Chapter 10

Cost Analysis and Financing of Urban Water Infrastructure

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Introduction

The purpose of this chapter is to provide summary information regarding the cost of water, wastewater, and stormwater infrastructure for U.S. cities. While the main theme of this report is stormwater, some of the innovative ideas proposed relate to water supply. An example is reusing stormwater for irrigation to reduce water supply demands.

Demand for Water Infrastructure

The effect of dwelling unit (DU) density on water use is shown in Table 10-1, on wastewater is shown in Table 10-2, and on stormwater is shown in Table 10-3. The wastewater table uses the indoor water supply as the estimate for base wastewater flows. A range from two to 10 DU's per gross acre is used since most residential developments fall within this range. Gross area is defined as the lot and the right-of-way in the neighborhood only. It does not include open space or other land uses. The procedure and the results are described next for the three components of urban water systems.

Effect of Density on Imperviousness

The effect of DU per acre on pervious and impervious areas was evaluated using the database described in Chapter 3. The square feet of land devoted to pervious and impervious areas, as a function of DU per acre, is shown in Figure 10-1. At two DU's per acre, the total land area is about 21,800 square feet. About 12,000 square feet of this land is pervious. At the other end of the scale, only 1,600 square feet of pervious area exists for a density of 10 DU's per acre. The difference in pervious area per DU is dramatic, even over this relatively small range of DU densities. Similarly, the impervious area increases from about 2,750 square feet at 10 DU per acre to 9,800 square feet per acre at two DU per acre, over a three-fold increase. Thus, even though the percent imperviousness decreases as density decreases, the total imperviousness per DU increases significantly.

Effect of Density on Pipe Length

Using the same database, the effect of density on lot width is shown in Figure 10-2. Between three and 10 dwelling units per acre, the lot width varies linearly ranging from 25 feet at 10 DU per acre to 90 feet at three DU per acre. Below three DU per acre, the lot width increases at a more rapid rate, reaching 140 feet at two DU/acre.

Table 10-1. Effect of dwelling unit density and irrigation rate on indoor and outdoor water use.

Percent of irrigable area that is watered:			**75%**					
	Irrigation rate (inches/yr.):		**5**	**10**	**15**	**20**	**30**	**40**
Dwelling Unit Density (DU/acre)	**Pervious Area (sq. ft./DU)**	**Indoor[1] Daily Use (gal./DU)**	**Annual average irrigation (gal./DU)**					
2	14,000	180	77	154	231	307	461	615
4	5,500	180	40	79	119	159	238	318
6	3,100	180	22	45	67	90	134	179
8	1,900	180	13	26	38	51	77	102
10	1,400	180	10	20	31	41	61	82

1) Assumed indoor water use in gallons per capita per day =60
Assumed number of people per dwelling unit =3

Table 10-2. Effect of dwelling unit density on wastewater and infiltration/inflow.

Dwelling Units Density (DU/acre)	**Indoor[1] Daily Use (gal./DU)**	**Lot Width Or Frontage (ft./DU)**	**Assigned[2] Feet of Pipe (DU)**	**I/I[3] Daily (gal./DU)**
2	180	140	70	350
4	180	82	41	205
6	180	62	31	155
8	180	42	21	105
10	180	22	11	55

1) Base wastewater flow is assumed to equal indoor water use from previous table.
2) Feet of pipe per dwelling unit is 0.5*feet of frontage per dwelling unit.
3) Assumed infiltration/inflow rate in gallons/day/foot = 5

Table 10-3. Effect of dwelling unit density and runoff rates on quantities of stormwater runoff.

Runoff from impervious area (inches/yr.):			**10**	**20**	**30**	**40**
Dwelling Units Density (DU/acre)	**Indoor Daily Use (gal./DU)**	**Impervious Surface (sq. ft/DU)**	**Daily Runoff (gal./DU)**	**Daily Runoff (gal./DU)**	**Daily Runoff (gal./DU)**	**Daily Runoff (gal./DU)**
2	180	9,780	167	334	501	668
4	180	4,690	80	160	240	320
6	180	3,760	64	128	193	257
8	180	3,445	59	118	176	235
10	180	2,756	47	94	141	188

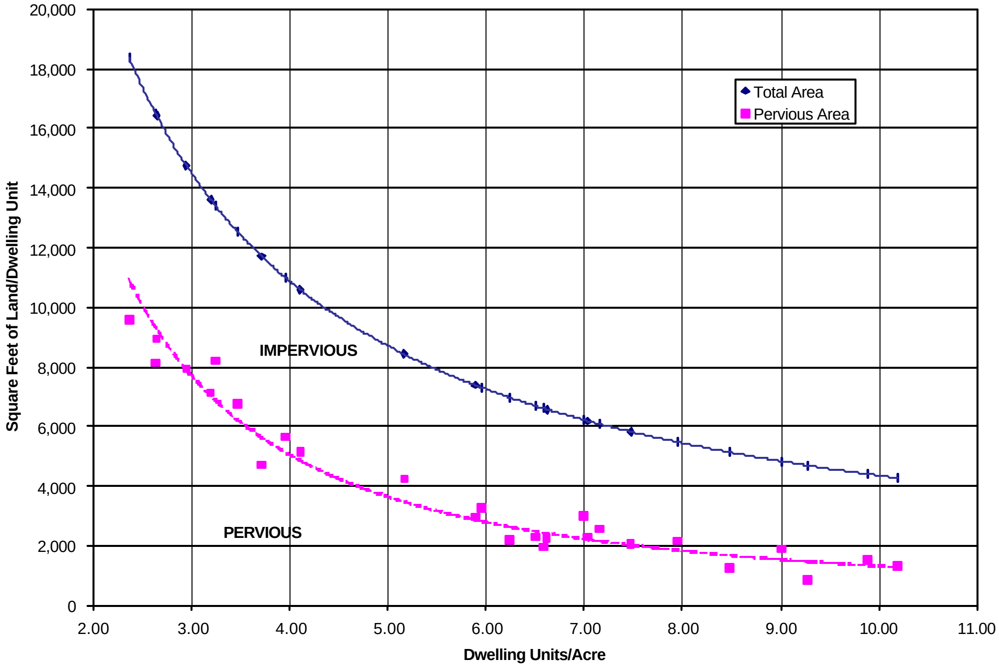

Figure 10-1. Pervious and impervious area as a function of dwelling unit density.

