with capital and operating costs for the installation of additional piping to predict the most economical policy in given circumstances. During the study, design variables and economic parameters have been assumed to range over the sets of values indicated in the following tabulation:

1. Basin types:

   a. Concrete with a pump station.
   b. Earthen with a pump station.
   c. Concrete with no pump station.
   d. Earthen with no pump station.

2. Pipe diameter from 8 inches to 30 inches.

3. Pipe slopes as calculated to correspond to assumed velocities of 2, 2.5, 3, and 3.5 ft/sec.

4. Flow capacity (Y), expressed as a fraction of the capacity of a completely filled pipe, of 0.7, 0.8, and 0.86.

5. Peak-to-average flow ratios: 1.5, 1.75, 2.0, 2.5, 3.5.

6. Equipment lifetime: pipes, 50 years; basins, 30 years*; installed equipment, 10, 20, and 30 years.

7. Interest rates; 4, 6, and 8 percent.

8. Basin aeration equipment designed for assumed BOD removals of 10 and 30 percent. (Based on activated sludge process to provide adequate aeration and mixing - 10 and 30 percent removals are not expected without sludge return.)

The general procedure for performing the calculations is the following: For a particular combination of assumed inputs selected from the tabulation above, evaluate (1) the size of the storage basin required, (2) the capital cost of the basin plus its auxiliary equipment, (3) the operating and maintenance costs of the basin, (4) the total operating cost of the basin including amortized debt service, (5) the capital cost per mile for additonal piping equivalent to that currently existing, (6) operating and maintenance costs per mile of the additional piping, (7) total operating costs per mile of the additional piping including amortized debt service, (8) the break-even length (BEL) or the length of additional piping that could be installed for the same total operating cost as the smoothing basin.

The BEL, in practical terms, is a measure of basin cost expressed in units of equivalent miles of pipe. Thus a high value for BEL, in general, reflects a more costly storage basin in a particular physical installation. If the length of additional piping required exceeds BEL, a smoothing basin is favored; otherwise, additional piping is favored. Although practice might differ depending on local circumstance, for simplicity in this analysis it has been assumed that additional piping will be the same diameter as existing piping. However, final BEL values are on a unit capacity basis for both basin and pipe. This tends to diminish the effect of a fixed pipe diameter choice. Final calculations for an actual cost comparison should be tailored to the individual case.

Detailed methods of calculation used in this present project are presented in the following section.

---

*Although it may seem that basins would outlast pipes, pipes are designed for longer periods to avoid costly excavation for replacement. The design lifetimes chosen are similar to those suggested in Fair and Geyer [4], page 117, for sewers and treatment works.

IV. METHODS OF CALCULATION

The detailed formulae and correlations that have been used in this study are listed in this section.

Estimation of Peak-to-Average Flow Ratio

Correlations for the determination of the peak-to-average flow ratio in municipal sewage systems have been reported by Gifft [1], Harmon [2], Johnson [3], Fair and Geyer [4], Babbitt and Baumann [5], and Geyer and Lentz [6]. For this study the following equation, based on Gifft's results, is recommended for estimation of the peak-to-average flow ratio, QP/QA, versus population for residential districts:

$$QP/QA \equiv X = 2.2(1/P)^{0.080} \tag{1}$$

where $QP/QA \equiv X$ = the ratio of the peak flow to the average flow for the max-day

P = the contributing population, thousands.

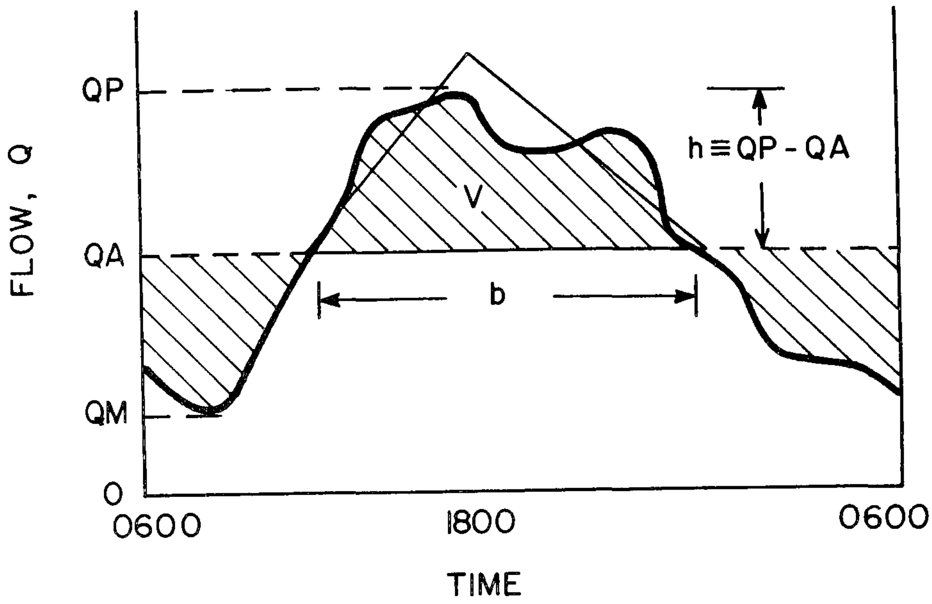
Estimation of Required Storage Basin Capacity

In order to compute the storage volume required to smooth a particular fluctuating flow, it is necessary to know or to be able to approximate some of the characteristics of the flow hydrograph. In Figure 1 is shown a typical sewage flow hydrograph for 1 day. The storage volume required to smooth this hydrograph is proportional to the portion of the shaded area above QA on the figure, and is labeled V.

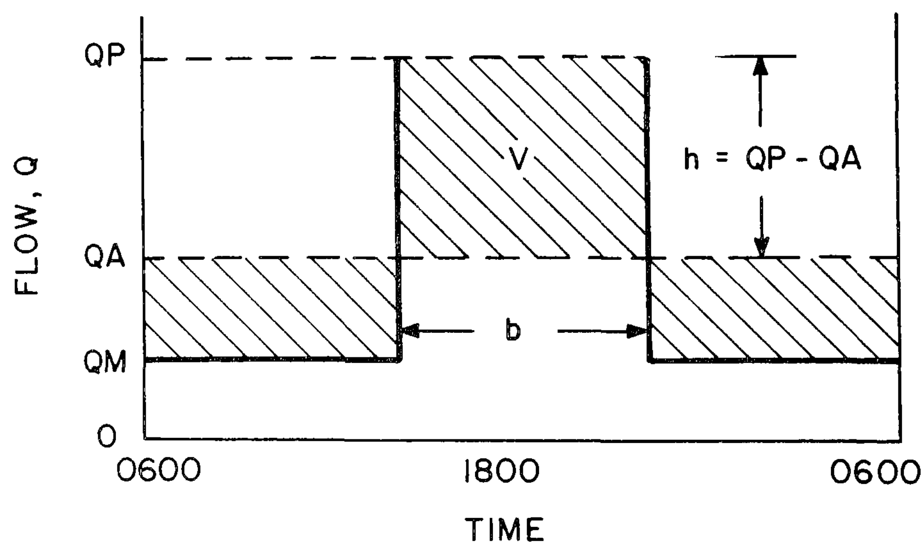
In general, detailed hydrographs of streams to be smoothed may not be available. In such circumstances it is desirable to have available a technique for approximating the characteristics of the hydrograph necessary for the estimation of the storage volume required for smoothing. Formulae for this purpose have been developed as a part of this study from a set of hydrographs representing the flow to the Durham New Hope Waste Treatment Plant.

One technique which was tried and subsequently discarded was to approximate the area above the average line with an oblique triangle whose base coincided with the average line (see Figure 1A). The required storage volume would then be estimated by the area of the triangle, (1/2)bh, where h = QP - QA and b represented the duration for which the flow exceeded QA. The method was discarded because daily variations in the value of b were difficult to generalize.

Another more valuable technique for the approximation of the storage volume required is to assume that the hydrograph is reasonably represented



(A) Representative Typical Sewage Flow Hydrograph for 1 Day. (Triangle Approximation Superimposed on Hydrograph for Determining VT.)



(B) Square Wave Model Hydrograph for 1 Day.

FIGURE 1. Representative Typical and Square Wave Model Sewage Flow Hydrographs.

by a square wave, as in Figure 1B, with the flow varying instantaneously between its peak and minimum values. For a hydrograph with this wave form, the storage volume required for smoothing can be obtained provided the maximum, average, and minimum flows, as well as the pulse time, can be estimated in terms of the nature of the flow. This can be done as follows: The literature [1,7] indicates that for sanitary flows the average-to-minimum flow ratio can be assumed identical to the peak-to-average ratio. Thus the relationship X = QA/QM = QP/QA is assumed. By the definition of the average, a material balance provides

$$QA = (QM - 0)\frac{1 \text{ day}}{1 \text{ day}} + (QP - QM)\frac{b \text{ day}}{1 \text{ day}},$$

and thus

$$b = \frac{QA - QM}{QP - QM} = \frac{X - 1}{X^2 - 1}. \qquad (2)$$

VS, the square-wave estimate of the storage requirement, can be calculated from

$$VS = h \times b$$

or

$$VS = (QP - QA)\frac{(QA - QM)}{(QP - QM)} = (QP - QA)\frac{(X - 1)}{(X^2 - 1)}. \qquad (3)$$

Since QP/QA ≡ X and we have assumed X = QA/QM, the above equation reduces to

$$VS = QA(X - 1)\frac{X - 1}{X^2 - 1}$$

or

$$VS = YQF\left(\frac{X - 1}{X + 1}\right)\frac{1}{X}. \qquad (4)$$

In Table 7, Appendix B, the results of the analysis of actual hydrographs are presented. Storage volumes required to smooth the actual flows have been estimated by planimeter (VD), by the triangular approximation (VT), and by the square-wave approximation (VS). The most conservative approximations (i.e., those assured of predicting sufficient storage volumes) are those resulting from the utilization of the square wave. Therefore, the square-wave estimates have been used in subsequent calculations.

Note that the installation of a smoothing basin of volume VS will cause the flow downstream of the basin to be constant at QA rather than to fluctuate between the maximum QP and the minimum QM. This means that the downstream pipe is now operating at less than its design capacity, QP. As a consequence of the introduction of the smoothing basin, the downstream pipe is now capable of handling a higher flow--that is, X times its present average flow, QA. This higher flow must also be smoothed. To do so requires a storage volume to smooth a fluctuating flow that has an average equal to the design capacity. This volume can be caluclated using the previous formula and assumptions, but with an average flow equal to the previous peak flow. If we designate the new conditions with primes, use the same value and definition of X for the new case and assume that the average-to-minimum flow ratio is equal to X for both cases,

$$QA' = QP = YQF$$

$$QP' = XQA' = XQP = XYQF$$

$$QM' = \frac{QA'}{X} = \frac{QP}{X} = \frac{YQF}{X} .$$

Now, let the smoothing volume required for maximum utilization be VM. Using Equation (3) for the new conditions,

$$VM = (QP' - QA')\frac{(QA' - QM')}{(QP' - QM')}$$

$$VM = (XYQF - YQF)\frac{(YQF - \frac{YQF}{X})}{(XYQF - \frac{YQF}{X})}$$

$$= YQF(X - 1)\ \frac{X - 1}{X^2 - 1} \qquad (5)$$

or

$$VM = YQF\ (\frac{X - 1}{X + 1}) \qquad (6)$$

Equation (6) provides the storage that would be needed if one were to use all the additional capacity resulting from smoothing, assuming that the new flow exhibits the same wave form and peak-to-average ratio as the existing flow. Note that VM is simply VS multiplied by X. This result can also be deduced directly from the next to last equation on page 9. QA will be the only quantity changed for the new case; its value will be increased by the factor X resulting in the same increase in the required smoothing volume.

Cost Estimation for Concrete Basins

Construction assumptions for concrete basins were the following:

1. A constant total variation of 15 feet between minimum and maximum levels.

2. A minimum level of 1 foot above the bottom with additional sump provision under each aerator as required by aerator size.

3. A minimum freeboard above the liquid surface of 3 feet for open stations and of 1 1/2 feet in excess of the exposed height of aerators for enclosed stations.

4. Minimum thickness of reinforced concrete of 1 foot for all sections including roofs for enclosed stations.

5. Three feet of additional excavation on all sides of excavations for erecting concrete forms.

6. Stations to be installed at a pipe depth of 3 feet with the maximum liquid level of the station at the invert (bottom inside) of the downstream pipe. Pipe installations deeper than 3 feet may be common, however a variation in pipe depth should have a negligible effect on BEL. For example, a 6-foot sewer depth would require increasing the excavation depth from 19 to 22 feet. The percentage increase in excavation costs may be about 14 percent but this would represent a maximum of 5 percent of the total basin cost. Considering the conservativeness of other assumptions, variation of pipe depth snould have little effect on the attractiveness of flow smoothing.

Costs were developed for several representative volumes with and without provision for concrete covers. The procedure was to assume a square of side L such that the product of the 15-foot variable depth and the area (L^2) equaled the chosen useful volume. Covers were assumed to be equal in area to L^2. The concrete height, h', was set equal to 15 + (1 + aerator clearance), feet [11]. Thus the required amount of concrete was V'_{conc},

$$V'_{conc} = [4L(1)h' + L^2(1)](\frac{1}{27}), \text{ cu yds}$$

for open construction; and

$$V_{conc} = [4L(1)h' + 2L^2(1)](\frac{1}{27}), \text{ cu yds}$$

for enclosed construction.

Excavation costs were developed by allowing for an excavation of suitable length to allow for wall thickness and backfill, $\ell(\ell = L + 2 + 6)$, ft, and of sufficient height to include wall thickness, sump allowance, and freeboard, $h(h = h' + 2 + 2 + 3)$, ft,

$$h = h' + 7 .$$

Thus the excavation volume was

$$V_{excav} = \ell^2 h (\frac{1}{27}), \text{ cu yds.}$$

Land areas were determined by assuming that a 10-foot clearance would be required around the excavation and, in addition, that a 50-percent increase in area would be required to supply an access road. Thus for concrete stations the land area was calculated by

$$A_{land} = \frac{(\ell + 10)^2(1.5)}{43,560}, \text{ acres.}$$

The costs determined by summing concrete, excavation, and land costs were increased by 20 percent for engineering and contingencies. Cost calculations for concrete smoothing basins are summarized in Table 8, Appendix B.

Cost Estimation for Earthen Basins

Construction assumptions for earthen basins were

1. A minimum dike width of 8 feet.

2. Inside slopes of 1:3 to the upper waterline and 1:1 below that.

3. An outside slope of 1:2.

4. A minimum freeboard of 3 feet.

5. A minimum waterline of 1 foot.

6. A maximum water level change of 15 feet.

7. A water surface area at the midline, between maximum and minimum water levels, equal to that of a square such that the volume generated by translating the square 15 feet vertically equals the desired basin volume.

8. An above-grade dike rise limited to using the excavated earth.

9. A maximum water level that coincides with the invert of the downstream side of the pipe. (Upstream pipe depth is essentially the same.)

For earthen basins an excavated volume, paved area, and total land requirement were calculated. Figure 2 shows a cross section of a typical earthen basin. Combining the 1:1 slope of the side walls (below) the waterline) with the 15-foot level variation, 1-foot minimum water level, and the assumption that the mid-waterline (1 + 15/2, feet from the bottom) had a side $L = \sqrt{V'/15}$ ft, the various areas and volumes can be found as follows. The bottom area (A_2) equals $[L - 8.5\ (1/1)2]^2$, ft^2. The wetted and paved side areas (adjusted to pave the aerator sump walls) equal $4[(L - 1\sqrt{2}(18)]$, where the "4" provides for the four sides and L is the width at the mid-waterline; hence, (L - 1) is the mid-width of a side including an additional 1 foot of depth for the minimum water level. The radical corrects for the pyramidal shape, and the (18) represents the wall height adjusted to include the sump area.

The volume of earth excavated was calculated from the formula for the volume of a truncated pyramid whose upper and lower base areas were A_1 and A_2,

$$A_1 = [L + 7.5\ (\tfrac{1}{1})\ 2]^2$$

$$A_2 = [L - 8.5\ (\tfrac{1}{1})\ 2]^2$$

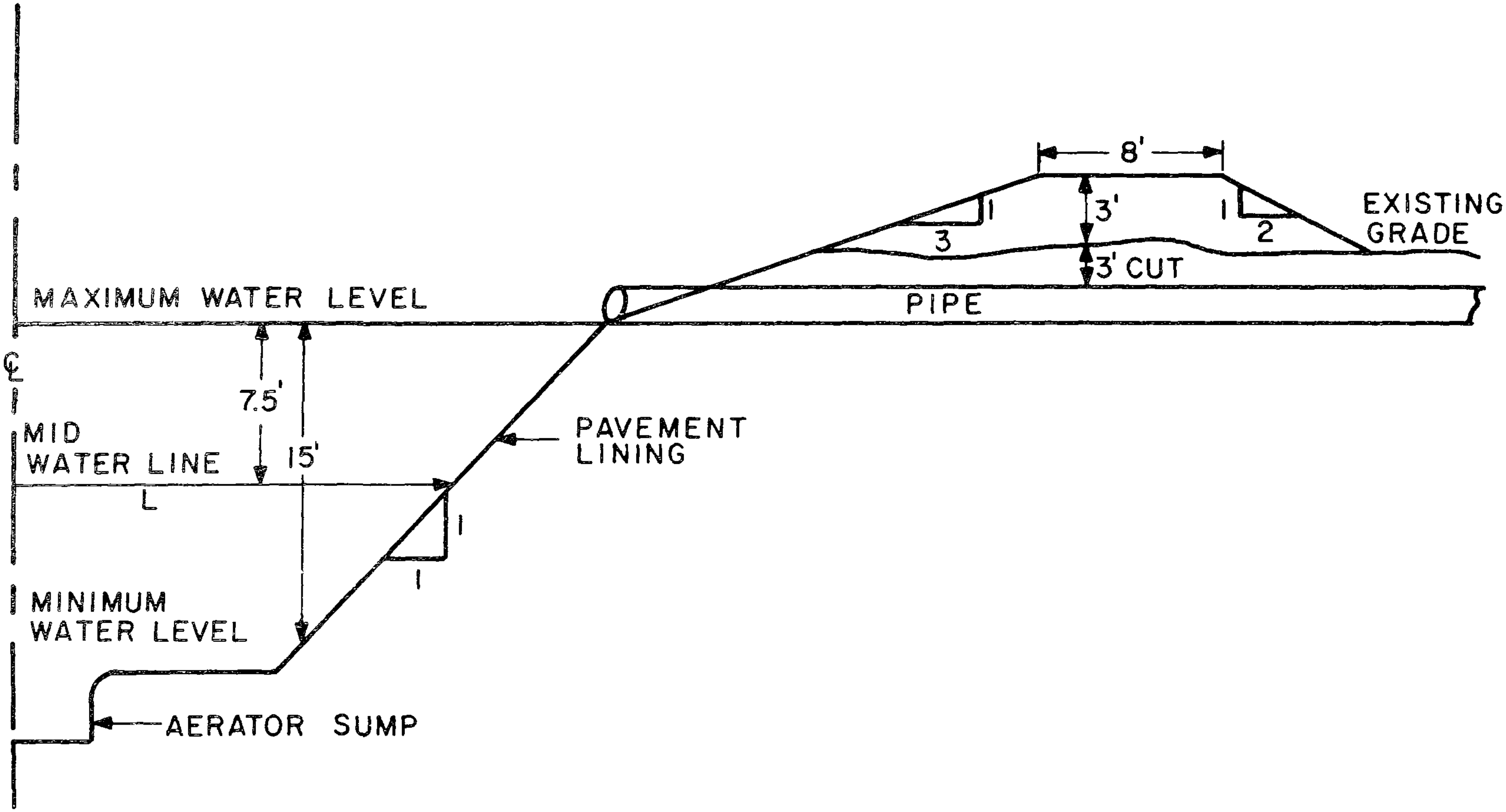


FIGURE 2. Half-Section Through Paved Earthen Basin.

and whose height (h) equaled the sum of the minimum water level plus the 15-foot maximum water level variation plus 2 feet sump allowance. The volume of the pyramid was increased by the product of the upper water level area (A_1) and the 3-foot thickness of the cut to the pipe. The volume of the excavation (VEX) was thus

$$VEX = \frac{1}{3}(A_1 + A_2 + \sqrt{A_1 A_2})\, h + (A_1)(3\ ft) .$$

The land area required was calculated by starting at the upper waterline (pipe invert) with [L = 7.5(1/1)2] and extending this line in both directions for the run required to achieve the necessary dike rise at the specified slope (but including the minimum dike width of 8 feet). The result was about (L + 90) feet for a 3-foot cut below grade plus a 3-foot minimum dike height above grade. A 15-foot wide buffer strip was assumed necessary beyond the dike, and thus the final area was $(L + 120)^2$, ft^2. Table 9, Appendix B, summarizes these calculations and the costs assigned to earthen basin construction.

Figure 3 shows the relationship of total basin construction costs versus live volume for enclosed concrete and open paved earthen stations.

<u>Capital Costs of Auxiliary Equipment--Pumps and Aerators</u>

The installed costs of pumping stations [8] (Figure 4) have been used in the present studies. They are probably on the high or "safe" side, since they include items for which costs have been allowed in smoothing station construction--that is, excavation, wet well construction, electrical and piping connections, fencing, and close-out. Finally, above-grade package plants are only 60 percent of the cost of below-grade package plants and could reduce pumping costs still further.

Installed costs of aerators as obtained from vendors [11,16,17,18] are shown in Figure 5. The Aqua Jet data were used in this analysis; these data were the most conservative and complete. Aerators were sized to provide aeration equivalent to that which would remove 10 and 30 percent of an assumed 200 mg/ℓ average BOD level, assuming 1.3 lb of oxygen per lb of BOD and a transfer rate of 2.5 lb oxygen per hp-hr. These levels of BOD removal may not actually be obtained without an activated sludge, but the aeration provided should be sufficient to prevent septicity. In order to provide sufficient mixing and aeration for different basin residence times, the horsepower calculations should be based on 30-percent BOD reduction for long average residence times (6 hr) and 10-percent reduction for short average residence times (2 hr). This method of sizing aerators for equalization basins, based on common aeration and mixing situations, is believed conservative. It is consistent with recommendations in Chapter 3 of the EPA Upgrading Manual (21). The method could be refined when data from actual applications are available. In this study, the aeration capacity was sized to handle the maximum flow through the storage volume and standby units were included.