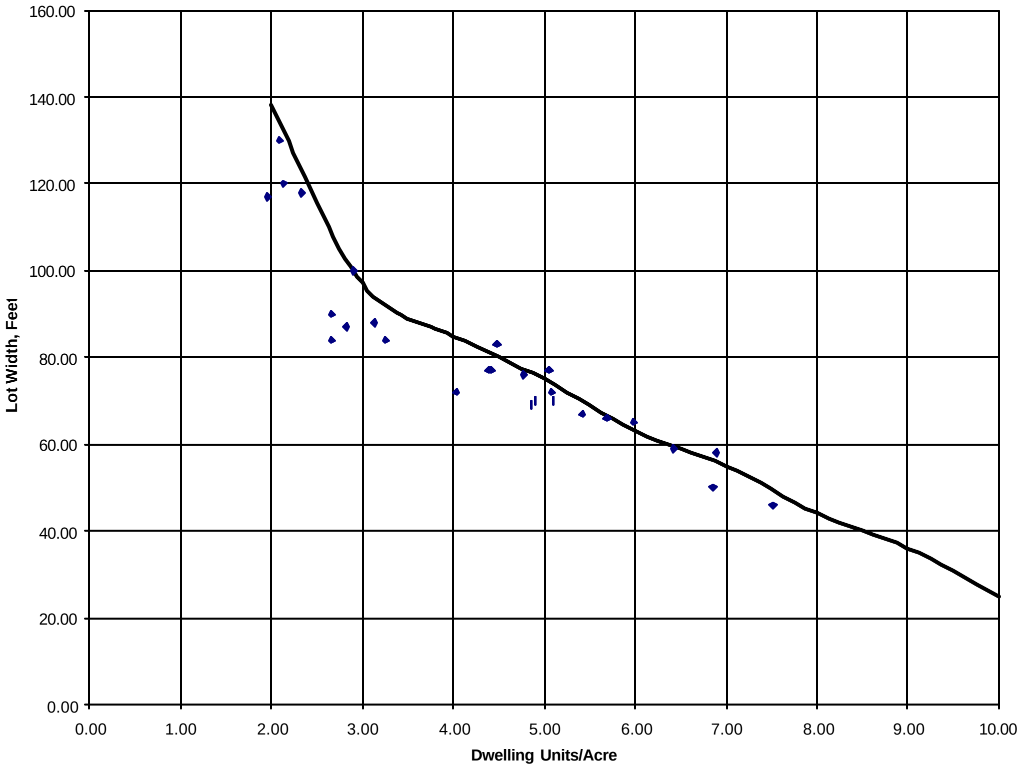

Figure 10-2. Lot width as a function of dwelling unit density.

The total pipe length required to serve a given customer is the sum of the length immediately in front of the property and a prorated share of the pipes in the system that serve multiple users. The mix of pipes depends on the nature of the network and the size of the system. The best general databases found on the network hierarchies, for purposes of this report, were for sanitary sewers and street networks. Dames and Moore (1978) conducted a national survey of 455 sewer construction projects. The final results for sanitary sewer pipe lengths and diameters arranged by population size groups, are presented in Table 10-4.

If local pipes are assumed to be 14 inches or less, then the ratio of large pipes to small pipes can be determined as shown in the last column of Table 10-4. These ratios are plotted as a function of population served in Figure 10-3. The ratios are seen to increase from about 0.15 for a small system serving about 1,000 people to about 0.4 for systems serving a population of 400,000.

Another measure of the reasonableness of the preceding ratio is obtained by looking at the urban street systems having a geometry similar to pipe networks. The results of a 1995 national summary of urban streets is presented in Table 10-5. The ratio of larger roads to local roads is 0.44 and the ratio of larger roads to collector and local roads is 0.25.

Lastly, an inventory of the water pipe network for Boulder, CO, shown in Table 10-6, indicates ratios ranging from 0.17 to 0.41 depending upon how “small” is defined. Boulder is a city of about 100,000. These comparative ratios for streets and water mains indicate that the ratios based on the Dames and Moore study are reasonable.

Table 10-4. Sanitary sewer pipe in place for various city sizes (Dames and Moore 1978).

Population Range		**Mileage of Various Pipe Sizes**					**Feet of larger pipe/feet of Smaller pipe[1]**
From	**To**	**<8"**	**8"-14"**	**15"-24"**	**> 24"**	**Total**	
500,000	>	1,094	39,649	14,971	12,646	68,360	0.68[2]
250,000	500,000	4,860	26,123	7,420	4,990	43,393	0.40
100,000	250,000	5,010	34,824	5,662	4,610	50,106	0.26
50,000	100,000	10,061	29,925	6,108	5,236	51,330	0.28
25,000	50,000	9,233	34,609	6,749	3,402	53,993	0.23
10,000	25,000	19,041	47,946	7,264	2,218	76,469	0.14
2,500	10,000	23,987	74,257	12,740	3,787	114,771	0.17

1) Assume neighborhood pipes are 14" in diameter or less. These pipes are considered to be "small".
2) Sample calculation: (14,971+12,646)/(39,649) = 0.68

Table 10-5. Street mileage in the U.S. - 1995.

Urban	Miles of road	% of urban
Interstate	13,307	1.6%
Other freeways/expressways	9,022	1.1%
Other principal arterial	53,044	6.4%
Minor arterial	89,013	10.8%
Collector	87,918	10.6%
Local	574,119	69.5%
Total Urban	826,423	100.0%
Total Rural	3,100,301	

Source: STAT: State Transportation Analysis Tables, (http://www.bts.gov/cgi-bin/stat/final_out.pl)

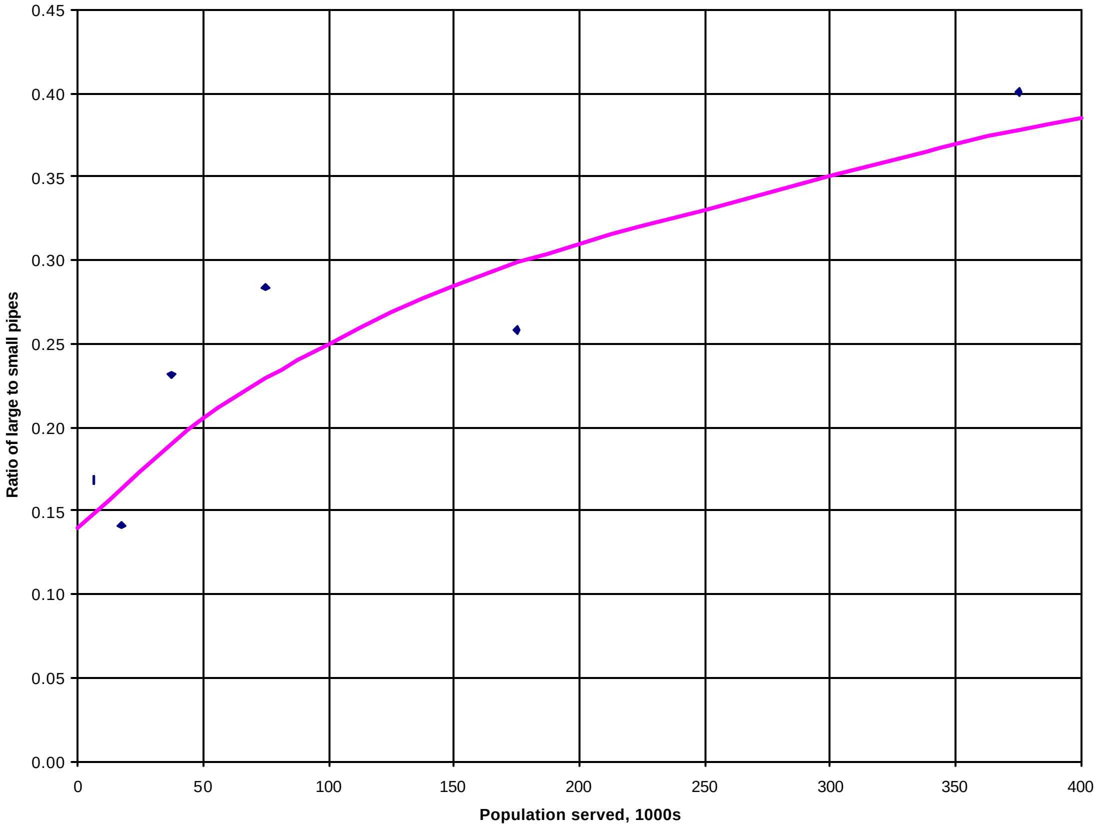

Figure 10-3. Effect of population on the ratio of length of large pipes to length of small pipes.

Table 10-6. Summary of water pipe diameters and lengths in Boulder, CO.

Diameter (inches)	Length, (1000 ft.)	Cumulative Length, (1000 ft.)	Cumulative %
4	107	107	5.3%
6	517	624	31.0%
8	806	1430	71.0%
10	1	1431	71.1%
12	288	1719	85.4%
14	14	1733	6.0%
16	132	1865	92.6%
18	19	1884	93.5%
20	35	1919	95.3%
24	59	1978	98.2%
26	2	1980	98.3%
30	34	2014	100.0%
Total	2,014		

Assume that all pipes <= 12" serve neighborhood systems

Length of smaller pipes in feet: 1431
Length of larger pipes in feet: 583

Ft. of larger pipe/ft. of smaller pipe = 0.41
If 12" is "small," the multiplier is 0.17
If 12" is “large,” the multiplier is 0.41
Use average of 0.29

Water Supply

Based on the recent North American End Use Study (NAREUS) described in Chapter 3, an average of 60 gpcd is used for indoor water use. Also, the assumed population per dwelling unit is three persons, based on the NAREUS results. Indoor water use per DU is independent of lot or house size.

Outdoor water use was estimated as a function of the pervious area. About 75% of the pervious area is assumed to be the potentially irrigable area. The water budget presented in Chapter 8 provides detailed information on the expected water deficits for various cities in the United States. Based on calibration data for Denver, the deficits shown in Table 8-3 should be doubled to reflect actual practice. Key reasons for the differences include the fact that not much of the precipitation is viewed as being “effective” by users. Also, they may over irrigate (Stadjuhar 1997). The resulting water use in gallons/DU as a function of the irrigation rate in inches per year was shown in Table 10-1.

For a given irrigation rate, say 15 inches per year, which is similar to Denver practice, the daily irrigation use exceeds the indoor water use at lower population densities. On the other hand, at DU densities greater than six, the outdoor water use remains less than the indoor water use even for high irrigation rates. The key factor that affects urban water supply systems is the strong trend towards lower DU density and the corresponding large increase in pervious area per DU. Thus, even with improved water conservation practices, outdoor water demand has been increasing due to the lower population densities associated with urban sprawl.

Wastewater

The base wastewater flow can be estimated as the indoor water use. The main source of uncertainty in wastewater flows is the amount of I/I. While I/I is a complex process, most predictive models use feet of sewer as a key explanatory variable. For this case, a rate of five gallons per day per foot of pipe is used. The resulting sewer flows, shown in Table 10-2, indicate that I/I exceeds base wastewater flow as the population density decreases below about five DU/acre. If the effect of population on pipe length per DU is included, then the dominance of I/I becomes even more apparent. Of course, all of these conclusions assume a constant I/I rate of five gallons per day per foot of pipe.