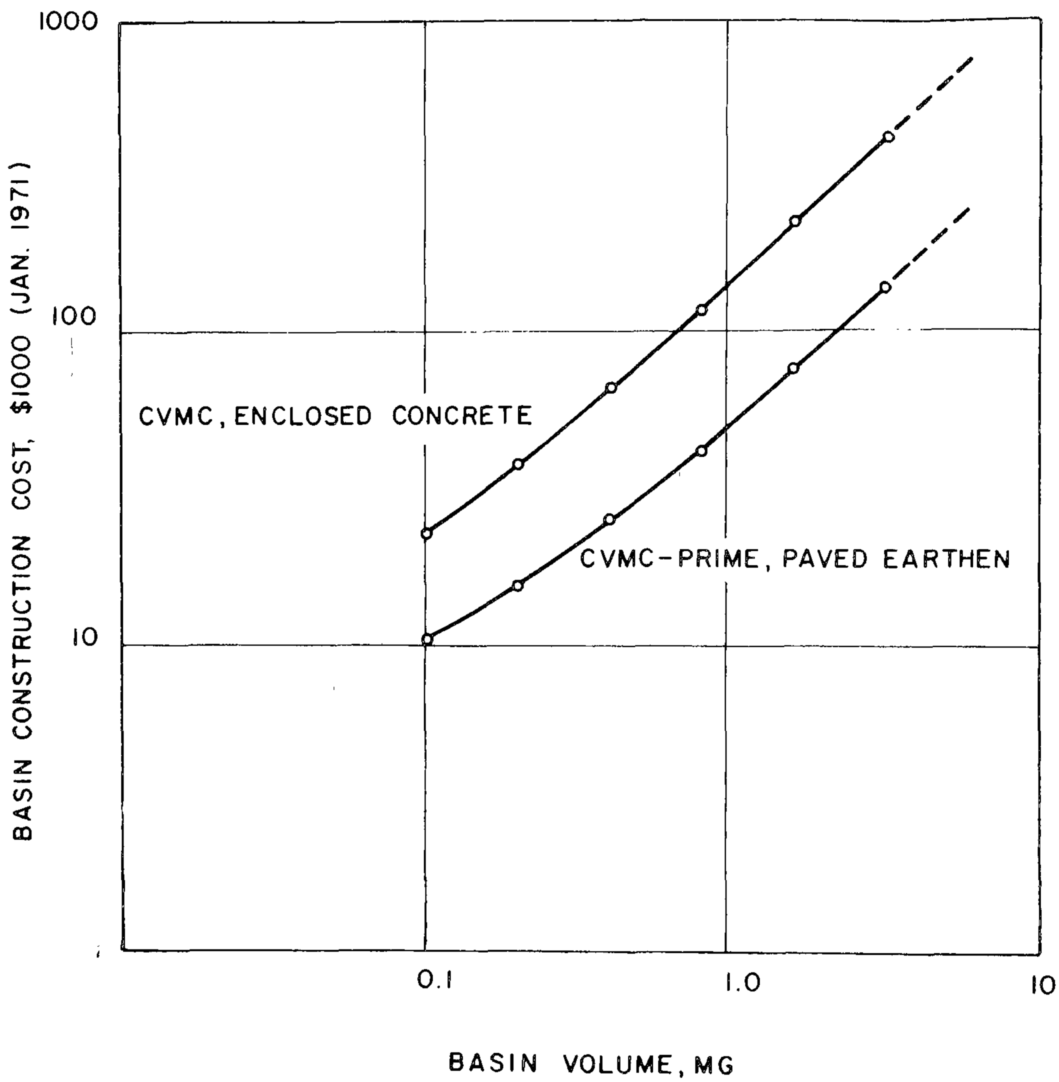


Figure 3. Construction Costs for Basins.

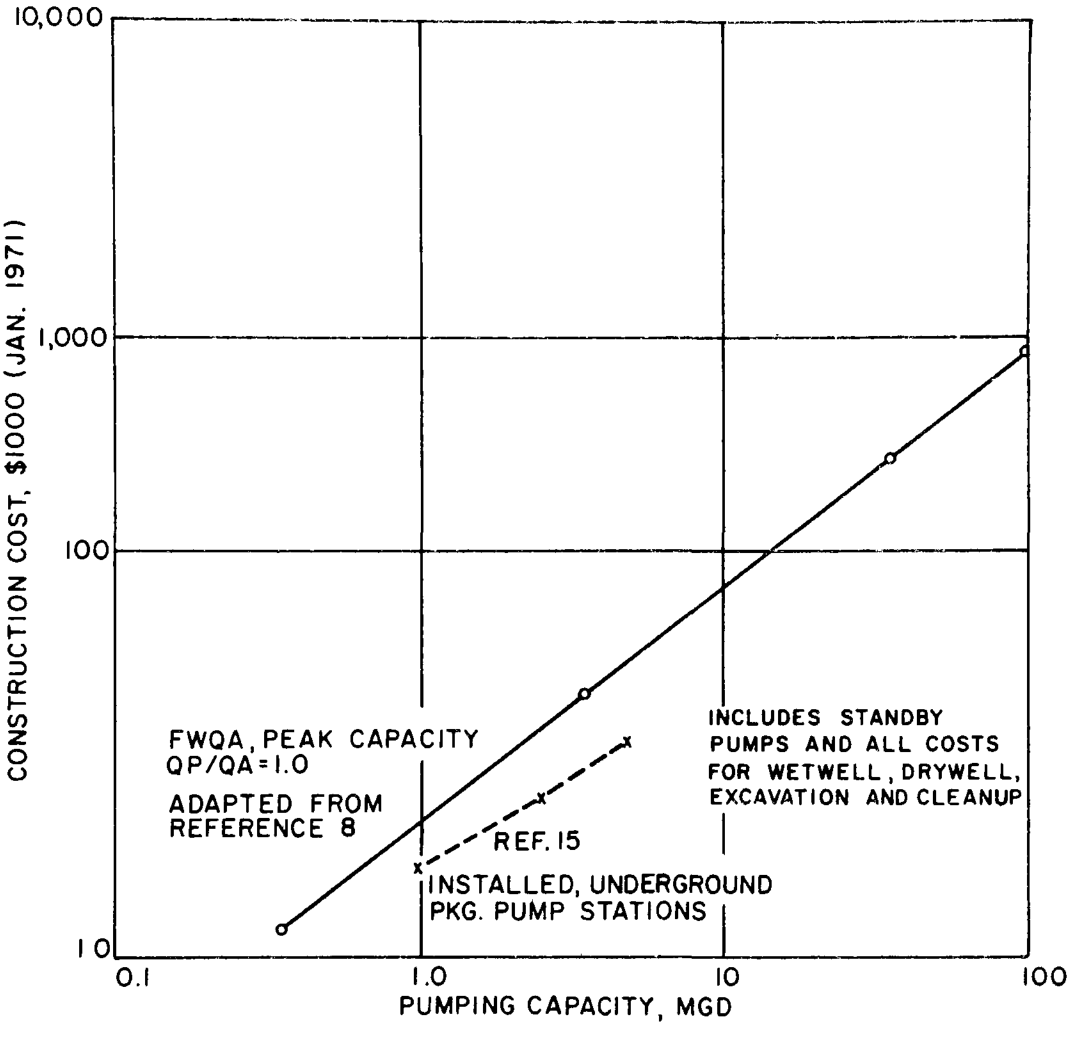


Figure 4. Construction Costs for Raw Sewage Pumping Stations To Be Used with Equalization Basins.

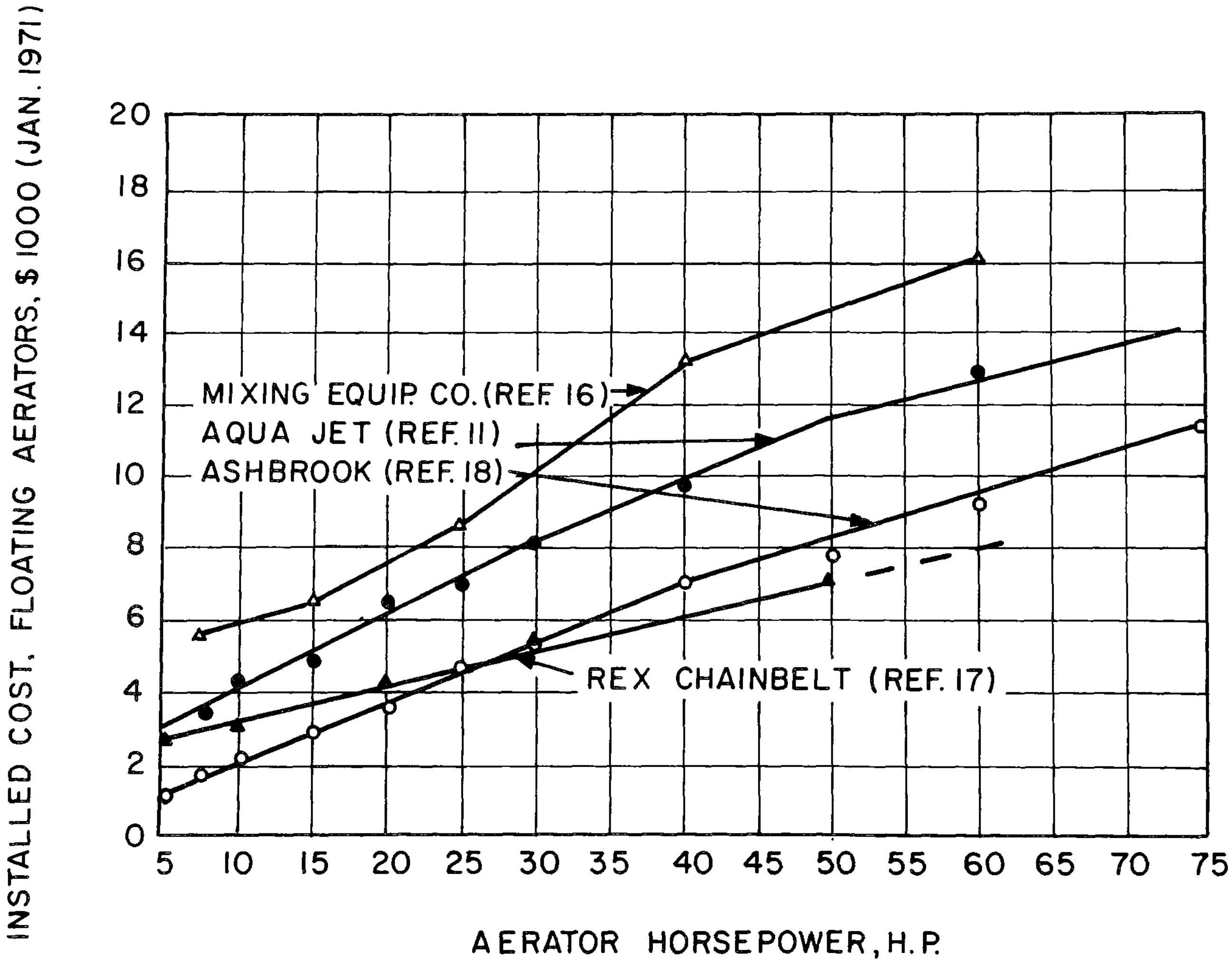


FIGURE 5. Installed Costs for Floating Aerators.

The calculations used to determine aerator sizes and costs are summarized in Table 10 in Appendix B. Table 8 includes operating and maintenance costs (O-M) for aerators and is developed for flow ratios (Q/V) of 4 and 2 and for BOD removal bases of 30 and 10 percent.

Graphs of installed equipment costs versus storage volume were developed with the parameter (Q/V) identical to (QP/VM); see Figures 6 and 7. Referring to the figures, specific curves show the costs of aerators alone and the sum of aerator and pump costs for a given basin size.

Capital Cost of Sewer Pipes

The installed costs of sewer pipes (CP) were based on the costs given in a recent EPA/Taft Research Center Internal Memo [8]. Recent local costs for pipes seem to conform well with this reference; see Figure 8. The equation of the curve in Figure 8, $CP = 1540.7(D + 2.0436)^{1.37949}$, was used to compute CP for cost calculations in this report.

Operating and Maintenance Costs

Pumps. Two relationships were used for pump operating and maintenance costs (PUOM). The first was taken from Reference 8; the second was developed from local data. Both relationships are compared in Figure 9.

Local costs were based on 1¢/kwh for power, a nominal head (TDH) of 40 feet, and an overall efficiency of 40 percent [19]. Power requirements are 0.025 hp/gpm, and power costs are 0.31¢/1000 gal.

In Durham, pump stations require 4.75 hours of routine maintenance labor per month plus an allowance for about one mechanical seal replacement per year regardless of flow [9]. Present (1971) rates for maintenance labor plus overhead result in an estimated cost of $50/month per urban station. This cost was converted to pump labor cost in ¢/1000 gallons by assuming various station flows. PUOM was obtained by summing the values for pump labor with the 0.31¢/1000 gal. charge for power and plotted in Figure 9 as $PUOM_{LOC}$. Conservating ln-ln straight line equations of the curves are

$$PUOM_{OSW} = 2.1\ (QP)^{-0.26} \quad (7)$$

$$PUOM_{LOC} = 0.75\ (QP)^{-0.26} \quad (8)$$

The more conservative Equation (7) was used for values tabulated in this report. QP is used as the variable, because this will be the maximum downstream average flow after smoothing.

Aerators. Aerator operating and maintenance costs (AEOM) were estimated from Reference 10, assuming Q/V of 4, an intermediate value; power at 1¢/kwh; and motor efficiency at 90 percent. Aerator power for 30-percent

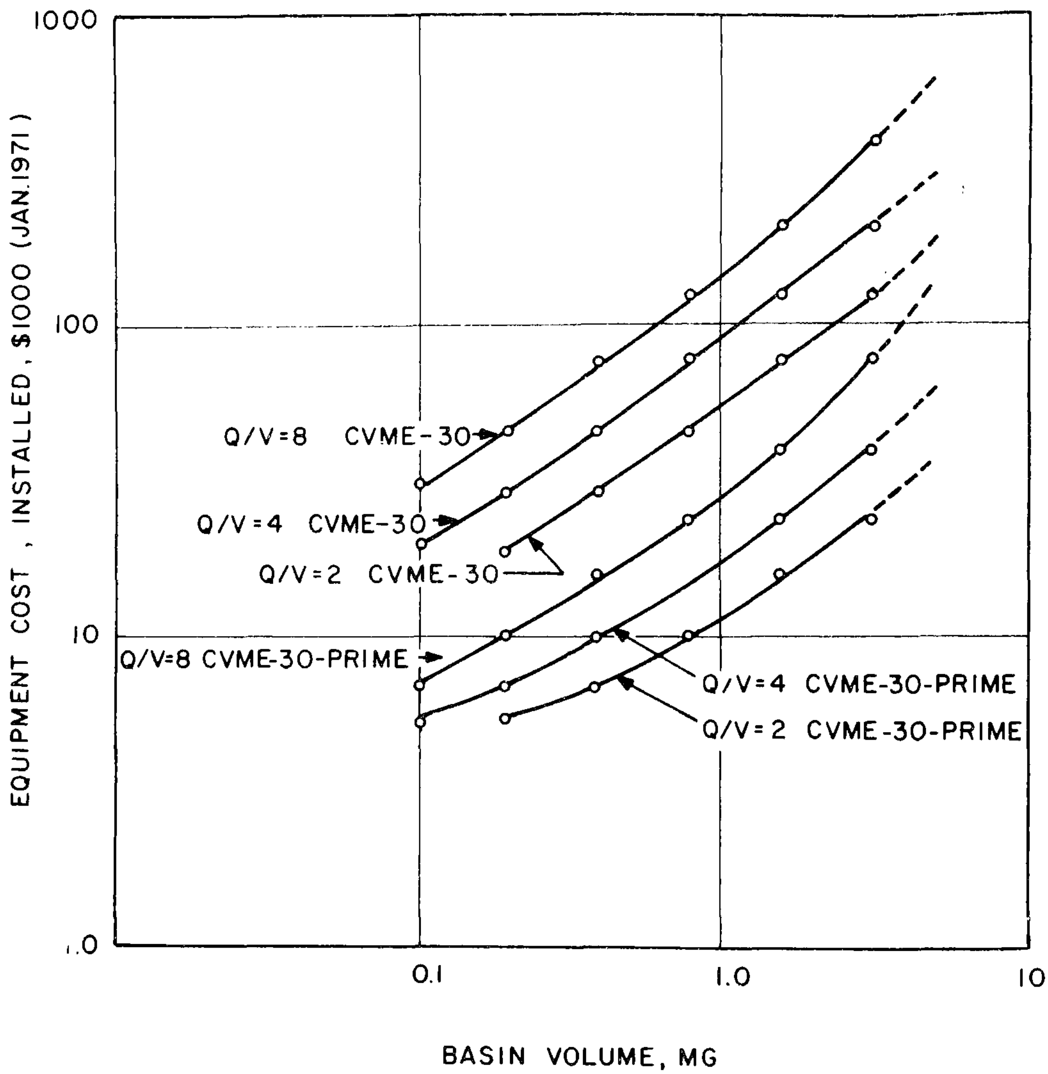


Figure 6. Installed Costs for Equipment (30-Percent BOD Removal)

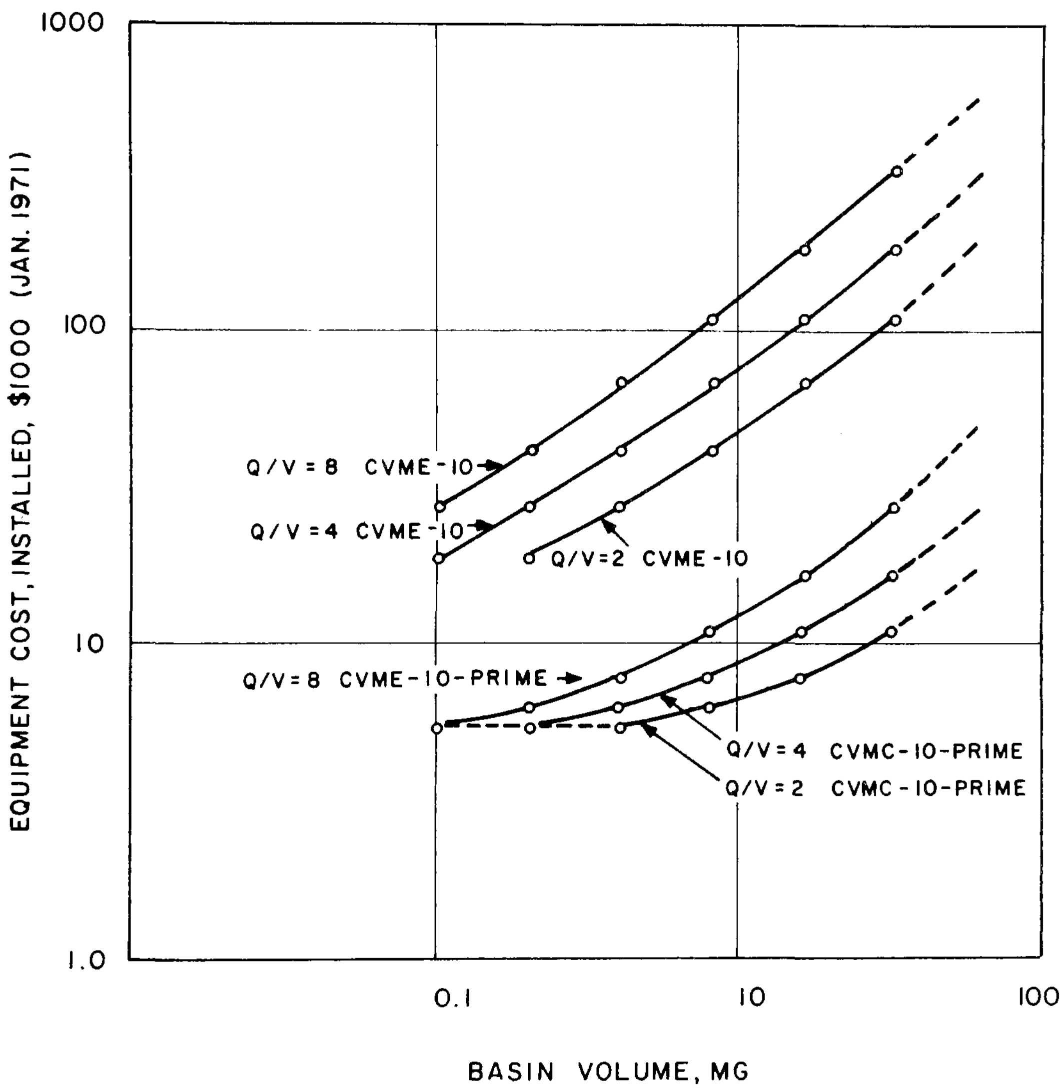


Figure 7. Installed Costs for Equipment (10-Percent BOD Removal)

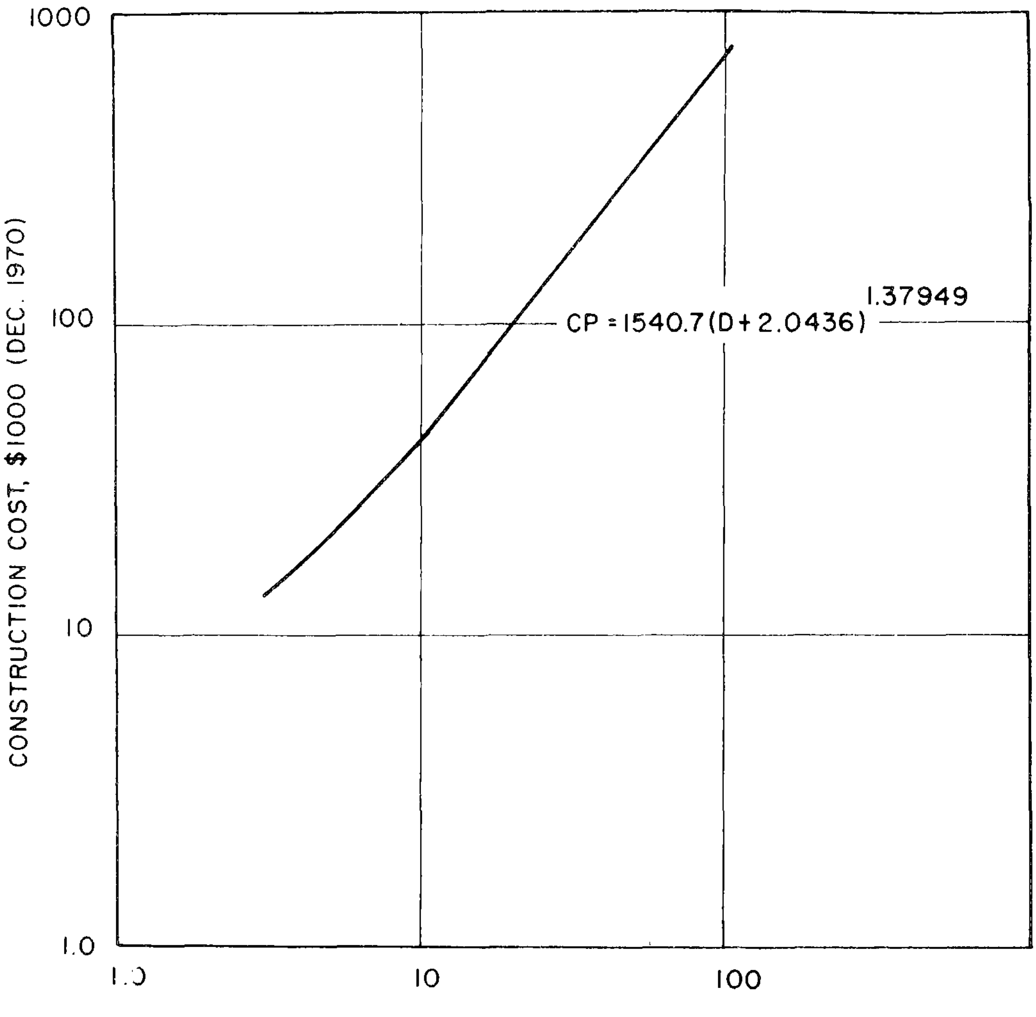


Figure 8. Construction Costs for Pipelines.