Stormwater

Stormwater runoff rates depend on local precipitation patterns and the extent of imperviousness. As shown in Table 10-3, the impervious area per DU increases almost by a factor of four as density decreases from 10 to two DU per acre. Thus, even though the percent imperviousness might decrease, the total impervious area increases greatly as densities decrease. For lower densities, the annual quantities of stormwater exceed indoor water use for most parts of the country. In addition, if storage of the first half inch of runoff is required, then the storage area per DU increases significantly as densities decrease. The feet of drainage pipe per DU can be estimated as a function of the lengths calculated above for sanitary sewers. The length of storm sewer required per DU would be less than for sanitary sewers in the more arid areas since overland flow on the street can be used instead of pipes for some of the local travel.

Optimal Scale of the Urban Water System

The regionalization problem addresses the tradeoff between the economies of scale of the treatment plant, and the spatial diseconomies of scale of pipeline distances, as distances become large. For a description of this problem, the reader is referred to Heaney (1997), Whitlach (1997), and Mays and Tung (1992).

Adams, Dajani and Gemmell (1972) evaluated the optimal size of service area for wastewater collection and treatment systems. They show that the collection systems exhibit diseconomies of scale because of the increasing lengths of pipe per unit of flow while treatment plants exhibit economies of scale. Their results, presented in Figure 10-4, show that the optimal size of wastewater service area decreases as population density decreases and that the diseconomy is quite significant if one exceeds this size service area.

The lowest population density shown in this figure is 15 persons per acre, or about four to five DU per acre. Sprawl is considered to occur at densities less than three units per acre. These results strongly suggest that the optimal size wastewater service area for contemporary low density developments is well within the neighborhood size suggested in this report. Also, Adams, Dajani and Gemmell (1972) argue that decentralized wastewater systems can provide better water quality than highly centralized systems because they make better use of the assimilative capacity of the receiving water and average out stochastic fluctuations in the performance of individual plants.

Clark (1997b) evaluates the effect of size on the least cost combination of collection and treatment using data collected for the City of Adelaide, Australia. He uses a spreadsheet model to calculate collection and treatment costs for systems ranging from on-site control (all treatment-no collection) to a completely centralized system. The summary results for capital costs, annual operation and maintenance (O&M), and total costs are shown in Figures 10-5 to 10-7. All values are in 1997 Australian dollars.

The capital cost per service for treatment plants decreases rapidly from over $7,000A to a minimum of around $1,000A at a very large system serving one million customers. However, the unit treatment costs are only about $1,500A per service for 1,000 services and about $1,100A per service for 10,000 services. Thus, of the total cost savings of about $6,500 per service as treatment goes from one to one million services, $6,000A or over 90% of the total potential savings in treatment are achieved at the 1,000 service size.

Offsetting the reduction in treatment plant costs per service is the increasing collection system costs per service that range from zero to about $5,000A. Operating costs for treatment are the most significant O&M cost. They decline from about $300A per service per year for individual systems to $50A per service per year for one million services. Here again, about 80% of the savings in O&M costs can be achieved by a system with 1,000 services. The total annualized cost (amortized construction plus O&M) for this case study, shown in Figure 10-7, indicates continually decreasing unit costs for the originally assumed density. However, virtually all of the economies of scale are realized in going from 1 to 100 services. Further increases in the number of services bring only a small added gain in savings. If density decreases, then a minimum cost is reached at about 100 services. Interestingly, Clark's (1997b) conclusions are similar to the results obtained by Adams et al. (1972).

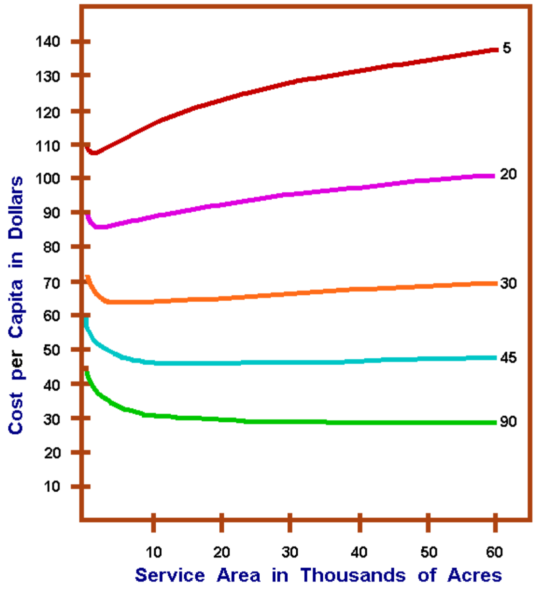

Figure 10-4. Total costs of wastewater collection and treatment systems (Adams et al. 1972). Curves represent average cost functions of collection and treatment (Numbers on curves represent population densities of number of persons/acre).