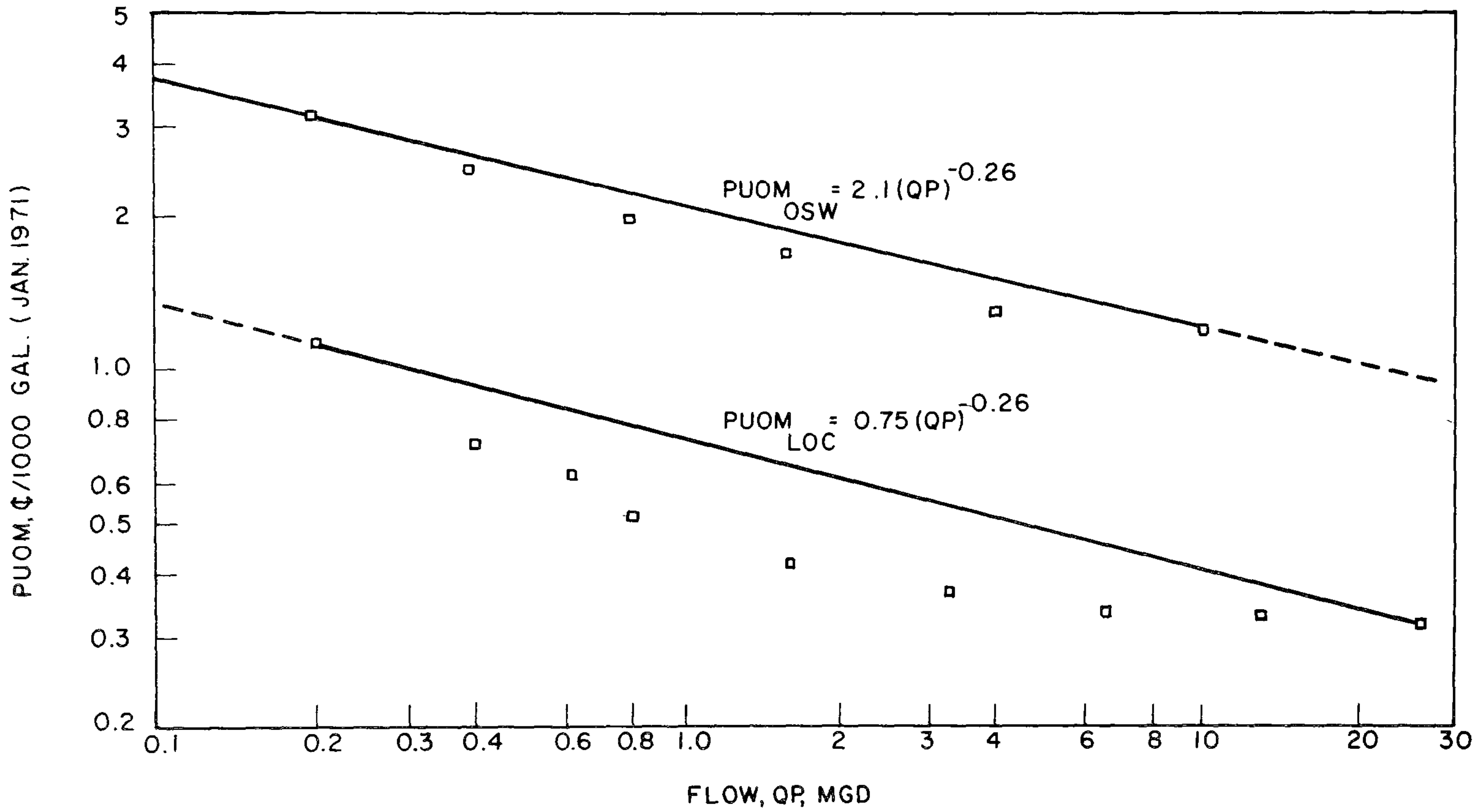


Figure 9. Pump Operating and Maintenance Cost Relationships.

BOD removal is 10.8 hp/MGD, and power cost is 0.216¢/1000 gal. Aerator maintenance labor, estimated from Reference 10, is

Item	Annual Hours	Labor Rate	Occurrence
(a) Motor overhaul	5	High	3--5 years
(b) Lint removal	13	Low	weekly
(c) Lubrication	1	High-Low	semiannual
(d) Painting	2	High	annual
(e) Miscellaneous, e.g., "jamming"	4	High	irregular
	25		

For city labor plus overhead at \$10.00/hr, the labor costs are 0.69¢/unit-day. Aerator maintenance costs, still for 30-percent BOD removal, in ¢/1000 gallons are

MGD	No. of Units Q/V=4 Rem = 30%	Maintenance Labor Cost at 69¢/unit-day \$/day	¢/1000 gal.	Operating Power Cost ¢/1000 gal.	AEOM-30 ¢/1000 gal.
0.4	1	0.69	.178	.216	.39
0.8	2	1.38	.178	.216	.39
1.6	2	1.38	.086	.216	.30
3.2	3	2.17	.069	.216	.285
6.4	3	2.17	.034	.216	.25
12.8	6	4.34	.034	.216	.25

The aerator operating and maintenance costs for 30- and 10-percent BOD removal were plotted as AEOM-30 and AEOM-10, respectively, in Figure 10. Conservative ln-ln straight line equations of the curves are

$$\text{AEOM-30} = 0.36\,\text{QP}^{-0.11}\,, \tag{9}$$

$$\text{AEOM-10} = 0.23\,\text{QP}^{-0.26}\,. \tag{10}$$

Aerator operating and maintenance costs are small, and hence, were not refined to different Q/V values.

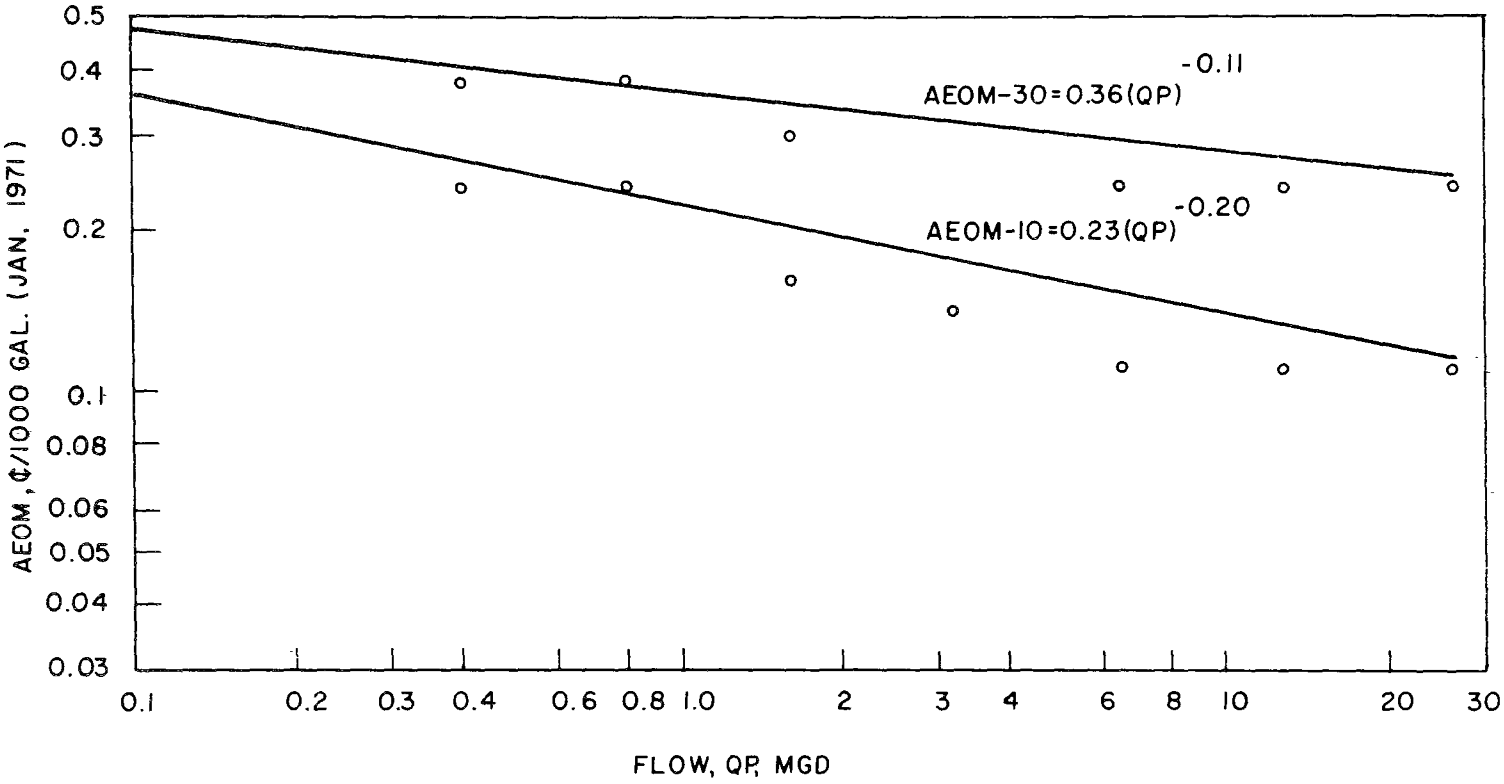


Figure 10. Aerator Operating and Maintenance Cost Relationships.

Total Costs, Including Amortized Capital

Basins Including Auxiliary Equipment. The total cost per unit of new capacity, TACC, is given by Equation (11):

$$\text{TACC} = (\text{DARC} + \text{DARE})/\text{TQI} + \text{DVOM} \tag{11}$$

where DARC and DARE, the daily debt service requirements for basin capacity and equipment, are determined by capital costs and the capital recovery factors,

$$\text{DARC} = \frac{(\text{CVMC})(\text{VMCRF})}{365}, \ \$/\text{day}$$

$$\text{DARE} = \frac{(\text{CVME})(\text{VMERF})}{365}, \ \$/\text{day} .$$

Division of DARC and DARE by the daily flow capacity increase, TQI, provides costs per unit of new sewage transport capacity in ¢/1000 gallons.

An example calculation of a capital recovery factor (crf) for I = 6 percent and LIFC = 30 years (basins) is

$$\text{VMCRF} = \frac{I(1 + I)^{\text{LIFC}}}{(1 + I)^{\text{LIFC}} - 1} = \frac{0.06(1.06)^{30}}{(1.06)^{30} - 1} = 0.0726 .$$

The second term on the right side of Equation (11), DVOM, represents the daily cost of basin operation and maintenance and is the sum of pump and aerator O-M costs,

$$\text{DVOM} = \text{PUOM} + \text{AEOM} .$$

Pipes. The total cost for pipes per unit of capacity, TACP, is given by Equation (12):

$$TACP = \frac{DARP + DPOM}{QA} \quad (12)$$

DARP is the daily debt service requirement for relief pipe and is determined by pipe capital cost (CP) and the pipe crf (PRF),

$$DARP = \frac{(CP)(PRF)}{365}, \$/\text{day-mile} .$$

The pipe capital costs, CP, were calculated from the equation given in Reference 8: $CP = 1540.7(D + 2.0436)^{1.37949}$, \$/mile. The pipe crf was caclulated as

$$PRF = \frac{I(1 + I)^{LIFP}}{(1 + I)^{LIFP} - 1} = \frac{0.06(1.06)^{50}}{(1.06)^{50} - 1} = 0.06344 .$$

The term for pipe operation and maintenance, DPOM, represents the daily charges for cleaning and repairing a mile of sewer pipe,

$$DPOM = \frac{40}{365}, \$/\text{day-mile} .$$

Division of DARP and DPOM by QA provides TACP as the cost of pipe per unit of sewage transported per mile in units of ¢/1000 gal.-mile.

BEL Calculation

The quantities TACC and TACP are divided to obtain BEL. The unit capacity basis of TACC and TACP tends to counteract the assumption that new pipe will be the same diameter as the original.

V. DISCUSSION

The effects of design and economic variables on the cost of smoothing basins for municipal sewage systems are summarized in this section. We continue to express basin cost in equivalent miles of pipe (BEL). Recall that low values for BEL favor the installation of smoothing basins; otherwise, additional piping is favored.

The trends exemplified in the tables and figures in this section have been developed by considering variation of the individual design parameters about some arbitrarily chosen base design. Unless otherwise indicated, the basic design is that indicated in Table 1.

TABLE 1

Base Values of Design and Operating Variables

Pipe diameter	12 in.
Interest rate	6%
Design pipe capacity	80% of full
Peak-to-average flow ratio	2.0
Slope to give velocity of	2.5 ft/sec
BOD removal	30%
Construction	A, concrete with pumps

<u>The Effect of Type of Construction</u>. The effect of the type of construction in basin costs is summarized in Table 2.

TABLE 2

Effect of Construction Type

Basin Type	BEL, miles
A, Concrete with pumps	2.358
B, Earthen with pumps	1.561
C, Concrete without pumps	1.437
D, Earthen without pumps	0.640

As might be expected, the cost depends rather strongly upon the elaborateness of the construction involved.

The Effects of Pumping Costs. The preceding results were obtained with the SWRI-OSW pump operating cost correlation [8]. If the local correlation is used, the above values for BEL can be reduced by about 25 percent.

The Effect of Slope. The effect of slope, hence flow velocity, on BEL is shown in Figure 11. The BEL values increase rather markedly as pipe slope or velocities increase. This means that flow smoothing is most attractive in areas where sewer line slopes are low.

The Effect of Pipe Diameter. The effect of pipe diameter on BEL is illustrated in Figure 12. The BEL increases with pipe diameter but not so dramatically as with velocity. The larger pipe diameter implies a larger flow together with a larger and more expensive basin. On the other hand, there is a slight increase in the unit cost of pipe as one goes to the larger sizes. The net result, as indicated, is an increase in BEL.

The Effect of Peak-to-Average Flow Ratio. The effect of the peak-to-average flow ratio is illustrated in Figure 13. Note that as the flow ratio increases, the BEL drops off rather dramatically. For a given pipe diameter, increasing the peak-to-average flow ratio implies reducing the average flow since the peak is fixed by the assumed pipe diameter. Such a change would require a basin of only moderate size increase (see Equation 4) but would provide high potential benefits from smoothing. Thus the basin costs would be lower per incremental unit of benefit as reflected in the reduced values of BEL.

The Effect of Pipe Capacity. The effect of pipe capacity expressed as the fraction of its capacity when flowing full is illustrated in Figure 14. With an increased pipe capacity the pipe is used more effectively, BEL's are higher, and smoothing is less attractive.

The Effect of Interest Rate. The effect of interest rate on the BEL is shown in Figure 15. Note that this plot is for Type D rather than Type A construction. The decreased values of BEL corresponding to higher interest rates result from the fact that pipe costs are almost entirely composed of debt service whereas basin costs include substantial amounts for operating and maintenance. Thus increased cost of debt service tends to favor basin construction, as is indicated by the lower values of BEL.

The Effect of Aeration. Increasing aeration by choosing the 30 percent basis rather than the 15 percent basis increased the BEL from 1.7 to 2.0 miles as illustrated in Figure 16. The velocity for this comparison was assumed to be 2 ft/sec rather than the basic 2.5 ft/sec.

The Effect of Equipment Life. The effect of equipment life on BEL is illustrated in Figure 17. Note that the velocity has been assumed at

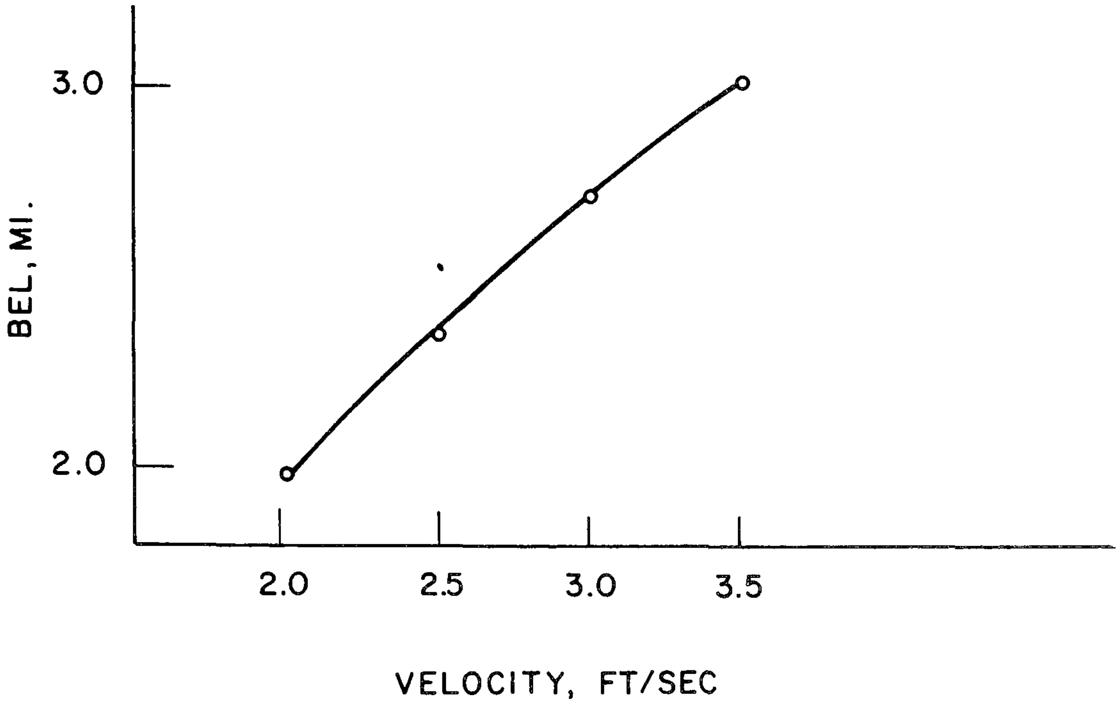


FIGURE 11. Effect of Velocity.

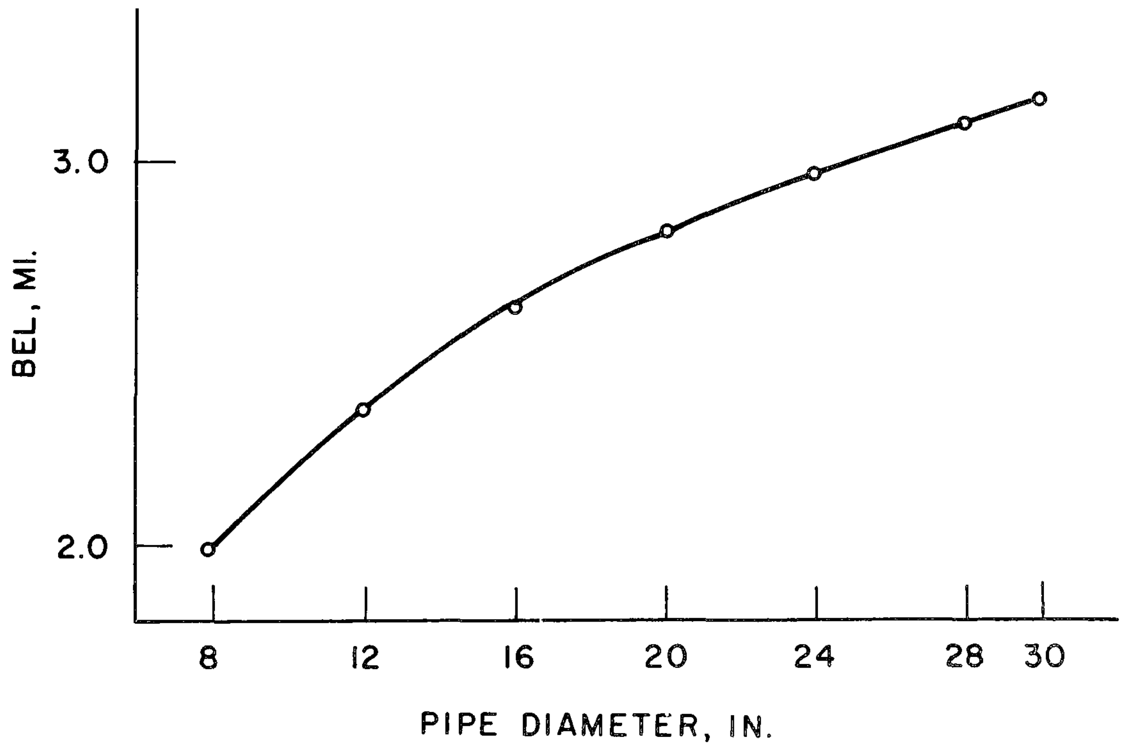


FIGURE 12. Effect of Pipe Diameter.

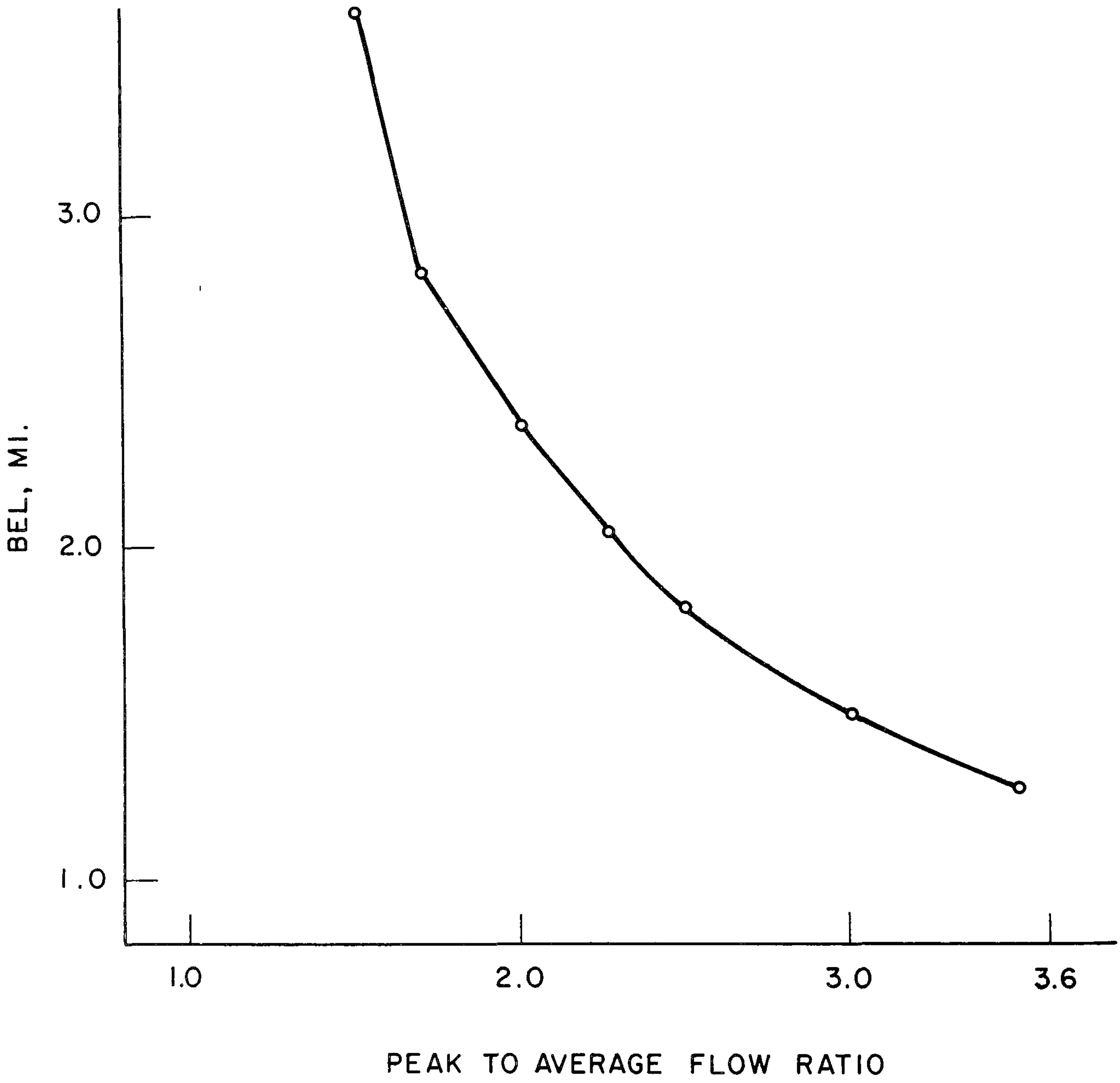


FIGURE 13. Effect of Peak to Average Flow Ratio.