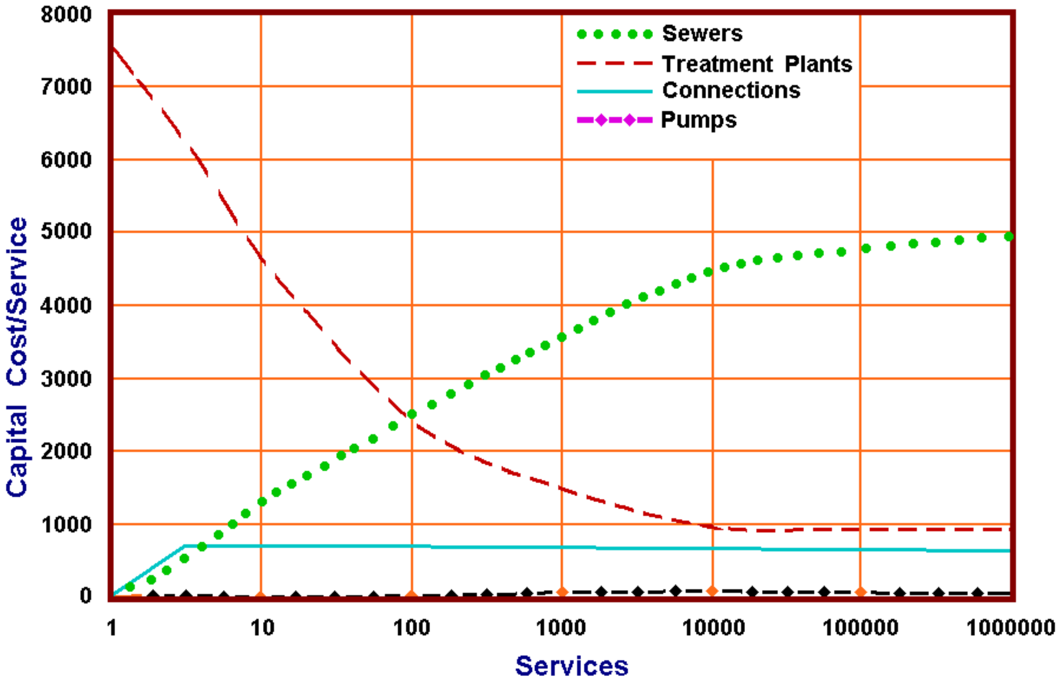

Figure 10-5. Service scale versus capital costs for components of a sewerage system. Costs are in 1997 Australian Dollars (Clark 1997b)

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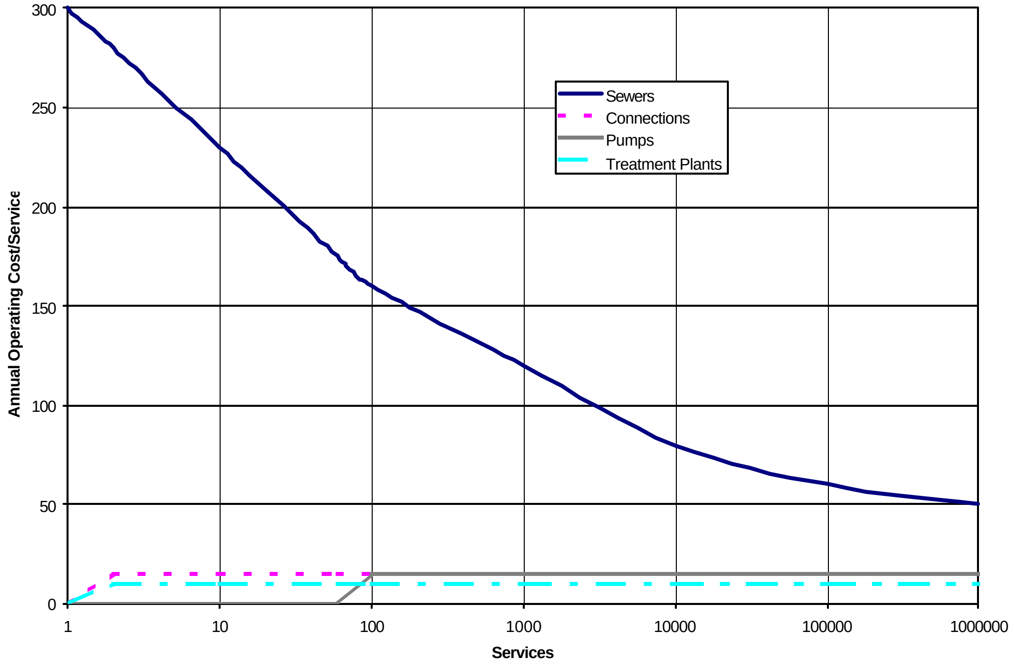

Figure 10-6. Service scale versus operating costs for components of a sewerage system. Costs are in 1997 Australian Dollars (Clark 1997b).

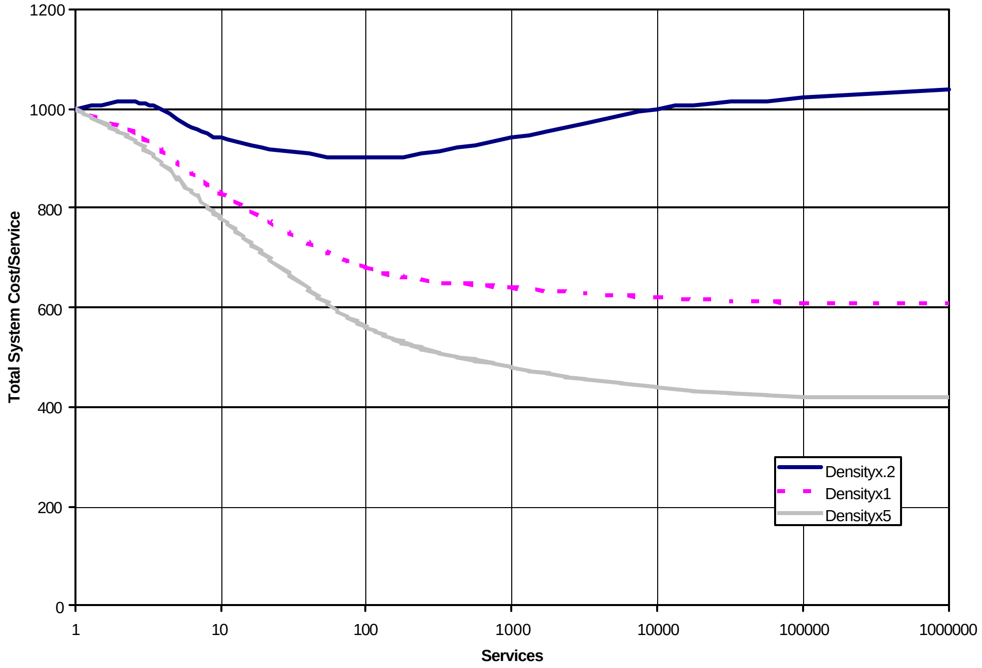

Figure 10-7. Effect of varying density of development on the minimum sewerage system cost/service and scale at which the minimum occurs. Costs are in 1997 Australian Dollars (Clark 1997b).