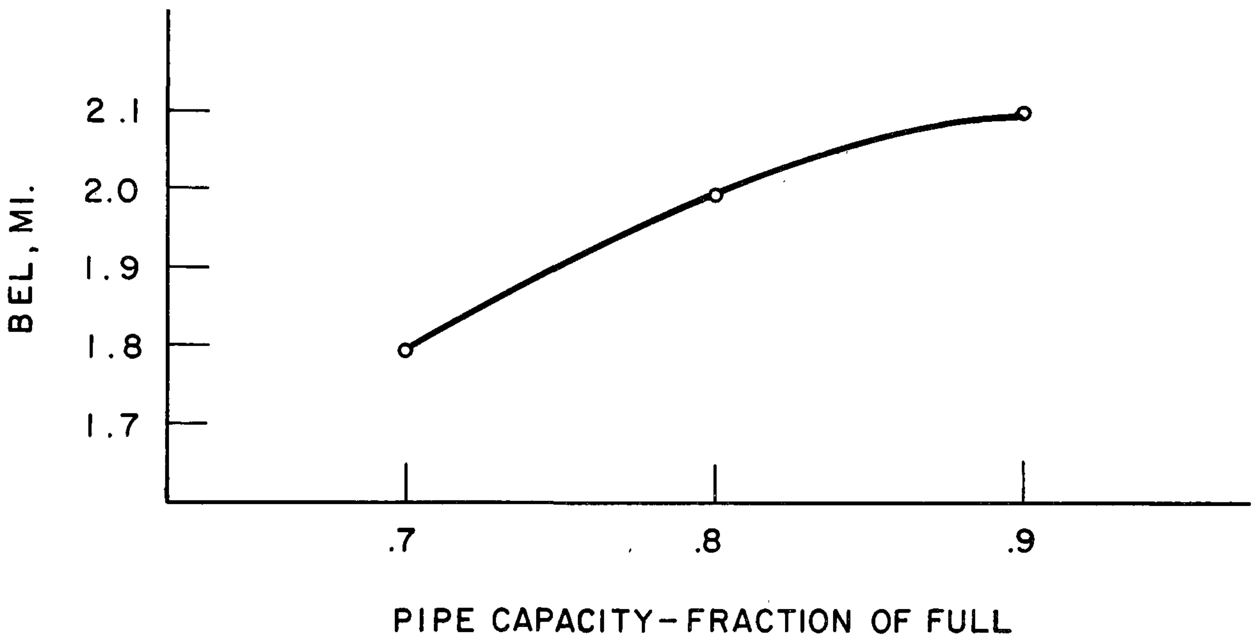


FIGURE 14. Effect of Pipe Capacity.

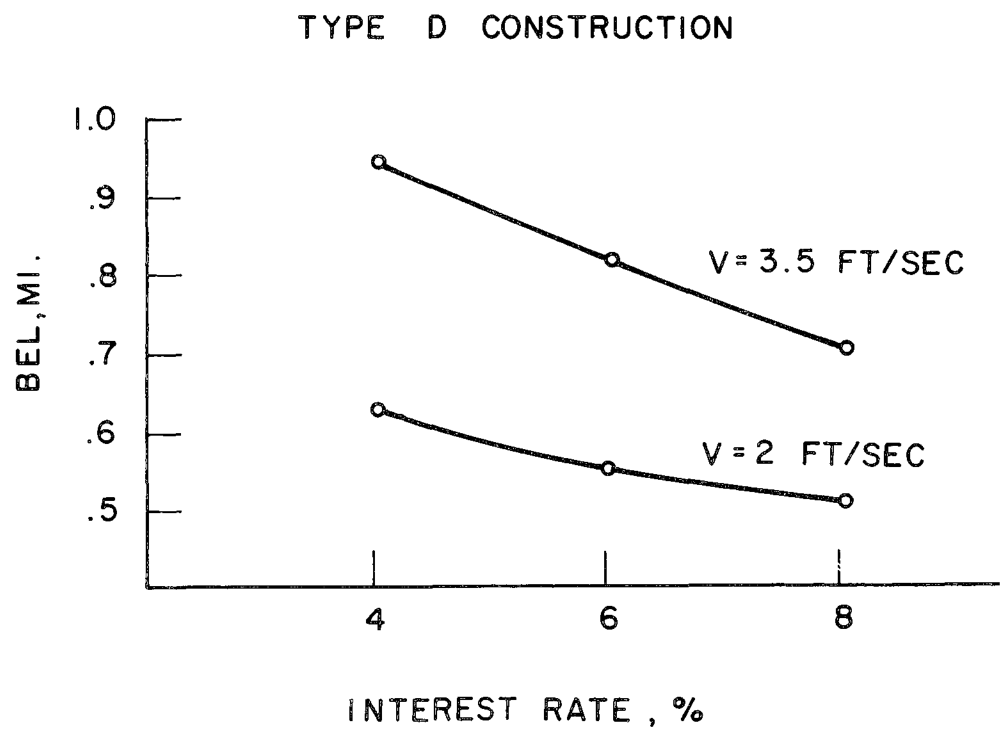


FIGURE 15. Effect of Interest Rate.

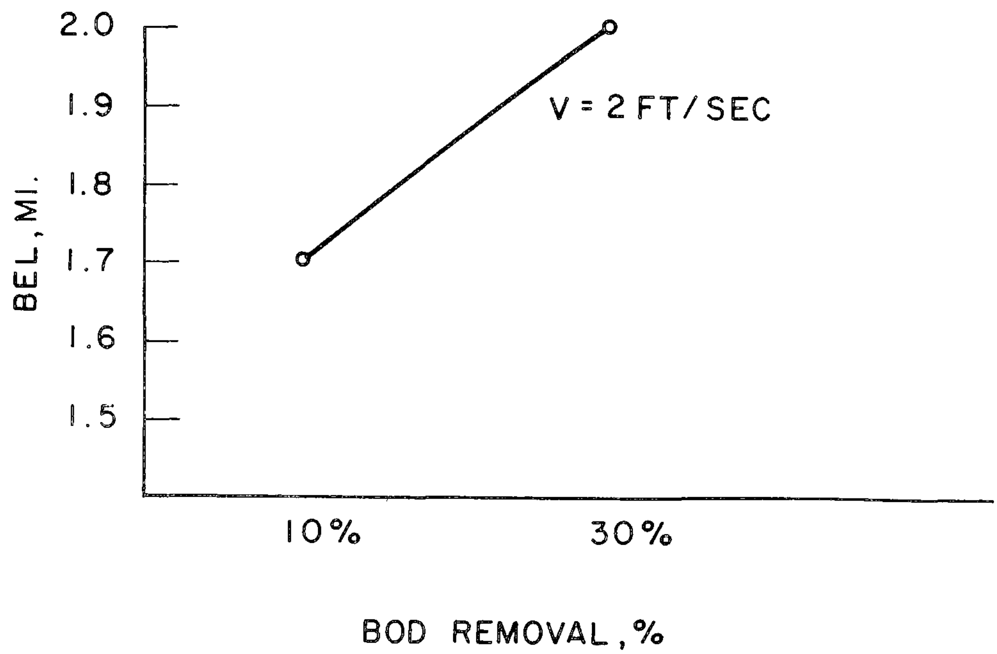


FIGURE 16. Effect of BOD Removal.

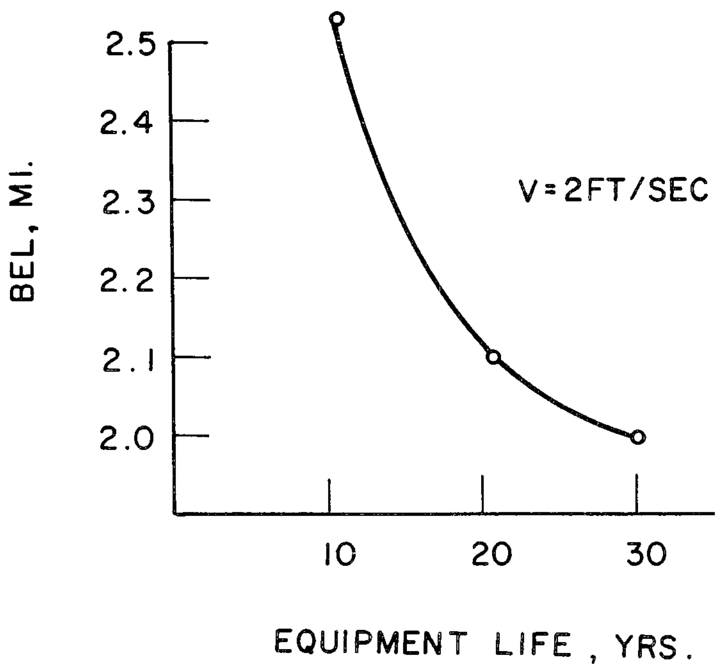


FIGURE 17. Effect of Equipment Life.

2 ft/sec rather than the basic 2.5 ft/sec. Since equipment life affects only the basin cost the decrease in BEL with longer equipment life is what would be expected.

Additional graphical and tabular presentation of the computed results are included in the Appendices. In general, the procedure for utilizing this information in a particular circumstance is to use the tabular data to ascertain the BEL values corresponding to the set of design and economic parameters then applicable. If the additional outfall line requirement should exceed the BEL, smoothing basin construction should be given serious consideration. The methods outlined in this report can serve as a basis for making further cost comparisons tailored to the requirements of the individual case.

VI. ADDITIONAL STUDIES

Population Increase

To this point the procedure has been to balance estimated basin costs against estimated costs of additional pipe to get the break-even length (BEL), assuming in both cases that the incremental capacity is sufficient to satisfy immediate demand. In general, the additional capacity obtained by smoothing basins will only equal that obtained by relief pipe when the peak-to-average flow ratio is 2. The question arises as to what conclusions can be drawn concerning basins versus relief pipes when the peak-to-average flow ratio is other than 2.

An additional pipe of identical construction will double the existing capacity; installation of a smoothing station will increase existing capacity by a factor X. Consequently, basins provide greater capacity when X exceeds 2, and additional piping provides greater capacity when X is less than 2.

If the demand for sewage capacity is assumed to grow at the annual rate Z, then the time (θ) during which a capacity increase by the factor X will remain adequate is given by the solution to

$$X = (1 + Z)^{\theta_p}$$

or

$$\theta_p = \frac{\ln X}{\ln (1 + Z)}, \text{ years .}$$

Designating as θ_P the adequacy time for pipe and as θ_{VM} the adequacy time for basins, it follows that for X = 2, $\theta_{VM} = \theta_P$ and the cost analysis via the BEL is on relatively firm ground. Even for this case, it is necessary to assume that significant refinancing costs will not be incurred due to the life of some basin component being less than the maturation time of the original financing. For cases involving very small values of Z such that θ_{VM} and $\theta_P \geq 50$ years, adequacy times exceed assumed equipment life and need not be considered. For the cases where $X \neq 2$ and Z is not small, some adjustment should be made to reflect the fact that the two alternatives are not equal lived.

Such an adjustment is simple to calculate if one assumes that Z is constant for the maximum life of 50 years. In this case, an adjustment can be made by computing the number of replacements necessary during the 50-year lifetime. Thus, if NRP and NRC are, respectively, the number of replacements required for pipes and pipes + basins:

$$NRP = \frac{50}{\theta_p} , \qquad (13)$$

and

$$NRC = \frac{50 - \theta_{VM}}{\theta_{VM} + \theta_p} . \qquad (14)$$

Equation (13) is just the number of times an equal-sized pipe would have to be replaced in 50 years due to a constant growth in demand. Equation (14) assumes an initial time, θ_{VM}, during which a basin will provide adequate capacity and allows for additional future capacity by using equal-sized pipes in conjunction with more basins. NRC must be applied to the total costs of replacements of pipes + basins. The adjusted costs reflecting differing "times of adequacy" can be calculated by multiplying the total costs of each alternative by the appropriate number of replacements required during the base period. If ATACC and ATACP represent the adjusted costs:

$$ATACC = NRC\ (TACC + TACP) ,$$

$$ATACP = NRP\ (TACP) .$$

These equations represent the total costs after NRC or NRP replacements have been made. The least expensive alternative should be chosen.

For practical applications, large values of Z cannot be assumed to remain constant for very long.

An example of the effect of Z on the "time of adequacy" is listed below.

Z, percent	$\theta_{VM} = \theta_p$, years (X = 2)	Z, percent	$\theta_{VM} = \theta_p$, years (X = 2)
1	70	5	15
2	36	6	12
3	24	7	10--11
4	18	8	9

Local regions tributary to a sewer system can be expected to grow faster when young and to reach a "saturation" condition as they grow older. Many city districts even show reduced populations after "maturity" [5]. Thus one would expect fewer replacements to be required than Equations (13) and (14) indicate.

Downstream Effects

It was assumed that the newly obtained capacity would apply to all the downstream units in the sewage system except the treatment plant. Thus if an existing downstream pumping station was operating at design capacity before flow smoothing, the capacity was assumed to be increased in proportion to that provided by smoothing. Of course, pumping station operating and maintenance costs will increase for increased flows.

If sewer tributaries feeding a trunk line are out of phase with the main flow such that the peaks in the tributary flow fill the valleys in the main flow, then an inherent smoothing will occur. Should this be the case, one would need to consider the hydrograph of the combined flow to evaluate the potential benefits of further smoothing.

VII. ACKNOWLEDGEMENTS

The investigators at Research Triangle Institute would like to express their special appreciation to the personnel of the Triangle Region cities for their fine cooperation in obtaining the records, maps, site access, and calibrations useful to this study.

Other agencies that were especially helpful to the investigators include the North Carolina Board of Air and Water Resources and the Research Triangle Regional Planning Commission.

Finally appreciation is expressed to the Office of Research and Monitoring of the Environmental Protection Agency for their financial support under Project No. 11010 FDI, Contract No. 14-12-935 and especially to Mr. C. L. Swanson and Dr. H. E. Bostian of EPA for their support and encouragement.

VIII. REFERENCES

1. Gifft, H. M.: "Estimating Variations in Domestic Sewage Flows," Water Works and Sewerage, May 1945.

2. Harmon, G. W.: "Forecasting Sewage Discharge at Toledo Under Dry-Weather Conditions." Engineering News Record, 80, June 27, 1918.

3. Johnson, C. F.: "Relation Between Average and Extreme Flow Rates," Engineering News Record, 90, October 8, 1942.

4. Fair, G. M., and J. C. Geyer: "Water Supply and Waste-Water Disposal," John Wiley and Sons, Inc., New York, New York, 1965.

5. Babbitt, H. E., and E. R. Baumann: "Sewerage and Sewage Treatment," Eighth Edition, John Wiley and Sons, Inc., New York, New York, 1958.

6. Geyer, J. C., and J. J. Lentz: "An Evaluation of the Problems of Sanitary Sewer System Design," Department of Sanitary Engineering and Water Resources, The John Hopkins University, Baltimore, Maryland, September, 1964.

7. "Design and Construction of Sanitary and Storm Sewers," Water Pollution Control Federation Manual of Practice, No. 9, Washington, D.C., 1969.

8. Internal Memo--AWTRL--from Robert Smith to Dr. William N. Fitch, "Cost-Effectiveness Task Force--Economics of Consolidating Sewage Treatment Plants by Means of Interceptor Sewers and Force Mains," March 10, 1971.

9. Private Communication: Mr. Otha Hursey, Superintendent of Maintenance, Department of Water Resources, City of Durham, North Carolina.

10. Private Communication: Mr. Tom Alspaugh, Superintendent of Water and Waste Treatment, Cone Mills, Inc., Greensboro, North Carolina.

11. Catalog Price List--Aqua-Aerobic Systems, Inc. 6306 North Alpine Road, Rockford, Illinois. Plus personal conversation with Mr. D. Crocker of Aqua-Aerobic Systems, Inc.

12. Personal Conversation: Mr. J. Goodman, Director of Utilities, City of Raleigh, North Carolina.

13. "Recommended Standards for Sewage Works," Health Education Service, Albany, New York.

14. Personal Conversations: Professor J. Lamb III, Environmental Sciences and Engineering Department, School of Public Health, University of North Carolina, Chapel Hill, North Carolina.

15. Private Communication: Mr. Harold Spaeder, Sales Representative for Smith & Loveless, Inc., P. O. Box 4476, Charlotte, North Carolina.

16. Private Communication: Mr. Gary Morse of Robert E. Mason Co., Sales Representative for Mixing Equipment Co., 1726 North Graham Street, Charlotte, North Carolina.

17. Private Communication: Mr. Charles Grimes of Rex Chainbelt, Inc., 4610 West Greenfield Avenue, Milwaukee, Wisconsin.

18. Private Communication: Mr. S. V. Tench, Sales Representative for Ashbrook Corp., P. O. Box 11730, Atlanta, Georgia.

19. Personal Conversations: Mr. Richard N. Edwards, President, Aerobic Control Corp., 5705 New Chapel Hill Road, Raleigh, North Carolina.

20. McJunkin, F. E., and P. A. Vesilind: "Practical Hydraulics for the Public Works Engineer--Part II." Public Works Magazine, October 1968.

21. Process Design Manual for Upgrading Existing Wastewater Treatment Plants. U. S. Environmental Protection Agency Technology Transfer. Program No. 17090 GNQ. October, 1971.

IX. NOMENCLATURE

A = pipe cross-sectional area, ft^2.

AEOM = see PUOM.

AEOM-10,AEOM-30
= respectively, daily equivalent of the annual cost of operation and maintenance of aerators for 10- and 30-percent BOD removal.

b = a fictitious time or duration for which flows exceed the daily average flow, defined by a square-wave hydrograph above the minimum flow, day/day.

BEL = a fictitious pipe length whose unit cost for sewage transport is just equal to the unit cost of sewage transport by smoothing basins, miles.

C = coefficient of friction in the Chezy formula.

CP = the capital cost of pipe, \$1000/mile.

CP1,CP2,CPN,CPT
= respectively, the total capital cost of pipe segments 1, 2, and "N", and of pipe, \$1000/segment.

crc = capital recovery charge, equals the product of the capital cost of an item and the capital recovery factor, crf, \$.

crf = general capital recovery factor, $crf = \dfrac{I(1+I)^n}{(1+I)^n - 1}$.

CV,CVM = respectively, the capital cost of volumes to achieve partial and maximum smoothing.

CVMC,CVME,CVMC-PRIME,CVME-PRIME
= respectively, the capital costs of concrete basins alone, of basin aerators and pumps, of earthen basins alone, and of basin aerators alone.

CVME-30,CVME-30-PRIME
= respectively, the capital cost of basin aerators and pumps, and of basin aerators alone; in both cases the aerators are sized to remove 30 percent of the basin influent BOD.

D = the inside diameter of any pipe, inches.

d = the depth of the wetted section in a partially filled pipe, inches.

d/D = the "standard", or design, depth of flow for a sewer.

DARC,DARE = respectively, the daily equivalent of the annualized capital recovery charge for basin capacity and for equipment, $.

DARP,DPOM = respectively, the daily equivalent of the annualized capital recovery charge for pipe and of the annual cost of pipe operation and maintenance.

DVOM = daily equivalent of the annual cost of basin capacity operation and maintenance on a flow basis (DVOM = PUOM + AEOM), ¢/1000 gal.

EQI = the estimated flow capacity increase obtained in a pipe by partial flow smoothing, MGD.

I = interest rate, percent.

LIFC,LIFE,LIFP
= respectively, the assumed component lives of basins, equipment, and pipes.

n = Mannings roughness factor assumed to vary with the depth of flow but to equal 0.013 for QF.

NRC,NRP = respectively, the number of replacements of pipes plus basins and of pipes during a 50-year planning period for a constant growth rate Z.

P = contributing population in thousands.

PRF = see VMERF.

PUOM,AEOM = respectively, daily equivalent of the annual cost of operation and maintenance for pumps and for aerators.

Q = the flow capacity in any pipe running at partially full depth d, MGD.

QA,QM,QP = respectively, the assumed average, minimum, and peak flow capacities of a pipe, MGD.

QA1,QA2,QAN = respectively, the original average design flow capacities for pipe segments 1, 2, and N, MGD.

QA18, QP18, etc.
= respectively, the assumed average and design peak flow capacities of 18-inch lines, etc., MGD.

QF = the nominal flow capacity in any pipe running full at atmospheric pressure, MGD.

QNP,QMP = respectively, the new partially and maximally smoothed flow capacities of pipes, MGD. (QMP = QP = YQF).

R = hydraulic radius equal to D/4 for circular channels.

S = the slope of the hydraulic grade line, ft/ft.

TACC = total annualized cost for capacity via smoothing, ¢/1000 gal.

TACP = total annualized cost for capacity via relief pipe, ¢/1000 gal.-mile.

TQI = the theoretical capacity increase available in a pipe by flow smoothing.

U = Manning velocity for open-channel flow.

V = the storage volume required to smooth the original average design flow in a pipe, MG.

VM = the maximum storage volume required to use the maximum flow capacity of a pipe, MG.

VMERF,VMCRF,PRF = respectively, the capital recovery factors for equipment, for basins, and for pipes.

VS,VT = respectively, a square-wave and a triangular approximation of the volume of storage required for smoothing.

X = the assumed or actual ratio of peak-to-average flow.

Y = Q/QF = the design capacity of a pipe defined as the ratio of its capacity, QP, at the design depth to its capacity when full, QF.

Z = growth rate of demand for sewage capacity.

η = recovery period, in years, assumed equal to the life of the component (LIFE, LIFP, LIFC).

θ_p, θ_{VM} = respectively, the time-of-adequacy of pipes and of smoothing basins, assuming growth rate Z.

X. APPENDICES

APPENDIX A

BEL-Value Graphs and Tables

As before, the type of basin construction is designated as follows:

Case A: Concrete with a pump station.
Case B: Earthen with a pump station.
Case C: Concrete with no pump station.
Case D: Earthen with no pump station.

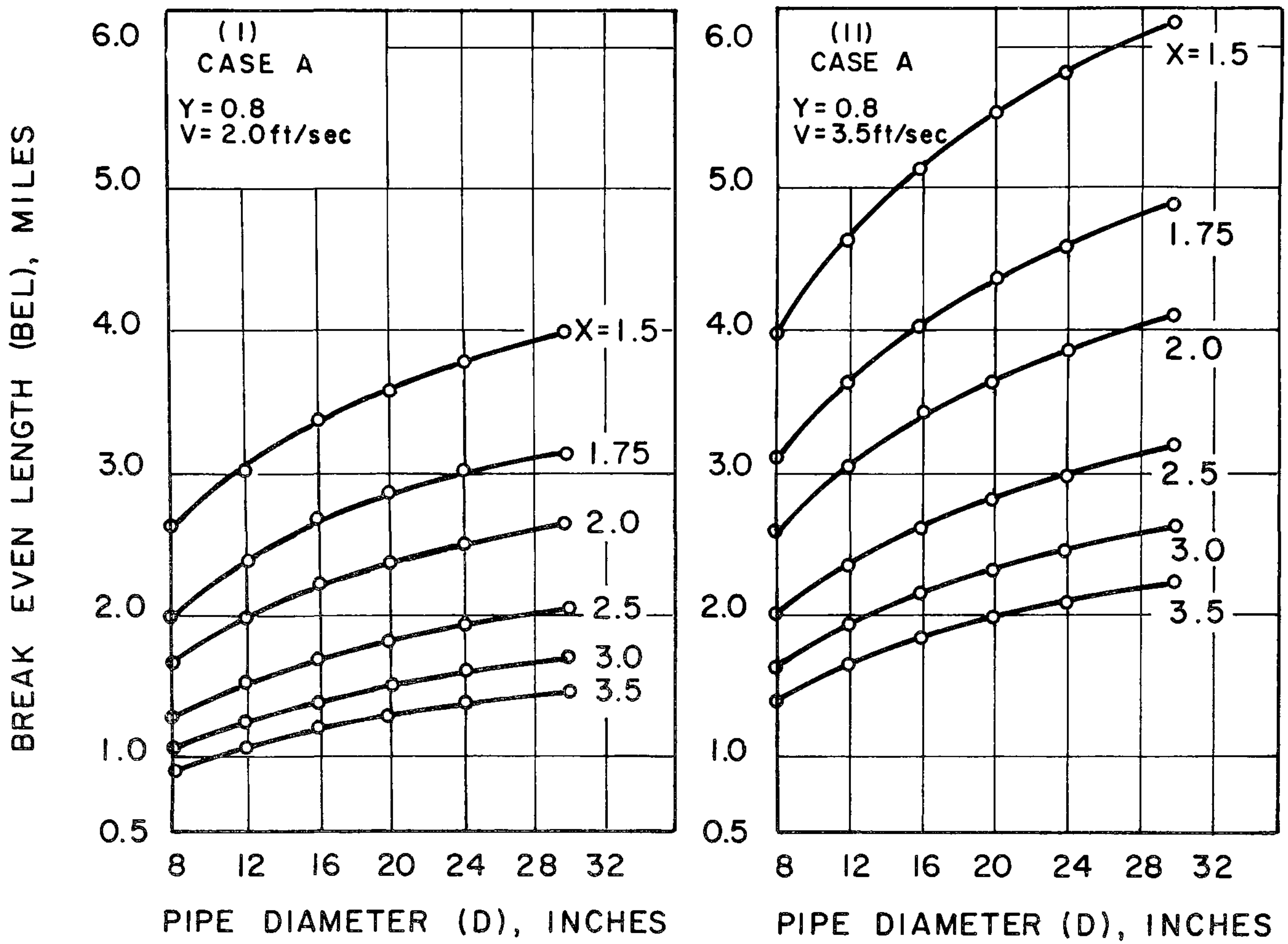


FIGURE 18. Break Even Length Versus Pipe Diameter for Case A (6-percent interest and 50-30-30 component lives).

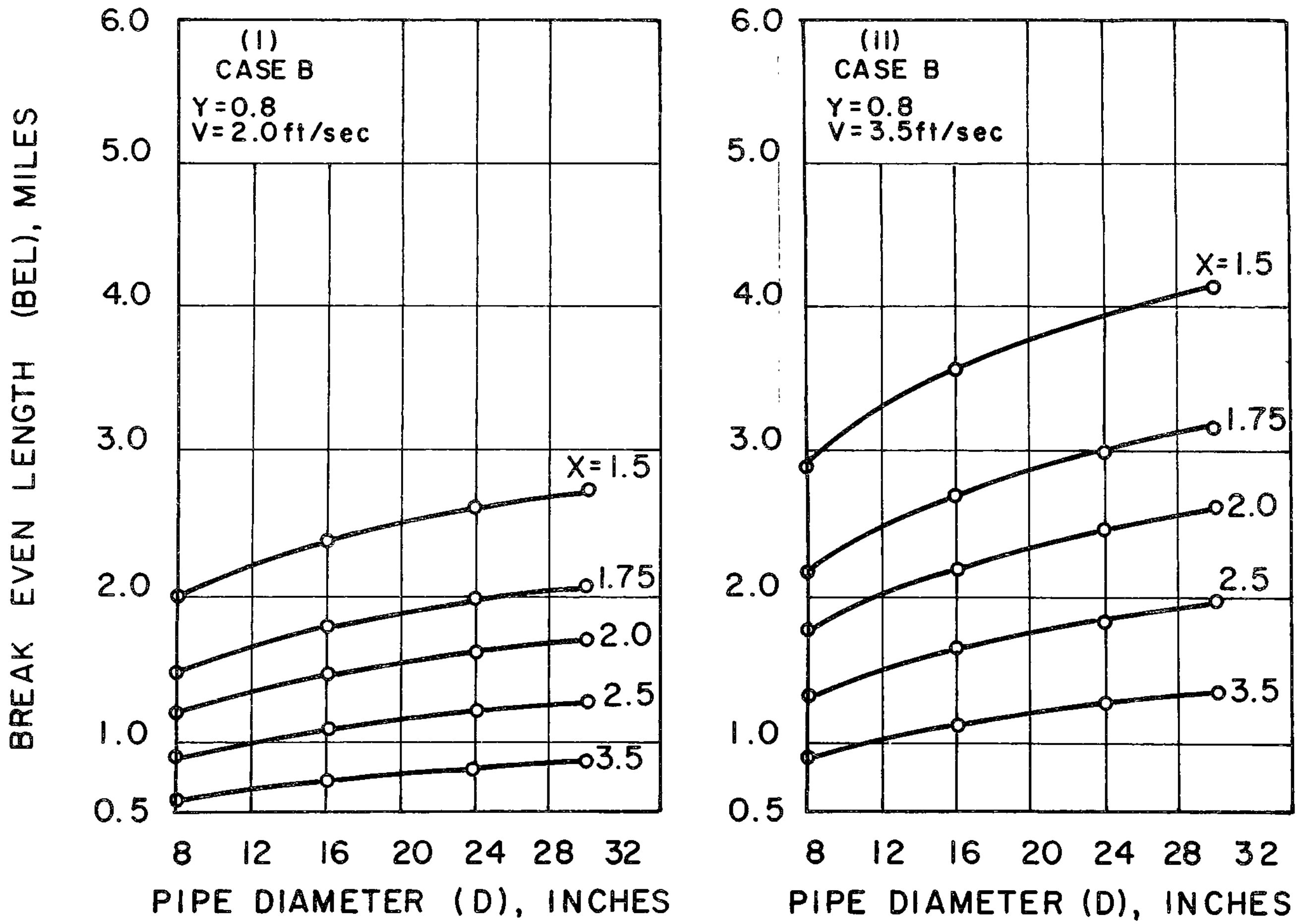


FIGURE 19. Break Even Length Versus Pipe Diameter for Case B (6-percent interest and 50-30-30 component lives).

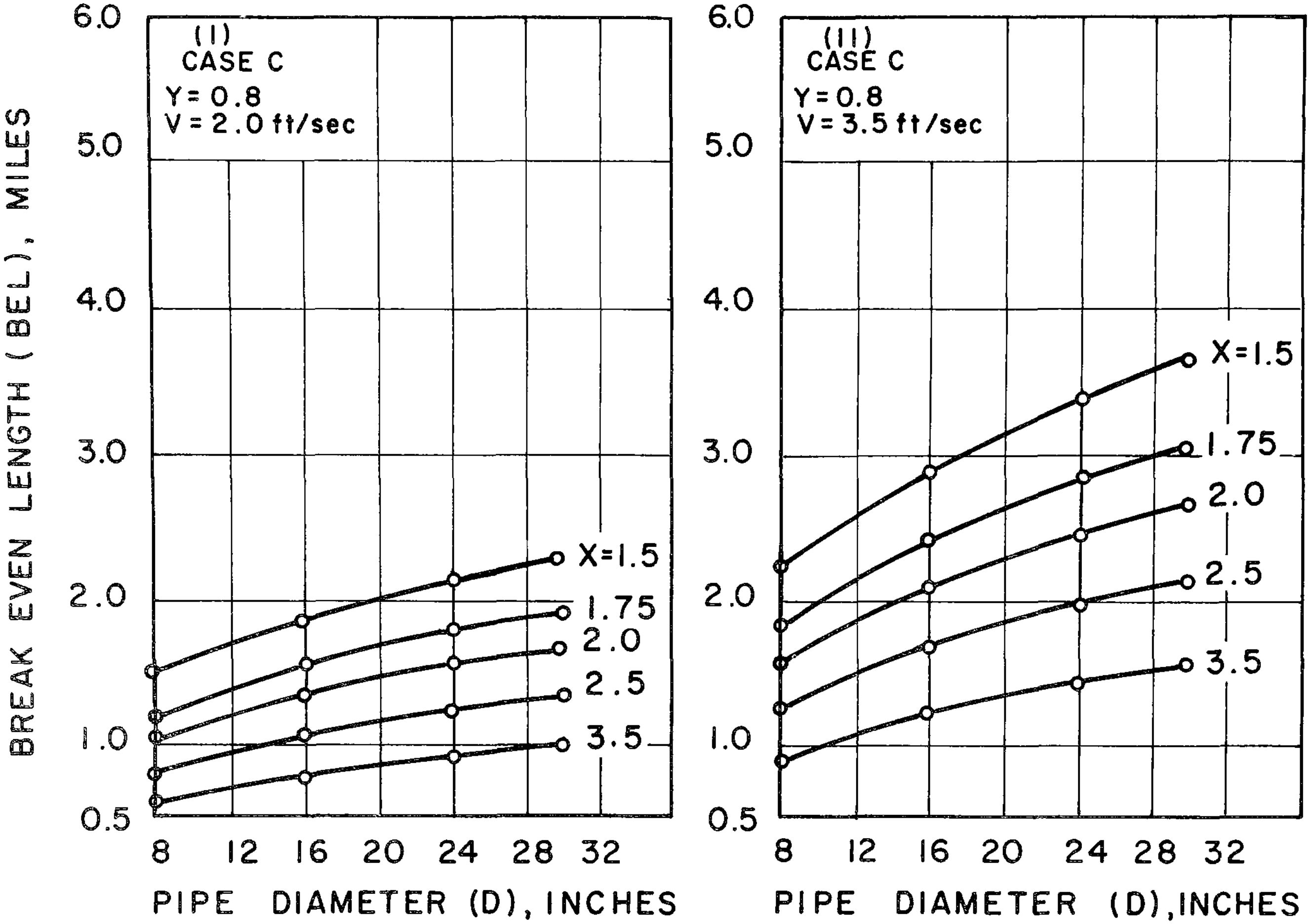
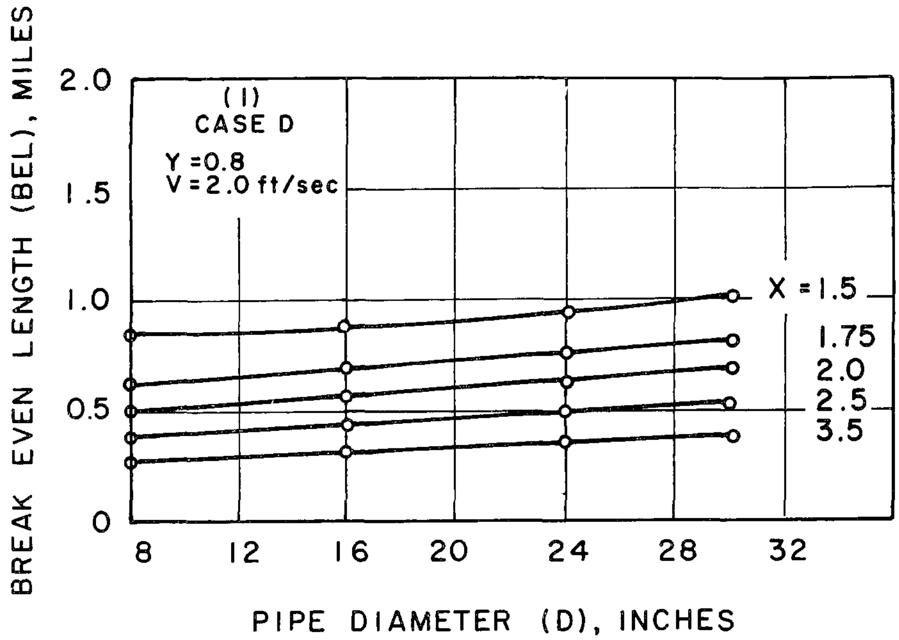


FIGURE 20. Break Even Length Versus Pipe Diameter for Case C (6-percent interest and 50-30-30 component lives).



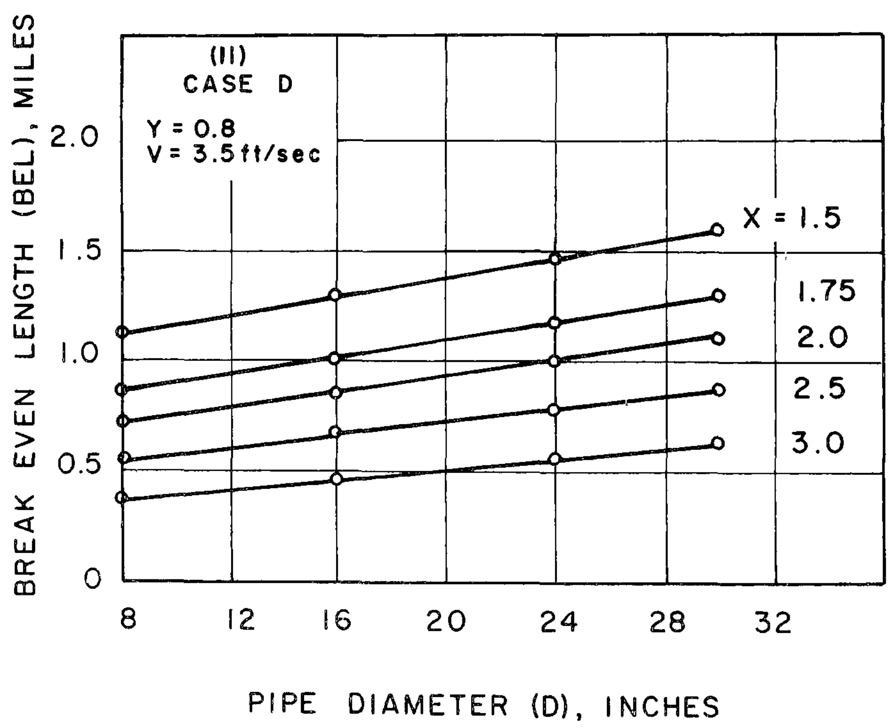


FIGURE 21. Break Even Length Versus Pipe Diameter for Case D (6-percent interest and 50-30-30 component lives).

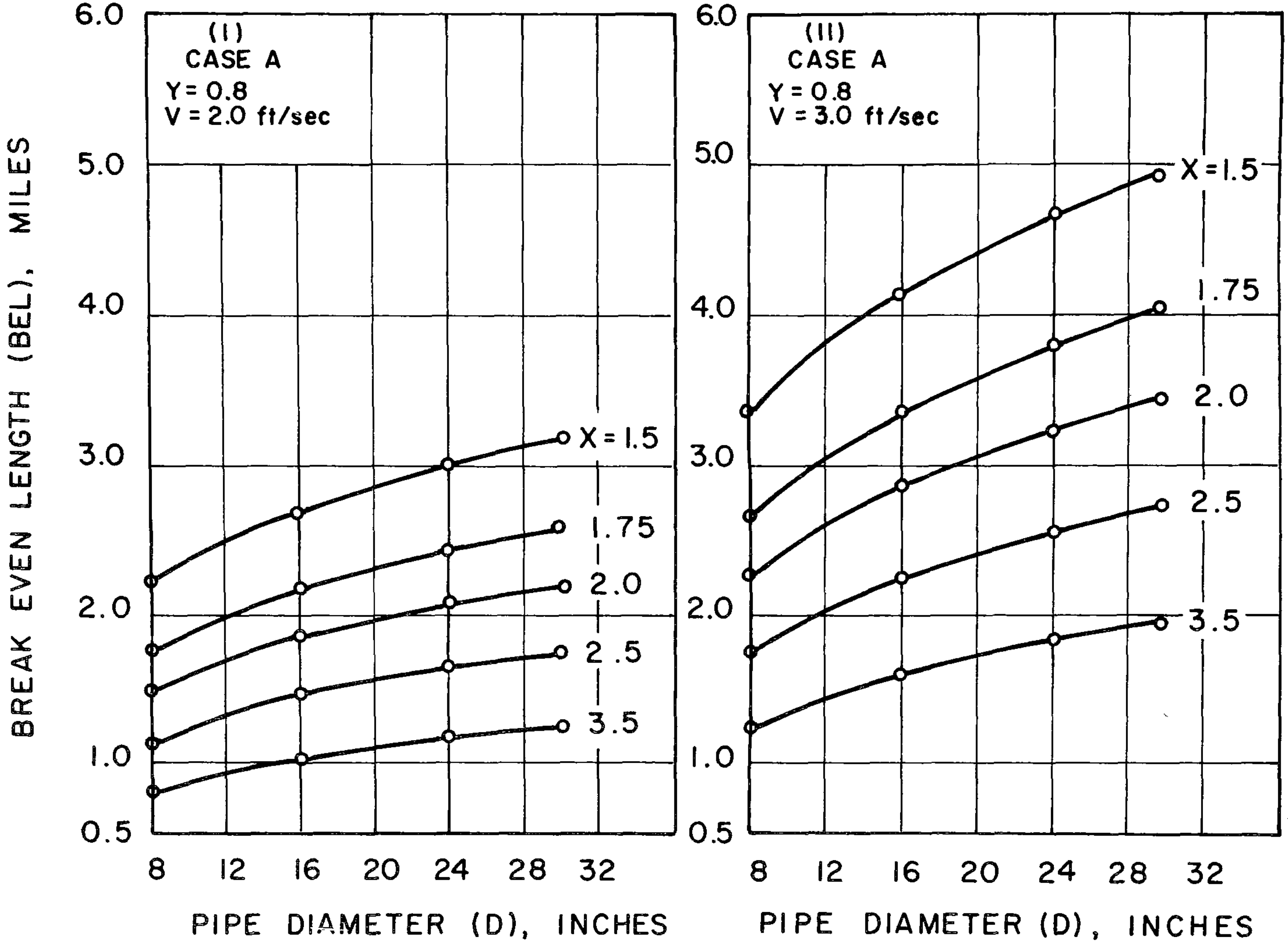


FIGURE 22. Break Even Length Versus Pipe Diameter for Case A with Aeration for 10-percent BOD Removal (6-percent interest and 50-30-30 component lives).

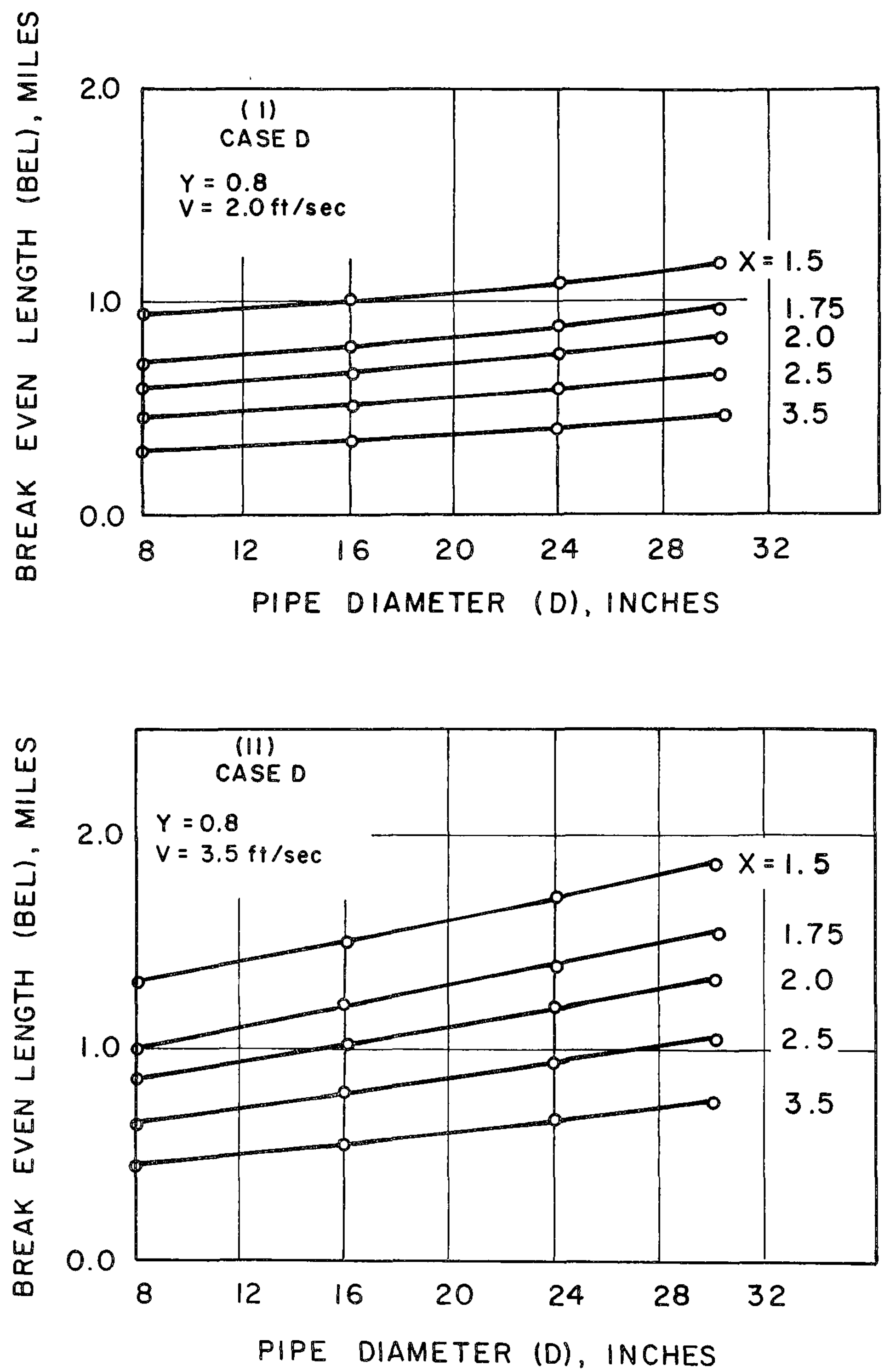


FIGURE 23. Break Even Length Versus Pipe Diameter for Case D (4-percent interest, 30-percent BOD removal, and 50-30-30 component lives).