Costs of Infrastructure Components

Capital cost estimating equations for conveyance systems, pump stations, storage facilities, water treatment, and wastewater treatment plants are shown in Table 10-7. The general form of all of these cost equations is:

$$C = aX^b \qquad \text{Equation 10-1}$$

where: C=cost, and
X=size

The two parameters, a and b, are determined from fitting a power function to the available data. The traditional way to estimate a and b was by plotting the data on log-log paper and finding the parameters of the resulting straight line approximation of the data in log-log space. Now, it is simple to find a and b from a least squares regression that is built into contemporary spreadsheets.

The exponent, b, represents the economies of scale factor. If b is less than 1.0, then unit costs decrease as size increases. All of these equations shown economies of scale for the output measures of either flow or volume. Pipe flow exhibits very strong economies of scale with b <0.5. The economies of scale factor for treatment plants is about 0.7. A generic economies of scale factor that has been used for years is b = 0.6 (Peters and Timmerhaus 1980). All of the cost equations shown in Table 10-7 are updated to 1985. In order to update them to 1998 $, the resulting estimated cost should be multiplied by 1.41.

Cost of Piping

Dames and Moore (1978) reviewed the results of 455 sewer construction projects as part of a nationwide study of sewer costs. They summarize the average construction costs of sanitary sewers per foot of pipe for pipes ranging in size from six to 72 inches. These costs have been updated to 1998 values. Also, they estimate the range of design flows for each pipe diameter. The results are shown in Table 10-8. A plot of construction costs versus pipe diameter is shown in Figure 10-9. A linear relationship is apparent and this line was forced through the origin. The resulting equation is:

$$C = 14.991D \qquad \text{Equation 10-2}$$

Where: C = construction cost/foot in 1998 \$,
D = pipe diameter in inches.

Simply stated, pipe construction costs per foot may be estimated as \$15 multiplied by the pipe diameter in inches.

Table 10-7. Typical capital cost equations for water resources facilities[1].

Facility	Units	1985 Cost Equation Capital Cost[1]	Range	Reference	Time
A. Conveyance					
1. Force main	$/ft	$C=6.97D^{1.19}$	$6 \le D \le 72$ in.	1	Fall, 1977
2. Gravity mains	$/ft	$C=5.08D^{1.19}$	$6 \le D \le 72$ in.	1	Fall, 1977
	$/ft-mgd	$C=150Q^{.46}$	$.13 \le Q \le 43$ mgd	1	Fall, 1977
3. Open channel	$/ft-mgd	$C=12.1Q^{.41}$	$1200 \le Q \le 5800$ mgd	2	1985
4. Tunnel	$/ft	$C=4.44D^{1.14}$	$120 \le D \le 360$ in.	3	
B. Pump Station					
1. Well Pump	1000$	$C=72H^{.64}Q^{.45}$	$10 \le Q \le 2000$ gpm	4	
	1000$		$100 \le H \le 1000$ ft		
2. Water Supply	1000$	$C=13H^{.22}Q^{.44}$	$1 \le Q \le 10$ mgd	5	
			$30 \le H \le 100$ ft		
		$C=3.8H^{.37}Q^{.76}$	$10 \le Q \le 100$ mgd	5	
			$30 \le H \le 100$ ft		
3. Wastewater	1000$	$C=27HQ^{.52}$	$.1 \le Q \le 100$ mgd	6	1976
			$10 \le H \le 20$ ft		
C. Storage facilities					
1. Reservoir	1000$	$C=160V^{.4}$	$10^4 \le V \le 10^6$ AF	7	1980
2. Covered concrete tank	1000$	$C=614V^{.81}$	$1 \le V \le 10$ mg	5	1976
3. Concrete tank	1000$	$C=532V^{.61}$	$1 \le V \le 10$ mg	5	1976
3. Earthen basin	1000$	$C=42V^{.76}$	$1 \le V \le 10$ mg	5	1976
4. Clearwell					
Below ground	1000$	$C=495V^{.56}$	$.01 \le V \le 10$ mg	5	1980
Ground level	1000$	$C=275V^{.43}$	$.01 \le V \le 10$ mg	5	1980
D. Water Treatment	1000$				
1. Package treatment	1000$	$C=580Q^{.64}$	$.1 \le Q \le 1$ mgd	5	
2. Conventional treatment	1000$	$C=680Q^{.74}$	$5 \le Q \le 130$ mgd	5	
3. Direct filtration	1000$	$C=640Q^{.62}$	$1 \le Q \le 100$ mgd	5	
4. Pressure filtration	1000$	$C=402Q^{.68}$	$1 \le Q \le 20$ mgd	5	
5. Reverse Osmosis	1000$	$C=1430Q^{.68}$	$1 \le Q \le 10$ mgd	5	
6. Ion exchange	1000$	$C=370Q^{.68}$	$1 \le Q \le 10$ mgd	5	
7. Lime softening	1000$	$C=1030Q^{.68}$	$10 \le Q \le 50$ mgd	5	
8. Corrosion cont.	1000$	$C=32Q^{.67}$	$1 \le Q \le 10$ mgd	5	
9. Activated carbon	1000$	$C=809Q^{.67}$	$2 \le Q \le 110$ mgd	5	
E. Wastewater treatment					
1. Primary	1000$	$C=2980Q^{.62}$	$1 \le Q \le 100$ mgd	6	1976
2. Secondary	1000$	$C=4375Q^{.68}$	$1 \le Q \le 100$ mgd	6	
3. Tertiary	1000$	$C=11400Q^{.72}$	$1 \le Q \le 100$ mgd	6	1976

References:
1. Dames and Moore (1978)
2. US Army Corps of Engineers (1979)
3. Merkle, C. (1983)
4. Benefield, L. D. et al. (1984)
5. Gummerman, R. C. et al. (1979)
6. US EPA (1976)
7. US Army Corps of Engineers (1981)

1) To update the resulting costs to 1998, multiply by 1.41.