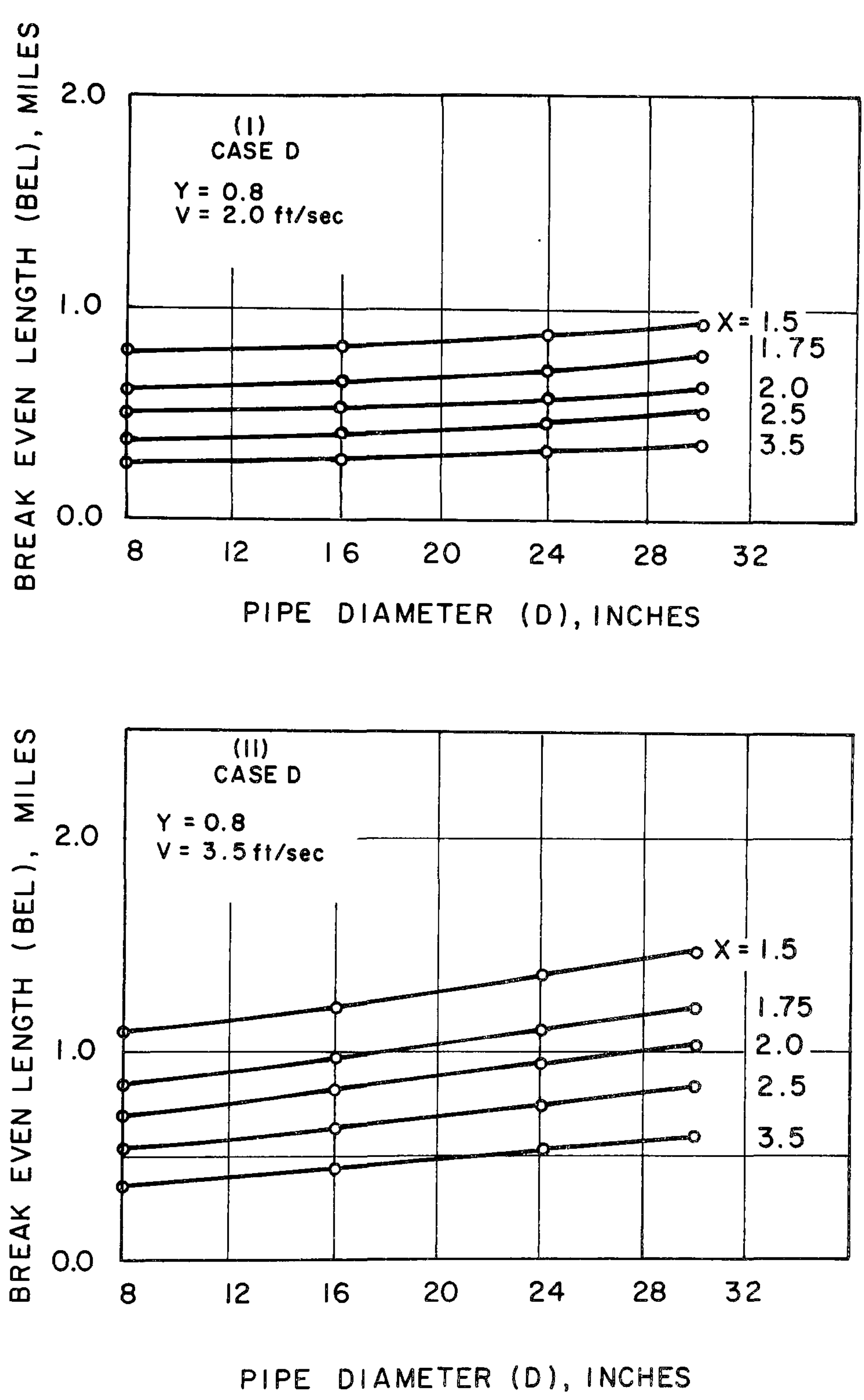


FIGURE 24. Break Even Length versus Pipe Diameter for Case D (8-percent interest, 30-percent BOD removal, and 50-30-30 component lives).

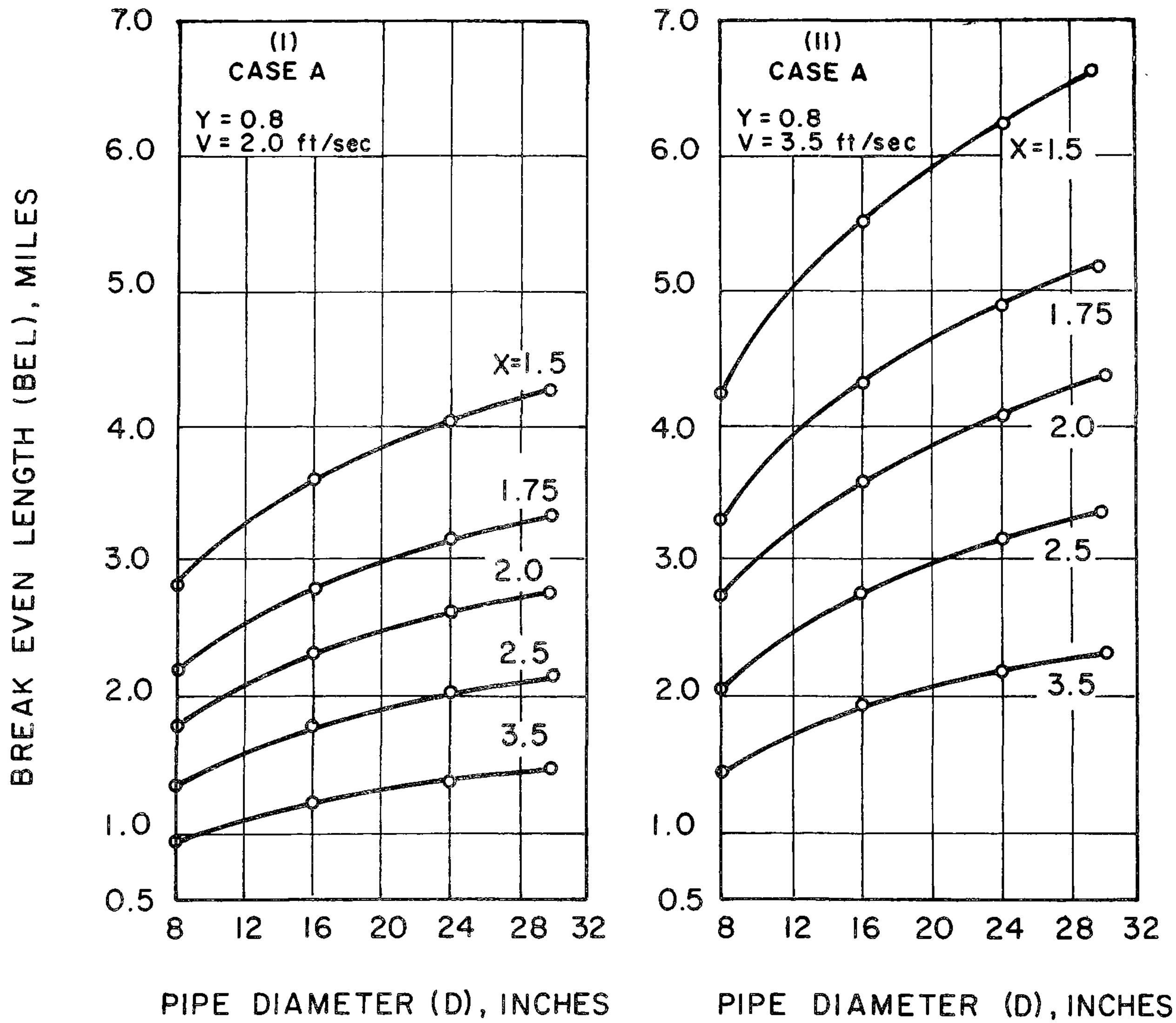


FIGURE 25. Break Even Length Versus Pipe Diameter for Case A for 20-Year Equipment Life (6-percent interest and 30-percent BOD removal).

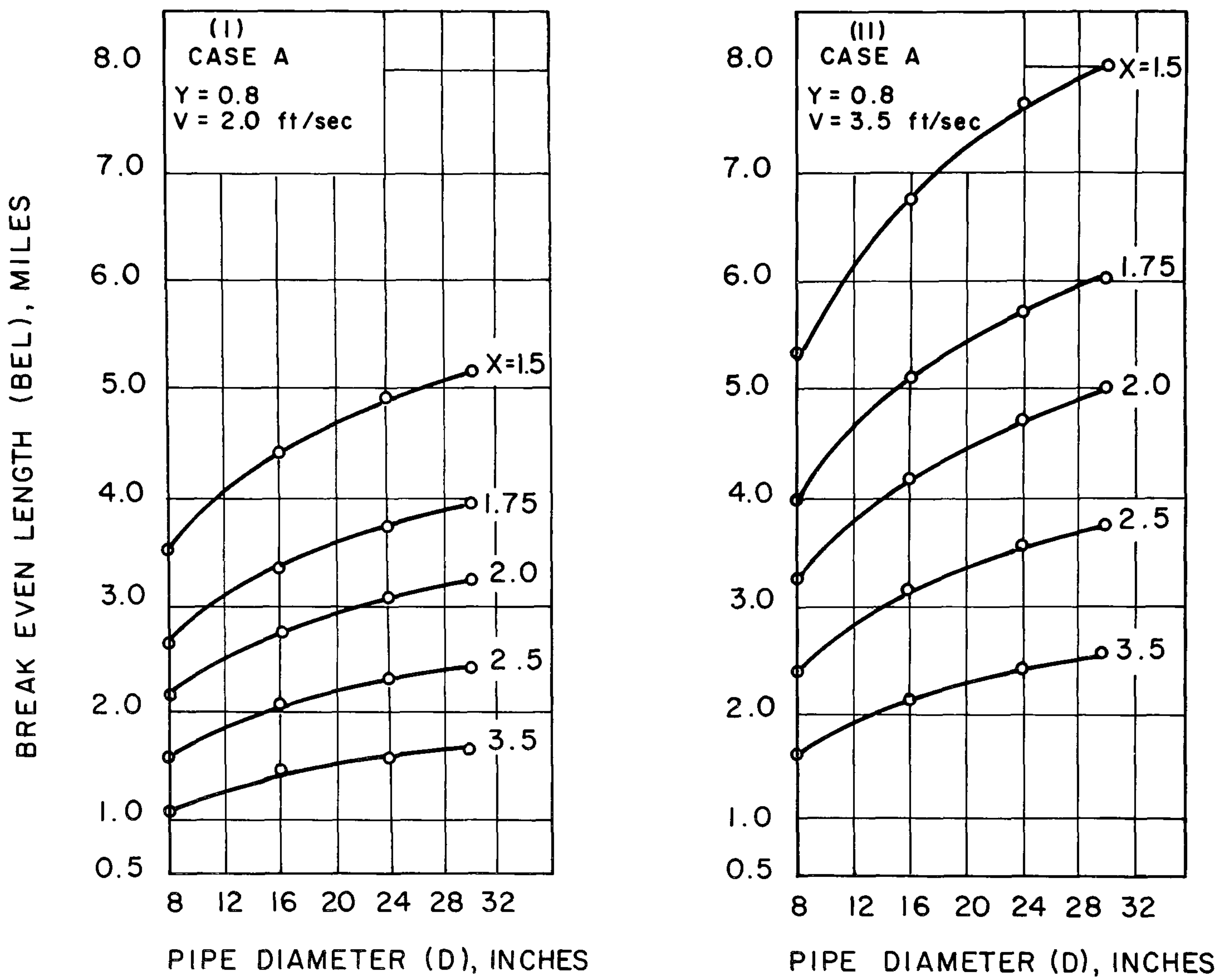


FIGURE 26. Break Even Length Versus Pipe Diameter for Case A for 10-Year Equipment Life (6-percent interest and 30-percent BOD removal).

Notes for Tables 3 through 6, Appendix A

1. CVMC implies the use of a capital cost relationship for a "maximum" smoothing volume constructed of reinforced concrete.

2. CVMC-PRIME implies the use of a capital cost relationship for a similar smoothing volume constructed of paved earth.

3. CVME implies the use of the capital costs of built-up pumping stations in addition to floating aerators designed to remove 30 percent of the feed BOD.

4. CVME-PRIME implies the use of capital costs for floating aerators designed to remove 30 percent of the feed BOD (but omits the capital costs of pump stations).

5. PVOM $\neq$ 0 implies that the pump station O-M costs were derived from the relationship PUOM = $0.75(1/QOP)^{0.26}$.

6. AEOM-30 implies that the aerator O-M costs were derived from an O-M relationship for 30-percent removal of BOD.

7. CVME-10 and AEOM-10 imply, respectively, the capital and operating costs for aeration equipment designed to remove 10 percent of the feed BOD. The "cases"--a, b, c, and d--are consistent as given (see Section III, Introduction); and therefore, in Table 7, the "A USED CVME-10 WITH AEOM-10" means costs for concrete tanks with built-up pumping stations but aeration for 10-percent BOD removal.

TABLE 3

CASE A. CVMC WITH CVME. PVOM NOT EQUAL ZERO. USED AEOM30

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 8 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0033	.0052	.0075	.0102	.0033	.0052	.0075	.0102	.0033	.0052	.0075	.0102
1.50	2.339	2.769	3.178	3.573	2.587	3.063	3.517	3.954	2.733	3.236	3.716	4.177
1.75	1.818	2.156	2.478	2.788	2.013	2.387	2.744	3.088	2.127	2.523	2.900	3.264
2.00	1.515	1.798	2.068	2.329	1.679	1.992	2.292	2.581	1.774	2.106	2.423	2.729
2.25	1.310	1.556	1.790	2.016	1.452	1.724	1.985	2.235	1.535	1.823	2.099	2.364
2.50	1.159	1.377	1.585	1.786	1.285	1.527	1.758	1.981	1.359	1.614	1.859	2.095
3.00	.948	1.127	1.298	1.463	1.051	1.250	1.440	1.623	1.112	1.322	1.523	1.717
3.50	.806	.958	1.104	1.244	.894	1.063	1.225	1.381	.945	1.124	1.296	1.461

BEL MILES, D = 12 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0019	.0030	.0044	.0060	.0019	.0030	.0044	.0060	.0019	.0030	.0044	.0060
1.50	2.740	3.247	3.732	4.199	3.033	3.596	4.133	4.650	3.205	3.800	4.368	4.915
1.75	2.142	2.542	2.924	3.293	2.373	2.817	3.241	3.650	2.508	2.978	3.427	3.860
2.00	1.791	2.127	2.449	2.759	1.985	2.358	2.716	3.060	2.099	2.494	2.872	3.236
2.25	1.552	1.844	2.124	2.394	1.720	2.045	2.356	2.656	1.820	2.163	2.492	2.810
2.50	1.375	1.635	1.884	2.124	1.525	1.814	2.090	2.357	1.613	1.919	2.211	2.493
3.00	1.127	1.341	1.546	1.744	1.251	1.488	1.716	1.935	1.323	1.575	1.815	2.048
3.50	.959	1.142	1.316	1.485	1.064	1.267	1.461	1.649	1.126	1.341	1.546	1.745

TABLE 3 (cont.)

CASE A. CVMC WITH CVME. PVOM NOT EQUAL ZERO. USED AEOM30

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 16 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0013	.0021	.0030	.0041	.0013	.0021	.0030	.0041	.0013	.0021	.0030	.0041
1.50	3.017	3.578	4.115	4.632	3.341	3.964	4.560	5.133	3.531	4.190	4.820	5.427
1.75	2.366	2.811	3.236	3.646	2.623	3.116	3.588	4.043	2.773	3.295	3.795	4.276
2.00	1.983	2.357	2.716	3.061	2.199	2.615	3.012	3.396	2.326	2.766	3.187	3.593
2.25	1.721	2.047	2.359	2.660	1.909	2.271	2.617	2.952	2.019	2.402	2.769	3.123
2.50	1.526	1.816	2.094	2.362	1.694	2.016	2.324	2.622	1.792	2.133	2.459	2.774
3.00	1.253	1.492	1.721	1.942	1.391	1.656	1.911	2.156	1.472	1.753	2.022	2.282
3.50	1.067	1.271	1.466	1.655	1.185	1.411	1.628	1.838	1.254	1.494	1.724	1.946

BEL MILES, D = 20 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0010	.0015	.0022	.0030	.0010	.0015	.0022	.0030	.0010	.0015	.0022	.0030
1.50	3.227	3.831	4.408	4.964	3.576	4.245	4.886	5.502	3.780	4.489	5.166	5.818
1.75	2.538	3.017	3.475	3.917	2.815	3.346	3.855	4.345	2.977	3.539	4.077	4.596
2.00	2.130	2.534	2.921	3.294	2.363	2.812	3.241	3.655	2.500	2.975	3.429	3.868
2.25	1.851	2.202	2.540	2.865	2.054	2.445	2.819	3.180	2.173	2.587	2.983	3.366
2.50	1.643	1.956	2.256	2.546	1.824	2.172	2.505	2.827	1.930	2.298	2.651	2.992
3.00	1.350	1.608	1.856	2.095	1.499	1.786	2.061	2.327	1.587	1.891	2.182	2.463
3.50	1.151	1.371	1.583	1.787	1.278	1.523	1.758	1.985	1.353	1.612	1.861	2.102

TABLE 3 (cont.)

CASE A. CVMC WITH CVME. PVOM NOT EQUAL ZERO. USED AEOM30

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 24 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0008	.0012	.0017	.0024	.0008	.0012	.0017	.0024	.0008	.0012	.0017	.0024
1.50	3.398	4.035	4.645	5.232	3.766	4.473	5.150	5.802	3.982	4.730	5.446	6.136
1.75	2.678	3.184	3.669	4.137	2.970	3.533	4.071	4.591	3.142	3.737	4.307	4.857
2.00	2.250	2.678	3.088	3.483	2.497	2.972	3.427	3.867	2.642	3.145	3.627	4.092
2.25	1.957	2.330	2.687	3.032	2.172	2.586	2.983	3.367	2.298	2.737	3.157	3.563
2.50	1.738	2.070	2.388	2.696	1.930	2.299	2.653	2.994	2.042	2.433	2.808	3.169
3.00	1.430	1.704	1.966	2.220	1.588	1.892	2.184	2.467	1.681	2.003	2.312	2.611
3.50	1.219	1.453	1.678	1.895	1.354	1.614	1.864	2.105	1.434	1.709	1.974	2.229

BEL MILES, D = 28 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0006	.0010	.0014	.0019	.0006	.0010	.0014	.0019	.0006	.0010	.0014	.0019
1.50	3.541	4.207	4.845	5.459	3.926	4.665	5.373	6.055	4.151	4.934	5.683	6.404
1.75	2.796	3.326	3.834	4.323	3.102	3.691	4.254	4.799	3.282	3.905	4.502	5.078
2.00	2.352	2.800	3.229	3.644	2.611	3.108	3.585	4.046	2.762	3.289	3.794	4.282
2.25	2.046	2.437	2.812	3.174	2.272	2.706	3.123	3.525	2.404	2.864	3.305	3.731
2.50	1.819	2.167	2.501	2.823	2.020	2.407	2.778	3.136	2.138	2.548	2.941	3.320
3.00	1.497	1.784	2.060	2.327	1.663	1.982	2.289	2.585	1.760	2.099	2.424	2.737
3.50	1.277	1.523	1.759	1.986	1.419	1.692	1.954	2.208	1.502	1.792	2.069	2.338

TABLE 3 (cont.)

CASE A. CVMC WITH CVME. PVOM NOT EQUAL ZERO. USED AEOM30

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 30 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0006	.0009	.0013	.0018	.0006	.0009	.0013	.0018	.0006	.0009	.0013	.0018
1.50	3.605	4.284	4.934	5.561	3.997	4.751	5.473	6.168	4.227	5.025	5.789	6.525
1.75	2.849	3.389	3.907	4.407	3.161	3.761	4.337	4.892	3.344	3.980	4.589	5.177
2.00	2.398	2.855	3.293	3.716	2.661	3.169	3.656	4.126	2.816	3.354	3.869	4.367
2.25	2.087	2.486	2.868	3.238	2.317	2.760	3.186	3.596	2.452	2.922	3.372	3.807
2.50	1.855	2.210	2.551	2.881	2.060	2.455	2.834	3.200	2.181	2.599	3.000	3.388
3.00	1.527	1.821	2.102	2.374	1.697	2.023	2.336	2.639	1.796	2.142	2.473	2.794
3.50	1.303	1.554	1.795	2.028	1.448	1.727	1.995	2.254	1.533	1.829	2.112	2.386

TABLE 4

CASE B. CVMC-PRIME WITH CVME. PVOM NOT EQUAL ZERO. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 8 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0033	.0052	.0075	.0102	.0033	.0052	.0075	.0102	.0033	.0052	.0075	.0102
1.50	1.774	2.074	2.357	2.628	1.947	2.277	2.590	2.889	2.049	2.396	2.726	3.042
1.75	1.316	1.541	1.754	1.957	1.446	1.694	1.929	2.154	1.522	1.783	2.031	2.268
2.00	1.064	1.246	1.419	1.585	1.169	1.371	1.562	1.745	1.231	1.443	1.645	1.839
2.25	.899	1.054	1.201	1.342	.989	1.160	1.323	1.479	1.041	1.222	1.394	1.559
2.50	.782	.917	1.046	1.169	.860	1.010	1.152	1.288	.906	1.064	1.214	1.358
3.00	.624	.732	.835	.935	.686	.806	.921	1.030	.723	.850	.971	1.086
3.50	.521	.612	.698	.782	.573	.674	.770	.862	.604	.710	.812	.909

BEL MILES, D = 12 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0019	.0030	.0044	.0060	.0019	.0030	.0044	.0060	.0019	.0030	.0044	.0060
1.50	1.991	2.335	2.662	2.975	2.190	2.570	2.931	3.278	2.306	2.707	3.089	3.454
1.75	1.485	1.745	1.992	2.229	1.635	1.922	2.195	2.457	1.723	2.026	2.314	2.591
2.00	1.204	1.416	1.618	1.812	1.327	1.561	1.785	2.000	1.399	1.646	1.883	2.110
2.25	1.021	1.201	1.374	1.539	1.125	1.325	1.516	1.699	1.186	1.398	1.599	1.793
2.50	.889	1.048	1.198	1.343	.981	1.156	1.323	1.484	1.034	1.219	1.396	1.566
3.00	.712	.839	.961	1.078	.785	.926	1.061	1.191	.828	.978	1.120	1.257
3.50	.596	.703	.805	.903	.657	.776	.889	.998	.694	.819	.939	1.054

TABLE 4 (cont.)

CASE B. CVMC-PRIME WITH CVME. PVOM NOT EQUAL ZERO. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 16 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0013	.0021	.0030	.0041	.0013	.0021	.0030	.0041	.0013	.0021	.0030	.0041
1.50	2.136	2.512	2.869	3.212	2.353	2.769	3.164	3.544	2.480	2.919	3.337	3.738
1.75	1.600	1.885	2.156	2.417	1.765	2.080	2.380	2.669	1.861	2.194	2.512	2.817
2.00	1.301	1.535	1.757	1.971	1.436	1.695	1.941	2.179	1.515	1.788	2.049	2.301
2.25	1.105	1.305	1.495	1.678	1.221	1.441	1.653	1.856	1.288	1.522	1.745	1.960
2.50	.965	1.140	1.307	1.467	1.066	1.259	1.445	1.624	1.125	1.330	1.526	1.715
3.00	.774	.915	1.050	1.180	.855	1.012	1.162	1.306	.903	1.069	1.227	1.381
3.50	.649	.767	.881	.991	.717	.849	.975	1.097	.757	.897	1.031	1.160

BEL MILES, D = 20 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0010	.0015	.0022	.0030	.0010	.0015	.0022	.0030	.0010	.0015	.0022	.0030
1.50	2.247	2.647	3.028	3.394	2.478	2.921	3.343	3.749	2.613	3.081	3.527	3.956
1.75	1.689	1.993	2.284	2.564	1.865	2.202	2.524	2.835	1.968	2.324	2.665	2.994
2.00	1.377	1.627	1.866	2.097	1.521	1.799	2.064	2.320	1.606	1.899	2.180	2.451
2.25	1.172	1.386	1.591	1.788	1.295	1.533	1.760	1.980	1.368	1.619	1.860	2.093
2.50	1.024	1.212	1.392	1.566	1.132	1.341	1.541	1.735	1.196	1.417	1.629	1.834
3.00	.823	.975	1.121	1.262	.911	1.080	1.242	1.399	.962	1.142	1.313	1.480
3.50	.691	.819	.942	1.061	.765	.908	1.045	1.177	.808	.960	1.105	1.246

TABLE 4 (cont.)

CASE B. CVMC-PRIME WITH CVME. PVOM NOT EQUAL ZERO. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 24 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0008	.0012	.0017	.0024	.0008	.0012	.0017	.0024	.0008	.0012	.0017	.0024
1.50	2.337	2.757	3.158	3.544	2.580	3.045	3.489	3.917	2.722	3.214	3.684	4.137
1.75	1.762	2.083	2.390	2.685	1.947	2.303	2.644	2.972	2.056	2.432	2.793	3.141
2.00	1.439	1.704	1.957	2.201	1.592	1.885	2.167	2.439	1.681	1.992	2.290	2.578
2.25	1.227	1.453	1.671	1.881	1.357	1.609	1.851	2.085	1.434	1.701	1.957	2.205
2.50	1.073	1.273	1.464	1.649	1.188	1.410	1.623	1.829	1.256	1.491	1.717	1.935
3.00	.864	1.026	1.181	1.332	.958	1.138	1.311	1.478	1.012	1.203	1.387	1.565
3.50	.726	.863	.994	1.122	.805	.957	1.104	1.246	.851	1.013	1.168	1.319

BEL MILES, D = 28 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0006	.0010	.0014	.0019	.0006	.0010	.0014	.0019	.0006	.0010	.0014	.0019
1.50	2.414	2.851	3.270	3.673	2.666	3.152	3.616	4.063	2.815	3.328	3.819	4.292
1.75	1.825	2.160	2.481	2.791	2.018	2.391	2.748	3.092	2.132	2.526	2.904	3.269
2.00	1.494	1.770	2.036	2.293	1.653	1.961	2.257	2.543	1.747	2.073	2.386	2.689
2.25	1.275	1.512	1.741	1.962	1.412	1.677	1.931	2.177	1.493	1.773	2.043	2.304
2.50	1.117	1.326	1.528	1.723	1.237	1.471	1.695	1.913	1.308	1.556	1.794	2.024
3.00	.900	1.071	1.235	1.394	.999	1.188	1.371	1.549	1.056	1.258	1.452	1.640
3.50	.758	.902	1.040	1.175	.841	1.001	1.156	1.307	.890	1.060	1.224	1.384

TABLE 4 (cont.)

CASE B. CVMC-PRIME WITH CVME. PVOM NOT EQUAL ZERO. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 30 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0006	.0009	.0013	.0018	.0006	.0009	.0013	.0018	.0006	.0009	.0013	.0018
1.50	2.449	2.894	3.320	3.731	2.706	3.200	3.673	4.130	2.857	3.380	3.881	4.363
1.75	1.854	2.196	2.523	2.840	2.051	2.431	2.795	3.147	2.167	2.569	2.955	3.328
2.00	1.518	1.801	2.073	2.335	1.681	1.996	2.298	2.590	1.777	2.111	2.431	2.741
2.25	1.297	1.540	1.773	2.000	1.437	1.707	1.968	2.220	1.519	1.806	2.082	2.350
2.50	1.136	1.351	1.557	1.757	1.260	1.499	1.728	1.951	1.333	1.586	1.829	2.066
3.00	.917	1.091	1.259	1.422	1.018	1.212	1.399	1.581	1.077	1.283	1.482	1.675
3.50	.772	.920	1.062	1.200	.857	1.022	1.180	1.335	.907	1.082	1.250	1.414

TABLE 5

CASE C. CVMC WITH CVME-PRIME. PVOM = 0.. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 8 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0033	.0052	.0075	.0102	.0033	.0052	.0075	.0102	.0033	.0052	.0075	.0102
1.50	1.359	1.583	1.800	2.012	1.488	1.739	1.982	2.218	1.564	1.831	2.089	2.339
1.75	1.101	1.290	1.473	1.650	1.210	1.421	1.625	1.824	1.274	1.498	1.715	1.926
2.00	.941	1.106	1.266	1.421	1.036	1.221	1.399	1.572	1.092	1.288	1.478	1.662
2.25	.828	.976	1.118	1.256	.913	1.078	1.237	1.391	.963	1.138	1.307	1.471
2.50	.743	.876	1.005	1.130	.819	.968	1.112	1.252	.865	1.023	1.176	1.324
3.00	.619	.731	.840	.946	.684	.809	.931	1.049	.722	.855	.984	1.110
3.50	.533	.630	.724	.816	.589	.698	.803	.905	.622	.738	.849	.958

BEL MILES, D = 12 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0019	.0030	.0044	.0060	.0019	.0030	.0044	.0060	.0019	.0030	.0044	.0060
1.50	1.533	1.812	2.082	2.343	1.694	2.005	2.306	2.599	1.789	2.119	2.439	2.750
1.75	1.263	1.498	1.725	1.945	1.398	1.660	1.914	2.160	1.478	1.756	2.025	2.286
2.00	1.090	1.295	1.493	1.685	1.208	1.437	1.658	1.873	1.278	1.521	1.756	1.984
2.25	.965	1.148	1.325	1.496	1.071	1.275	1.472	1.663	1.133	1.349	1.559	1.762
2.50	.869	1.035	1.194	1.349	.964	1.149	1.328	1.501	1.021	1.217	1.406	1.590
3.00	.728	.868	1.003	1.134	.809	.965	1.115	1.261	.856	1.022	1.181	1.336
3.50	.629	.750	.867	.980	.699	.834	.964	1.091	.740	.883	1.022	1.156

TABLE 5 (cont.)

CASE C. CVMC WITH CVME-PRIME. PVOM = 0.. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 16 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0013	.0021	.0030	.0041	.0013	.0021	.0030	.0041	.0013	.0021	.0030	.0041
1.50	1.684	2.003	2.311	2.611	1.868	2.224	2.568	2.903	1.976	2.354	2.720	3.076
1.75	1.398	1.666	1.925	2.177	1.552	1.852	2.142	2.423	1.643	1.962	2.269	2.568
2.00	1.211	1.446	1.672	1.892	1.346	1.608	1.861	2.106	1.426	1.704	1.972	2.233
2.25	1.075	1.284	1.486	1.682	1.196	1.429	1.654	1.873	1.267	1.514	1.754	1.986
2.50	.970	1.159	1.341	1.519	1.079	1.290	1.494	1.692	1.143	1.367	1.584	1.794
3.00	.815	.974	1.128	1.278	.907	1.085	1.256	1.423	.961	1.150	1.332	1.510
3.50	.705	.843	.976	1.106	.784	.938	1.087	1.232	.831	.995	1.153	1.307

BEL MILES, D = 20 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0010	.0015	.0022	.0030	.0010	.0015	.0022	.0030	.0010	.0015	.0022	.0030
1.50	1.814	2.165	2.505	2.835	2.016	2.409	2.788	3.157	2.136	2.552	2.955	3.348
1.75	1.512	1.807	2.092	2.370	1.682	2.012	2.331	2.641	1.782	2.132	2.471	2.801
2.00	1.313	1.570	1.820	2.062	1.461	1.749	2.027	2.298	1.549	1.855	2.150	2.438
2.25	1.167	1.397	1.619	1.835	1.299	1.556	1.804	2.045	1.377	1.650	1.913	2.170
2.50	1.054	1.261	1.462	1.657	1.173	1.406	1.630	1.848	1.244	1.490	1.729	1.960
3.00	.886	1.061	1.231	1.395	.987	1.183	1.372	1.556	1.047	1.254	1.455	1.651
3.50	.767	.919	1.065	1.208	.854	1.024	1.188	1.347	.906	1.086	1.260	1.429

TABLE 5 (cont.)

CASE C. CVMC WITH CVME-PRIME. PVOM = 0.. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 24 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0008	.0012	.0017	.0024	.0008	.0012	.0017	.0024	.0008	.0012	.0017	.0024
1.50	1.928	2.307	2.673	3.029	2.146	2.569	2.979	3.378	2.275	2.724	3.160	3.583
1.75	1.610	1.929	2.236	2.536	1.794	2.149	2.493	2.828	1.902	2.279	2.645	3.001
2.00	1.400	1.678	1.946	2.207	1.560	1.870	2.170	2.462	1.654	1.984	2.303	2.613
2.25	1.246	1.493	1.732	1.965	1.388	1.665	1.932	2.192	1.472	1.766	2.050	2.326
2.50	1.125	1.349	1.565	1.776	1.254	1.504	1.746	1.981	1.330	1.596	1.853	2.102
3.00	.947	1.136	1.318	1.495	1.056	1.266	1.470	1.668	1.120	1.343	1.560	1.770
3.50	.820	.983	1.141	1.295	.914	1.097	1.273	1.445	.969	1.163	1.351	1.533

BEL MILES, D = 28 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0006	.0010	.0014	.0019	.0006	.0010	.0014	.0019	.0006	.0010	.0014	.0019
1.50	2.030	2.433	2.823	3.203	2.262	2.713	3.149	3.574	2.399	2.878	3.341	3.793
1.75	1.698	2.036	2.364	2.682	1.893	2.271	2.637	2.994	2.008	2.410	2.799	3.178
2.00	1.478	1.773	2.058	2.336	1.648	1.977	2.296	2.607	1.748	2.098	2.437	2.767
2.25	1.315	1.578	1.832	2.080	1.466	1.760	2.045	2.321	1.556	1.868	2.170	2.464
2.50	1.188	1.426	1.656	1.880	1.325	1.591	1.848	2.098	1.406	1.688	1.961	2.227
3.00	1.000	1.201	1.394	1.583	1.116	1.340	1.556	1.767	1.184	1.422	1.652	1.875
3.50	.866	1.040	1.208	1.371	.966	1.160	1.348	1.530	1.025	1.231	1.430	1.624

TABLE 5 (cont.)

CASE C. CVMC WITH CVME-PRIME. PVOM = 0.. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 30 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0006	.0009	.0013	.0018	.0006	.0009	.0013	.0018	.0006	.0009	.0013	.0018
1.50	2.078	2.492	2.892	3.283	2.316	2.779	3.228	3.665	2.457	2.949	3.426	3.891
1.75	1.739	2.086	2.422	2.750	1.939	2.327	2.704	3.070	2.057	2.470	2.870	3.259
2.00	1.513	1.816	2.109	2.395	1.688	2.027	2.354	2.674	1.791	2.151	2.499	2.838
2.25	1.347	1.617	1.878	2.132	1.503	1.804	2.096	2.381	1.594	1.915	2.225	2.527
2.50	1.217	1.461	1.697	1.927	1.358	1.631	1.895	2.152	1.441	1.731	2.011	2.284
3.00	1.025	1.231	1.429	1.623	1.143	1.373	1.596	1.812	1.213	1.457	1.694	1.924
3.50	.887	1.066	1.238	1.406	.990	1.189	1.382	1.569	1.051	1.262	1.467	1.666

TABLE 6

CASE D. CVMC-PRIME WITH CVME-PRIME. PVOM = 0. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 8 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0033	.0052	.0075	.0102	.0033	.0052	.0075	.0102	.0033	.0052	.0075	.0102
1.50	.794	.888	.979	1.067	.848	.953	1.055	1.153	.880	.992	1.099	1.203
1.75	.599	.675	.748	.820	.643	.728	.810	.889	.669	.759	.846	.930
2.00	.489	.554	.617	.678	.527	.599	.669	.737	.549	.626	.700	.772
2.25	.417	.474	.529	.582	.450	.513	.575	.635	.469	.537	.602	.665
2.50	.365	.416	.465	.513	.395	.451	.506	.560	.412	.472	.531	.587
3.00	.294	.337	.377	.417	.319	.366	.412	.456	.333	.383	.432	.479
3.50	.248	.284	.319	.353	.269	.309	.348	.386	.281	.324	.366	.406

BEL MILES, D = 12 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0019	.0030	.0044	.0060	.0019	.0030	.0044	.0060	.0019	.0030	.0044	.0060
1.50	.784	.900	1.011	1.120	.850	.980	1.105	1.226	.890	1.027	1.160	1.289
1.75	.607	.701	.792	.880	.661	.766	.868	.967	.693	.804	.913	1.018
2.00	.504	.584	.662	.738	.550	.640	.728	.813	.578	.673	.766	.857
2.25	.435	.505	.574	.641	.475	.555	.632	.707	.499	.584	.666	.745
2.50	.384	.447	.509	.569	.420	.491	.560	.628	.442	.518	.591	.663
3.00	.313	.366	.417	.467	.344	.403	.460	.517	.362	.425	.486	.546
3.50	.266	.311	.355	.398	.292	.343	.392	.441	.307	.361	.414	.466

TABLE 6 (cont.)

CASE D. CVMC-PRIME WITH CVME-PRIME. PVOM = 0. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 16 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0013	.0021	.0030	.0041	.0013	.0021	.0030	.0041	.0013	.0021	.0030	.0041
1.50	.804	.936	1.065	1.191	.880	1.029	1.173	1.314	.925	1.083	1.237	1.386
1.75	.632	.740	.845	.948	.694	.816	.934	1.049	.731	.860	.986	1.109
2.00	.530	.623	.714	.802	.584	.688	.790	.889	.615	.726	.834	.940
2.25	.460	.542	.622	.700	.508	.600	.689	.777	.535	.634	.729	.823
2.50	.409	.482	.554	.624	.451	.534	.614	.694	.476	.564	.650	.735
3.00	.336	.397	.457	.516	.371	.440	.508	.574	.392	.466	.538	.608
3.50	.286	.339	.391	.442	.317	.376	.434	.491	.335	.398	.460	.521

BEL MILES, D = 20 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0010	.0015	.0022	.0030	.0010	.0015	.0022	.0030	.0010	.0015	.0022	.0030
1.50	.833	.981	1.125	1.265	.918	1.084	1.245	1.403	.969	1.145	1.317	1.485
1.75	.662	.783	.901	1.017	.732	.868	1.000	1.130	.773	.918	1.059	1.198
2.00	.559	.663	.765	.865	.619	.736	.851	.963	.655	.779	.901	1.021
2.25	.488	.580	.670	.758	.541	.644	.746	.845	.572	.683	.791	.897
2.50	.435	.517	.598	.678	.482	.575	.666	.756	.510	.610	.707	.803
3.00	.359	.428	.496	.562	.399	.477	.553	.628	.422	.505	.587	.667
3.50	.307	.366	.425	.483	.341	.408	.474	.539	.361	.433	.504	.573

TABLE 6 (cont.)

CASE D. CVMC-PRIME WITH CVME-PRIME. PVOM = 0. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 24 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0008	.0012	.0017	.0024	.0008	.0012	.0017	.0024	.0008	.0012	.0017	.0024
1.50	.867	1.028	1.186	1.341	.960	1.141	1.319	1.493	1.015	1.208	1.397	1.584
1.75	.694	.827	.956	1.084	.770	.920	1.066	1.210	.816	.975	1.131	1.285
2.00	.589	.703	.815	.926	.655	.784	.910	1.034	.694	.831	.966	1.099
2.25	.516	.617	.716	.814	.574	.688	.800	.910	.608	.730	.850	.968
2.50	.460	.552	.641	.729	.513	.616	.717	.816	.544	.654	.761	.868
3.00	.382	.458	.533	.607	.425	.512	.596	.680	.451	.544	.634	.724
3.50	.327	.393	.458	.522	.365	.439	.513	.585	.387	.467	.545	.623

BEL MILES, D = 28 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0006	.0010	.0014	.0019	.0006	.0010	.0014	.0019	.0006	.0010	.0014	.0019
1.50	.903	1.077	1.248	1.416	1.003	1.199	1.392	1.582	1.062	1.272	1.478	1.681
1.75	.727	.870	1.011	1.150	.809	.971	1.130	1.287	.858	1.031	1.201	1.369
2.00	.619	.743	.865	.985	.690	.830	.968	1.104	.733	.882	1.02[illegible]	1.175
2.25	.543	.653	.761	.868	.606	.731	.853	.974	.644	.777	.907	1.037
2.50	.486	.585	.683	.779	.543	.655	.765	.874	.577	.696	.814	.931
3.00	.404	.487	.569	.650	.452	.546	.638	.730	.480	.580	.680	.778
3.50	.347	.419	.489	.560	.388	.469	.550	.629	.412	.500	.585	.671

TABLE 6 (cont.)

CASE D. CVMC-PRIME WITH CVME-PRIME. PVOM = 0. USED AEOM30.

INTRST	LIFP	LIFC	LIFE	VMAX	VMIN	RFVMC
.60000E -1	.50000E 2	.30000E 2	.30000E 2	.35000E 1	.20000E 1	.72652E -1

RFVME	RFP
.72652E -1	.63445E -1

BEL MILES, D = 30 INCHES

	Y = .70				Y = .80				Y = .86			
	S				S				S			
X	.0006	.0009	.0013	.0018	.0006	.0009	.0013	.0018	.0006	.0009	.0013	.0018
1.50	.921	1.102	1.279	1.453	1.025	1.228	1.428	1.626	1.086	1.304	1.518	1.729
1.75	.743	.892	1.038	1.183	.829	.997	1.162	1.326	.880	1.059	1.236	1.411
2.00	.634	.763	.889	1.014	.708	.853	.996	1.138	.752	.907	1.060	1.212
2.25	.557	.671	.783	.894	.622	.751	.879	1.005	.661	.799	.935	1.070
2.50	.499	.602	.703	.803	.558	.674	.789	.903	.593	.717	.840	.962
3.00	.415	.501	.586	.671	.464	.562	.659	.755	.494	.599	.702	.805
3.50	.356	.431	.505	.578	.399	.484	.568	.651	.425	.515	.605	.694

APPENDIX B

Size and Cost Tables

Table 7. *Various Estimates of Required Storage Volume (V) to Smooth the* Diurnal Variations in the Design Flow for the New Hope Plant[1]

	Observed Data						Calculated Quantities				
	By Graphical Estimation				By Planimeter				Triangle Approx.	"Square-wave" Calculation	"Square-wave" Calculation Max
	Average	Peak	Minimum	Time Flow Above Avg.	QA'	Direct Estimate[2]	X =	h =		VS =	VM =
	QA	QP	QM	t		VD	QP/QA Dimension-less	QP - QA	$VT = \frac{1}{2}bh$	$YQF(\frac{X-1}{X+1})\frac{1}{X}$	$YQF(\frac{X-1}{X+1})$
Date	MGD	MGD	MGD	hours	MGD	MG		MGD	MG	MG	MG
5 Jam 1967	1.89	2.75	0.75	14.7	1.96	0.204	1.43	0.86	0.263	0.335	0.479
6 Jan 1967	1.88	2.90	1.00	13.6	1.86	0.250	1.54	1.02	0.289	0.357	0.550
7 Jan 1967	1.81	2.90	0.80	12.3	1.86	0.228	1.60	1.19	0.278	0.372	0.595
8 Jan 1967	1.63	2.60	0.90	12.6	1.65	0.186	1.60	0.97	0.256	0.372	0.595
9 Jan 1967	1.59	2.20	1.00	15.6	1.67	0.146	1.39	0.61	0.199	0.302	0.420
23 Jan 1967	1.60	2.10	1.00	14.0	1.57	0.141	1.30	0.50	0.146	0.258	0.335
1967 Avg.	1.73	2.57	0.91	13.8	1.76	0.192	1.48	0.86	0.2385	0.333	0.496
26 Jan 1971	1.58	2.20	0.80	15.0	1.63	0.174	1.46	0.62	0.194	0.330	0.482
27 Jan 1971	2.12	3.05	1.00	11.0	2.08	0.305	1.44	0.93	0.212	0.322	0.464
29 Jan 1971	1.92	3.10	0.80	11.1	1.94	0.351	1.61	1.18	0.270	0.375	0.604
30 Jan 1971	1.87	3.05	0.80	10.0	1.95	0.295	1.63	1.18	0.246	0.380	0.620
8 Feb 1971	1.84	2.70	1.00	12.3	1.88	0.183	1.47	0.86	0.220	0.333	0.489
10 Feb 1971[3]	2.40	3.60	1.15	14.0	2.59	0.380	1.50	1.20	0.350	0.335	0.502
1971 Avg.	1.96	2.95	0.93	12.2	2.02	0.281	1.52	0.995	0.249	0.346	0.527

[1] Durham's New Hope Plant (18-inch influent line with QF = 3.0 MGD). Y assumed = 0.86 for d/D = 0.80.

[2] The direct estimate was made by averaging two to four planimeter determinations. The volume VD was measured from the planimeter avg. line QA'.

[3] The "design flow" for the 18-inch line was preseumably exceeded. The "maximum" storage volume VM calculation is shown for comparison.

TABLE 8

Calculations for the Cost of Concrete Smoothing Basins[1]

(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8) (A)	(8) (B)	(9)	(10)	(11)	(12)	(13)
				CONCRETE QUANTITY REQUIRED										
Volume	Volume	Surface area, depth of 15 ft	Square side length	Bottom or top edge, 1 ft thick	Free-board, 1 ft + aerator clearance	Total side height w/o sump	Four sides 1 ft thick	Sump allow. under aerators		Five sides	Six sides	l'=L+2+6 h'=h+2+sump allow+3 h'=h+4+3 VEX=l'²h'/27		
MG	cu ft	ft²	ft	cu yd	ft	ft	cu yd	each, cu yd	total, cu yd	cu yd	cu yd			
(V)	(V')	(A)	(L)	(1)(A)/27		(h)	4L(1)h/27			(4)+(7)+(8b)	(4)+(4)+ (7)+(8b)	(l')	(h')	(VEX)
0.1	13,340	890	29.8	32.9	3	18	79.4	3	6	120	150	38	25	1,340
0.2	26,680	1,776	42.1	65.8	3	18	112.1	3	6	184	250	50	25	2,300
0.4	53,360	3,550	59.6	131.6	4	19	167.6	4	12	312	445	68	26	4,450
0.8	106,700	7,100	84.2	263.2	4	19	236.7	4	12	510	775	92	26	8,100
1.6	213,400	14,200	119.2	526.4	5	20	352.8	7	21	900	1,430	128	27	16,400
3.2	426,900	28,440	168.5	1,052.8	5	20	498.6	7	42	1,580	2,630	177	27	31,300

(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
LAND AREA			CONCRETE COSTS		EXCAV COSTS	LAND COSTS	Σ COSTS		COSTS W. 20% E&C	
A'=(l'+10)²(1.5)			Five sides at $90/cu yd	Six sides at $90/cu yd	Excav at $3/cu yd	Land at $10K/acre	Five sides	Six sides	Five sides	Six sides
ft	ft²	acres	$	$	$	$	$	$	$1000	$1000
(l'+10)	(l'+10)²	A	$90×(9)	$90×(10)	$3×(13)	$10K×(16)	(17)+(19)+(20)	(18)+(19)+(20)	1.2×(21)	1.2×(22)
48	2,300	0.080	10,380	13,380	4,000	800	15,180	18,180	18,216	21,816
60	3,600	0.124	16,280	22,200	6,900	1,240	24,420	30,340	29,304	36,408
78	6,080	0.209	27,290	39,100	13,300	2,090	42,680	54,490	51,216	65,388
102	10,400	0.357	45,350	69,000	24,300	3,570	73,220	96,870	87,864	116,244
138	19,000	0.655	79,760	127,100	49,200	6,550	135,510	182,850	162,612	219,420
187	35,000	1.20	140,260	235,000	94,000	12,000	246,260	341,000	295,512	409,200

(1) For 15 feet of vertical level change.