The next relationship, called a production function, relates the input (pipe diameter) and the output (pipe flow). The resulting curve, shown in Figure 10-9, indicates that flow increases at the 2.64 power of pipe diameter, or

$$Q = 0.0005D^{2.6451} \qquad \text{Equation 10-3}$$

Where: Q=pipe flow in cfs

Algebraically, Equation 10-3 can be solved for D and the result substituted into Equation 10-2 to find C as a function of Q. Alternatively, as was done here, a power function was fit to C as a function of Q. The result is shown in Figure 10-10 and Equation 10-4.

$$C = 217.66Q^{0.4385} \qquad \text{Equation 10-4}$$

Equation 10-4 demonstrates the strong economies of scale for pipe flow with an exponent of 0.4385. Thus, the good news is that larger sewers are more cost effective in transmitting flow. The bad news is that probably more feet of sewer pipe will be needed per service to construct a more complex pipe network.

Hassett (1995) compares the initial cost of sanitary sewers as a function of population density. His results for construction in wet and dry conditions are shown in Figures 10-11 and 10-12 respectively. Construction in wet conditions costs roughly twice the construction costs for dry conditions. Costs per dwelling unit for two DU/acre range from a high of $10,000 for wet conditions to $5,000 for dry conditions. At 10 DU/acre, costs per DU are only $2,000 (wet) or $1,000 (dry). These results appear to be a bit unrealistic. The negative exponent of nearly –1 suggests that total costs are fixed and that the costs per unit are simply total costs divided by the number of units.

Results for sanitary sewer pipe costs as a function of DU densities are shown in Table 10-9. The feet of pipe in front of the house were determined as described above. The additional amount of “larger” pipe needed per foot of local pipe is estimated as a function of population as described earlier. The unit costs of pipes were based on the 1978 Dames and Moore study updated to 1998. The results indicate the very strong influence of dwelling unit density with base costs ranging from only $1,100 per DU at 10 DU/acre to $7,000 per DU at 2 DU/acre. The effect of population is also seen to be quite significant because of the higher unit cost for larger pipes and the extra feet per DU as population increases.

Table 10-8. Sanitary sewer pipe costs and flow rates (Dames and Moore 1978).

Pipe Diameter (inches)	Average 1998 Cost ($/foot)	Flow Range (mgd)		
		Min.	Max.	Mean
6	56	0	0.08	
8	101	0.08	0.17	0.125
10	111	0.17	0.29	0.23
12	139	0.29	0.47	0.38
15	172	0.47	0.82	0.645
18	221	0.82	1.3	1.06
21	278	1.3	1.9	1.6
24	292	1.9	2.7	2.3
27	320	2.7	3.8	3.25
30	419	3.8	4.9	4.35
36	506	4.9	8	6.45
42	588	8	11.8	9.9
48	710	11.8	17	14.4
54	793	17	22.5	19.75
60	983	22.5	29.5	26
66	1,047	29.5	37.5	33.5
72	1,136	37.5	48	42.75

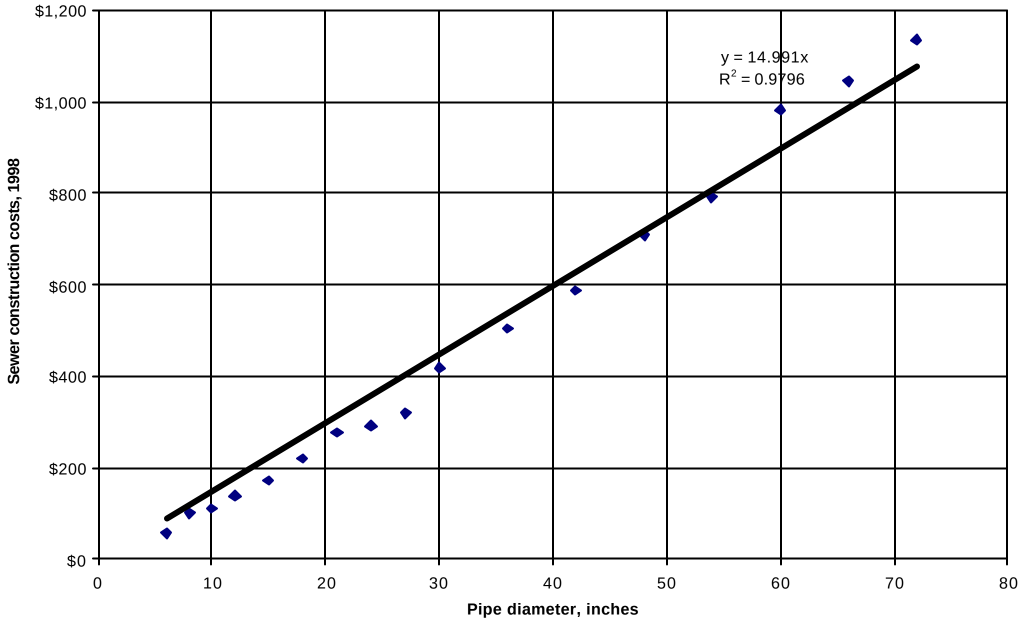

Figure 10-8. 1998 sewer construction costs per foot of length as a function of pipe diameter.