TABLE 9

Calculations for the Cost of Earthen Smoothing Basins(1)

(1)		(2)	(3)	(4)	(5)	(6)
				PAVING QUANTITY REQUIRED		
Volume	Volume	Cross-Sectional Surface Area (depth of 15 ft)	Square Side Length at Mid Line	Bottom Area	Wetted Side Area Includes Sump	Total Paved Area
MG	cu ft	ft^2	ft	sq yd		sq yd
(V)	(V')	(A)=V'/15	$(L)=\sqrt{V'/15}$	$[L-8.5(\frac{1}{1})2]^2/9$	$\frac{4[(L-1)\sqrt{2}\times 18]}{9}$	(4)+(5)
0.1	13,340	890	29.8	19	327	350
0.2	26,680	1,776	42.1	70	466	540
0.4	53,360	3,550	59.6	200	691	890
0.8	106,700	7,100	84.2	500	943	1,440
1.6	213,400	14,200	119.2	1,160	1,338	2,500
3.2	426,900	28,400	168.5	2,530	1,900	4,400

(7)	(8)	(9)	(10)	(11)	(12)	(13)
			COSTS[3,4,5]			
EXCAVATION	LAND AREA		PAVING	EXCAV	LAND	TOTAL COSTS
Earth Removed and Placed as Diking	$\frac{(L+91)^2}{43,560}$	$\frac{(L+120)^2}{43,560}$ With 30-ft Buffer	$8/yd²	$3/cu yd	$6000/acre	With E&C
cu yd VEX^2	acres	acres	$8(6)	$3(7)	6K$(9)	1971 $
840	0.33	0.52	2,800	2,500	3,100	10,000
1,540	0.41	0.61	4,300	4,600	3,700	15,000
2,960	0.53	0.76	7,100	8,900	4,600	24,700
5,740	0.70	0.96	11,500	17,200	5,800	41,400
11,250	0.99	1.32	20,000	34,000	7,900	74,300
22,300	1.54	1.93	35,000	67,000	11,600	136,000

(1) For 15 feet of vertical level change.

(2) VEX $\frac{1}{3}(A_1 + A_2 + \sqrt{A_1 A_2})h + (3ft)A_1$, where A_1, A_2 equal, respectively, the area of the water surface at the max level and the area of the paved bottom.

(3) 1969 Chapel Hill Bid for street pavement replacement.

(4) R. Smith, Cincinnati estimated excavation for small operations, 1967 (large basins could justify use of large equipment at significantly lower cost).

(5) Author's estimate for undeveloped residential-to-rural land in the Triangle Cities area.

TABLE 10. Calculations for Size and Cost of Aerators and Aerator O-M[1] Costs

Useful Basin Volume	Max. Flow	BOD Load	Oxygen Required (1.3 Load)	Oxygen Req'd	Aerat. hp Req'd	Aerators Req'd			Aerator Costs[3] (1971) Installed		Aerator Operating and Maintenance
						Op	Spare[2]	Power Each	Each,	Total,	
MG	MGD	lb/hr	lb/hr	lb/hr	hp	No.	No.	hp	$1000	$1000	¢/1000 gal.
	(Q/V=4)			(30% Rem)							
0.1	0.4	28	37	11	4.4	1	1	5	2.75	5.5	0.33
0.2	0.8	56	73	22	8.8	2	½	5	2.75	6.875	0.31
0.4	1.6	112	146	44	17.6	2	½	10	4.1	10.25	0.29
0.8	3.2	225	290	90	35	3	½	15	4.6	16.1	0.27
1.6	6.4	450	580	180	70	3	½	25	6.8	23.8	0.25
3.2	12.8	900	1160	350	140	3	½	50	11.5	40.25	0.23
	(Q/V=2)			(30% Rem)							
0.1	0.2	14	19	5	2.2	1	1	5	2.75	5.5	0.36
0.2	0.4	18	37	11	4.4	1	1	5	2.75	5.5	0.33
0.4	0.8	56	73	22	8.8	2	½	5	2.75	6.875	0.31
0.8	1.6	112	146	44	17.6	2	½	10	4.1	10.25	0.29
1.6	3.2	225	290	90	35	3	½	15	4.6	16.1	0.27
3.2	6.4	450	580	180	70	3	½	25	6.8	23.8	0.25
	(Q/V=4)			(10% Rem)							
0.1	0.4	28	37	3.7	1.5	1	1	5	2.75	5.5	0.16
0.2	0.8	56	73	7.3	2.9	1	1	5	2.75	5.5	0.14
0.4	1.6	112	146	14.6	5.8	1	1	7.5	3.2	6.4	0.13
0.8	3.2	225	290	29	12	2	½	7.5	3.2	8.0	0.115
1.6	6.4	450	580	58	23	3	½	7.5	3.2	11.2	0.10
3.2	12.8	900	1160	116	47	2	½	25	6.8	17.0	0.09
	(Q/V=2)			(10% Rem)							
0.1	0.2	14	19	1.9	0.8	1	1	5	2.75	5.5	0.18
0.2	0.4	18	37	3.7	1.5	1	1	5	2.75	5.5	0.16
0.4	0.8	56	73	7.3	2.9	1	1	5	2.75	5.5	0.14
0.8	1.6	112	146	14.6	5.8	1	1	7.5	3.2	6.4	0.13
1.6	3.2	225	290	29	12	2	½	7.5	3.2	8.0	0.115
3.2	6.4	450	580	58	23	3	½	7.5	3.2	11.2	0.10

[1] Operating costs based on 1¢/kwh for power; O-M smoothed to fit equations (9) and (10).

[2] Installations requiring only one aerator were assumed to need a complete standby unit, but multiple-unit stations were assumed to have adequate protection with only a spare motor and frame costed at one-half unit price (per Reference 10).

[3] From Reference 11.

APPENDIX C

BEL Computer Program

```
      REAL INTRST, LIFP, LIFC, LIFE
      DIMENSION BELL(15,7,2), KW(2), ITEXT(20)
      DIMENSION A(3,10)
      DIMENSION DOVRD(10),DD(12),SS(10),XX(10),VV(10)
    2 FORMAT(16I5)
    5 FORMAT(8F10.0)
   11 FORMAT(1H-,10X2H N,11X1HD,11X1HY/1X3E12.5)
   12 FORMAT(//16X1HS,10X2HQF.9X3HQOP,8X4HPVOM,8X4HAEOM,8X4HDVOM/5X6E12.
     15)
   13 FORMAT(/18X4HBEL1,8X4HBEL2,8X4HTACC,8X4HTACP,6X6HDARCTQ,6X6HDARETQ
     1,9X3HTQI,9X3HQOP;9X3HQOA/10X9E12.5//18X4HCVME,8X4HCVMC,9X3HVMI,8X
     24HDPOM,6X6HDARPOO,6X6HDPOMQO,11X1HX,10X2HCP,9X3HCVM/10X9E12.5//16X
     36HCVMTQI,7X5HCPQOA/10X2E12.5)
   14 FORMAT(/6X6HINTRST,8X4HLIFP,8X4HLIFC,8X4HLIFE,8X4HVMAX,8X4HVMIN,
     1 7X5HRFVMC/7E12.5//7X5HRFVME,9X3HRFP/2E12.5)
   15 FORMAT(/8X4HTACC,8X4HDVOM,8X4HAEOM/3E12.5//5X,6X6HDARCTQ,8X4HCVMC,
     17X5HRFVMC,7X5HLIFC/5X4E12.5//5X,6X6HDARETQ,8X4HCVME,7X5HRFVME,8X4H
     2LIFE,8X4HQOAV,9X3HQOA/5X6E12.5//4X8HINTEREST,11X1HV,11X1HS/3E12.5)
   17 FORMAT(32X3HBEL,I2,11H MILES, D = ,I3,7H INCHES//6X3(9X3HY =,F4.2,
     111X)//6X3(12X1HS,14X)/6X3(4F6.4,3X)/3X1HX   )
   18 FORMAT(1XF5.2,*(¬F6.3,3X))
   32 FORMAT(1XF5.2,15F6.4)
   20 FORMAT(1H-/////)
   22 FORMAT(//)
   28 FORMAT(20A4)
    1 CALL AMAKE(A)
      READ 5, XN
      READ 2,NUMY,NUMD,NUMV,NUMX
      READ 5,(DO.RD(I),I=1,NUMY)
      READ 5,(XX(L),L=1,NUMX)
      READ 5, (VV(K),K=1,NUMV)
      READ 5,(DD(J),J=1,NUMD)
      VMIN = VV(1)
      VMAX = VV(NUMV)
    4 READ 5, INTRST, LIFP, LIFC, LIFE
      IF(INTRST) 3,1,6
    6 READ 2, ISS
      RFVMC = RECOVR(INTRST,LIFC)
      RFVME = RECOVR(INTRST,LIFE)
      RFP = RECOVR(INTRST,LIFP)
      READ 2, NCASES
      DO 19  NC=1,NCASES
      READ 28, ITEXT
      READ 2, IAN, IAEOM
      ANUMBR   IAN
      READ 2, KW
      DO 19 J=1,NUMD
      D   DD(J)
      CP = 1540.7*(D+2.0436)**1.37949
      DARP = CP*RFP/3.64
C   D SHOULD BE READ-IN IN INCHES
C
C
      IS   0
      DO 100 I=1,NUMY
      Y - DOVRD(I)
      IF(ISS) 95,95,94
   94 PRINT 11,     XN,D,Y
   95 R = D/4.
```

```
      DO 100 K=1,NUMV
      S = ((48./D)**(2./3.)*XN*VV(K)/1.486)**2
      SS(K) = S
      QF = 3.2E-2*(D**(8./3.)*SQRT(S))
      QOP = Y*QF
C     PVOM =(1.61/QOP**.26257)*ANUMBR
C     AEOM = .216 + 357./(QOP*1000.)
      AEOM10 = .14/QOP**.157
      AEOM30 = 0.3/QOP**.104
      PVOM =(.75/QQP**.264)*ANUMBR
      AEOM = AEOM30*FLOAT(IAEOM/30) + AEOM10*FLOAT(10/IAEOM)
      DVOM = PVOM + AEOM
      IF(ISS) 97,97,96
   96 PRINT 12,S,QF,QOP,PVOM,AEOM,DVOM
   97 IS = IS+1
      IX = 0
      DO 99 L=1,NUMX
      IX = IX + 1
      X = XX(L)
      QOA = QOP/X
      VMI = QOP*(X-1.)/(X+1.)
      V - VMI
      VM    V
      QOAV = QOA/V
C
C  CVMC = (IW=1)
C  CVME - (IW=2)
C  CVMC-PRIME = (IW=3)
C  CVME-PRIME = (IW=4)
C  2 VALUES OF KW PER CASE, ONE FOR CVMC OR CVMC-PRIME, THE OTHER FOR
C  CVME OR CVME-PRIME.
C
      IW - KW(1)
      CVMC - COSTF(V,IW,A)
C
      IW = KW(2)
      VX = VM*(QOP/VM/2.)
      CVME - COSTF(VX,IW,A)
      DARPQO = DARP/QOA*1.E-3
      DPOM = 4000./364.
      DPOMQO = 4./(364.*QOA)
      TACP = DARPQO + DPOMQO
      TQI - QOP - QOA
      DARCTQ    CVMC*1000.*RFVMC/(3640.*TQI)
      DARETQ = CVME*1000.*RFVME/(3640.*TQI)
      TACC = DARCTQ+DARETQ + DVOM
      CVM = CVMC + CVME
      CVMTQI = CVM/TQI
      CPQOA = CP/QOA
      BEL1 = CVMTQI/CPQOA*1.E3
      BEL2= TACC/TACP
      BELL(IS,IX,1) = BEL1
      BELL(IS,IX,2) = BEL2
      IF(ISS) 99,99,98
   98 PRINT 13,BEL1,BEL2,TACC,TACP,DARCTQ,DARETQ,TQI;QOP,QOA,CVME,CVMC,
     1VMI,DPOM,DARPQO,DPOMQO,X,CP,CVM,CVMTQI,CPQOA
   99 CONTINUE
  100 CONTINUE
      ID = D + 0.5
```

```
C  SUPPRESS BEL-1 ENTIRELY.
C      DO 24 MV=1,2
       MV = 2
       NV = -MV
       IF(MOD(J,2))33,34,33
   33  PRINT 20
       PRINT 28, ITEXT
       PRINT 14,INTRST,LIFP,LIFC,LIFE,VMAX,VMIN,RFVMC;RFVME,RFP
   34  PRINT 22
       PRINT 17,NV,ID,(DOVRD(II),II=1,3),((SS(KK),KK=1,4),MM=1,3)
       DO 21 LL=1,NUMX
       L = NUMX + 1 - LL
       X = XX(L)
       IX = L
   31  PRINT 18, X, (BELL(IS,IX,MV),IS=1,12)
   21  CONTINUE
   19  CONTINUE
       GO TO 4
    3  CALL EXIT
       STOP
       END
1
REQUIRED SUBPROGRAMS:

$ST          EXIT         MOD          $FX
COSTF        FLOAT        SQRT         $XA
$PR          $XE          $FL          $EQ
RECOVR       $ON          $AQ          $RC
AMAKE        $A           $)           $(
$E           $/           $X           $H
$F           $)F          $I

STORAGE ASSIGNMENTS:

VV        R 00034   XX      R 00046   SS      R 00060   DD      R 00074
DOVRD     R 00106   A       R 00144   ITEXT   R 00170   KW      R 00172
BELL      R 00514   LL      R 02457   MM      R 02460   KK      R 02462
II        R 02464   NV      R 02465   MV      R 02466   ID      R 02470
BEL2      R 02471   BEL1    R 02472   CPQOA   R 02473   CVMTQI  R 02474
CVM       R 02475   TACC    R 02476   DARETQ  R 02477   DARCTQ  R 02502
TQI       R 02503   TACP    R 02504   DPOMQO  R 02505   DPOM    R 02510
DARPQO    R 02512   CVME    R 02513   VX      R 02514   CVMC    R 02515
IW        R 02516   QOAV    R 02517   VM      R 02520   V       R 02521
VMI       R 02523   QOA     R 02524   X       R 02525   IX      R 02526
DVOM      R 02527   AEQM    R 02532   PVOM    R 02535   AEOM30  R 02540
AEOM10    R 02543   QOP     R 02544   $1T2    R 02545   QF      R 02550
$1T1      R 02551   S       R 02557   R       R 02561   Y       R 02562
IS        R 02564   DARP    R 02566   CP      R 02572   D       R 02573
ANUMBR    R 02574   IAEOM   R 02575   IAN     R 02576   NC      R 02577
NCASES    R 02600   RFP     R 02601   RFVME   R 02602   RFVMC   R 02603
ISS       R 02604   VMAX    R 02605   VMIN    R 02606   J       R 02607
K         R 02610   L       R 02611   I       R 02613   NUMX    R 02614
NUMV      R 02615   NUMD    R 02616   NUMY    R 02617   XN      R 02620
LIFE      R 02621   LIFC    R 02622   LIFP    R 02623   INTRST  R 02624
END COMPILATION
```

```
      SUBROUTINE AMAKE(D)
C
      DIMENSION B(3,10),A(10,3), Y(10), C(3,3), D(3,10)
      IW = 1
  103 READ 1, MANY
      IF(MANY) 101,101,102
  102 DO 2 I=1,MANY
      I=I
      READ 3, X,Z
      Y(I) = ALOG10(Z)
      A(I,1) = 1.
      A(I,2) = ALOG10(X)
      A(I,3) = A(I,2)**2
C     PRINT 13,I,X,Z,Y(I),(A(I,J),J=2,3)
    2 CONTINUE
    1 FORMAT(16I5)
    3 FORMAT(8F10.4)
C     DO 4 I - 1,MANY
C     DO 4 J = 1,3
C   4 B(J,I) = A(I,J)
C
C    ROWS OF B * COLUMNS OF A
C
      DO 5 I = 1,3
   13 FORMAT(/I5,6E12.5)
C     DO 5 J =1,3 BUT C(I,J)= C(J,I)
      DO 5 J =I,3
      C(I,J) - 0.
      DO 5 K - 1,MANY
C     C(I,J) = C(I,J) + B(I,K)*A(K,J)
      C(I,J) = C(I,J) + A(K,I)*A(K,J)
    5 C(J,I) = C(I,J)
      EPS = 1.0E-15
      N=3
      CALL GJR(C,N,EPS,MSING)
   14 FORMAT(/3E12.5)
      GO TO (7,6), MSING
    6 PRINT 8, IW, MSING
    8 FORMAT(/1X22HSINGULAR MATRIX.  IW =,I3,10H.  MSING =,I3)
      GO TO 100
  101 RETURN
    7 DO 9 I=1,3
      DO 9 J = 1, MANY
      B(I,J) = 0.
C    (ATRAN*A)INVERSE * ATRAN
      DO 9 K = 1,3
    9 B(I,J) = B(I,J) + C(I,K)*A(J,K)
   15 FORMAT(/10E12.5)
C                                   * Y
      DO 10 I = 1,3
      D(I,IW) = 0.
      DO 10 K = 1,MANY
   10 D(I,IW) = D(I,IW) + B(I,K)*Y(K)
      DO 20 I=1,MANY
      SS = 0.
      DO 19 J=1,3
   19 SS = SS + A(I,J)*D(J,IW)
      SD = Y(I) - SS
   20 CONTINUE
```

```
   100 IW = IW+1
       GO TO 103
       END
1
REQUIRED SUBPROGRAMS:

$H          $X          $PR         GJR
$E          $/          $F          $)F
$I          $XA         ALOG10      $ON
$AQ         $RC

STORAGE ASSIGNMENTS:

C       R 00025    Y       R 00037    A       R 00075    B       R 00133
SD      R 00700    SS      R 00701    MSING   R 00702    N       R 00703
EPS     R 00705    $1T6    R 00706    $1T5    R 00707    $1T4    R 00710
$1T3    R 00711    $1T2    R 00712    K       R 00713    $1T1    R 00715
J       R 00716    Z       R 00722    X       R 00723    I       R 00724
MANY    R 00725    IW      R 00727
END COMPILATION
```

```
1
REQUIRED SUBPROGRAMS:

$XE         $XA        ALOG10

STORAGE ASSIGNMENTS:

$1T4      R 00053    $1T3      R 00055    $1T2      R 00056    $1T1      R 00057
COST      R 00060    VLOG      R 00061    COSTF     R 00062
END COMPILATION
```

```
1
REQUIRED SUBPROGRAMS:

$XE

STORAGE ASSIGNMENTS:

$1T1      R 00024     Z          R 00026     RECOVR    R 00027
END COMPILATION
```

```
      SUBROUTINE GJR(A,N,EPS,MSING)
      INTEGER P,Q
      DIMENSION A( 3, 3),B(25),C(25),P(25),Q(25)
      MSING = 1
      DO 10 K=1,N
C     DETERMINATION OF THE PIVOT ELEMENT
      PIVOT=0.
      DO 20 I=K,N
      DO 20 J=K,N
      IF ( ABS(A(I,J))- ABS(PIVOT))20,20,30
   30 PIVOT=A(I,J)
      P(K)=I
      Q(K)=J
   20 CONTINUE
      IF ( ABS(PIVOT)-EPS)40,40,50
C     EXCHANGE OF THE PIVOTAL ROW WITH THE KTH ROW
   50 IF(P(K)-K)60,80,60
   60 DO 70 J=1,N
      L=P(K)
      Z=A(L,J)
      A(L,J)=A(K,J)
   70 A(K,J)=Z
C     EXCHANGE OF THE PIVOTAL COLUMN WITH THE KTH COLUMN
   80 IF(Q(K)-K)85,90,85
   85 DO 100 I=1,N
      L=Q(K)
      Z=A(I,L)
      A(I,L)=A(I,K)
  100 A(I,K)=Z
   90 CONTINUE
C     JORDAN STEP
      DO 110 J=1,N
      IF(J-K)130,120,130
  120 B(J)=1./PIVOT
      C(J)=1.
      GO TO 140
  130 B(J)=-A(K,J)/PIVOT
      C(J)=A(J,K)
  140 A(K,J)=0.
  110 A(J,K)=0.
      DO 10 I=1,N
      DO 10 J=1,N
   10 A(I,J)=A(I,J)+C(I)*B(J)
C     REORDERING THE MATRIX
      DO 155 M=1,N
      K=N-M+1
      IF(P(K)-K)160,170,160
  160 DO 180 I=1,N
      L=P(K)
      Z=A(I,L)
      A(I,L)=A(I,K)
  180 A(I,K)=Z
  170 IF(Q(K)-K)190,155,190
  190 DO 150 J=1,N
      L=Q(K)
      Z=A(L,J)
      A(L,J)=A(K,J)
  150 A(K,J)=Z
  155 CONTINUE
```

```
  151 RETURN
   40 PRINT 45,     P(K),Q(K),PIVOT,EPS
      MSING   2
   45 FORMAT(/16H SINGULAR MATRIX3H I=I3,3H J=I3,7H PIVOT=E16.8,
     1 5H EPS=,E16.8, 7H KOUNT= ,I3/)
      RETURN
      END
1
REQUIRED SUBPROGRAMS:

$)F          $E          $I          $H
$/           $ON         $AQ         $PR
ABS

STORAGE ASSIGNMENTS:

C        R 00045   B        R 00076   Q        R 00127   P        R 00160
M        R 01060   $1T4     R 01062   Z        R 01063   L        R 01064
$1T3     R 01065   $1T2     R 01066   $1T1     R 01067   J        R 01070
I        R 01071   PIVOT    R 01073   K        R 01074
END COMPILATION
```


☆U.S. GOVERNMENT PRINTING OFFICE:1973 514-153/209

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

1. Report No. | 2. | 3. Accession No.

W

4. Title "THE FEASIBILITY OF FLOW SMOOTHING STATIONS IN MUNICIPAL SEWAGE SYSTEMS"

5. Report Date

6.

8. Performing Organization Report No.

7. Author(s)

Click, C. N.

10. Project No.

11010 FDI

9. Organization

Research Triangle Institute
Research Triangle Park, N. C.

11. Contract/Grant No.

14-12-935

13. Type of Report and Period Covered

12. Sponsoring Organization

U.S. Environmental Protection Agency, Environmental Protection Technology Series Report EPA-R2-73-138. February 1973.

16. Abstract

Flow smoothing in sanitary sewers was studied to determine under what conditions the resulting higher flow capacities can be economically obtained. Conservative assumptions were made in this preliminary design and economics study to provide a severe test for the cost effectiveness of the concept. In many situations, flow smoothing is an attractive alternative when compared to relief pipe installation. Circumstances which favor flow smoothing are high interest rates, high peak-to-average flow ratios, low pipe slopes, small diameters, and low design depths of flow. Flow smoothing is strongly favored where earthen construction can be utilized.

17a. Descriptors *Surge Tanks, *Sewers, *Economic Feasibility, *Domestic Wastes, Waste Water (Pollution), Municipal Wastes, Sewage, Sanitary Engineering, Water Pollution Control, Feasibility Studies, Cost Comparisons, Estimated Benefits, Design Criteria, Hydraulic Conduits, Sewerage

17b. Identifiers *Flow Smoothing, Flow Equalization

17c. COWRR Field & Group 05 D

18. Availability | 19. Security Class. (Report) | 20. Security Class. (Page) | 21. No. of Pages | 22. Price

Send To:

WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U S DEPARTMENT OF THE INTERIOR
WASHINGTON D C 20240

Dr. H. E. Bostian | Environmental Protection Agency