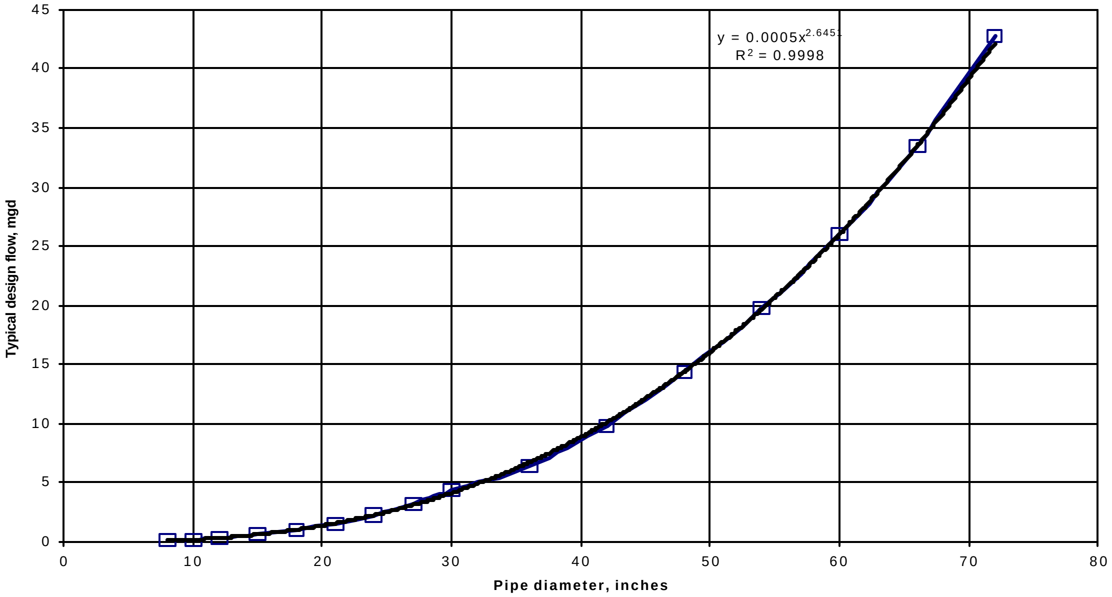

Figure 10-9. Typical flows versus pipe diameter.

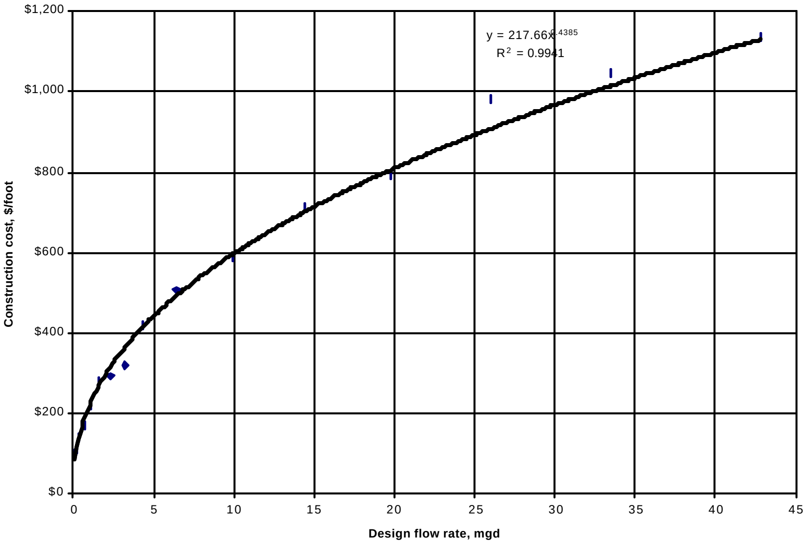

Figure 10-10. Sewer construction costs per foot of length versus design flow rate.

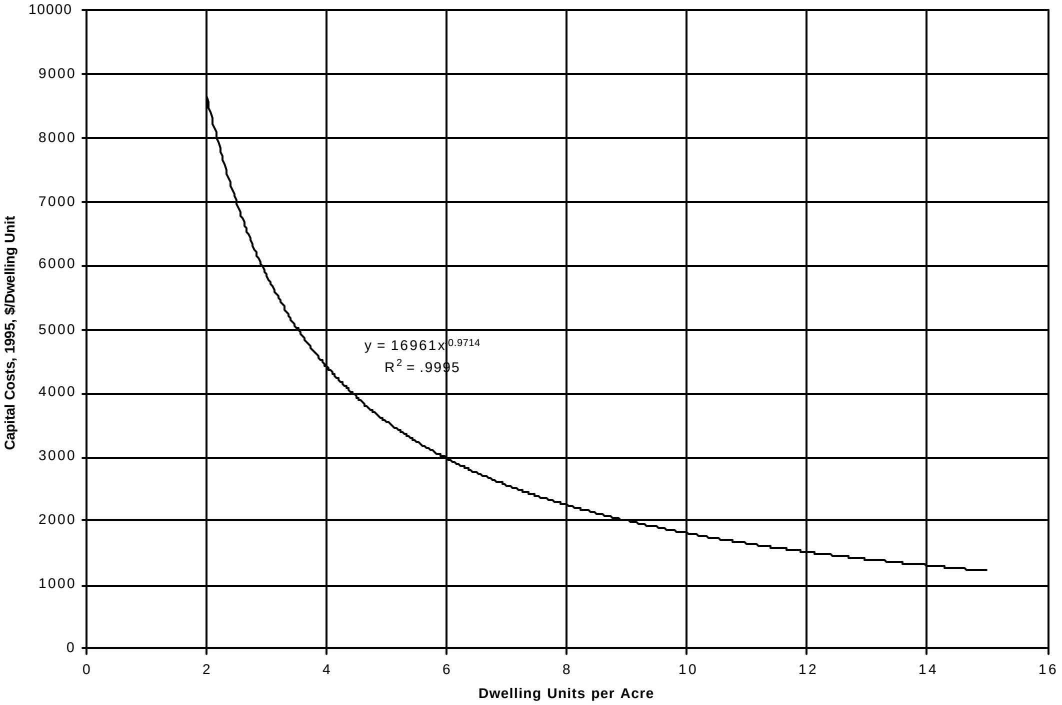

Figure 10-11. Effect of dwelling unit density on sanitary sewer construction costs in wet areas (1996).

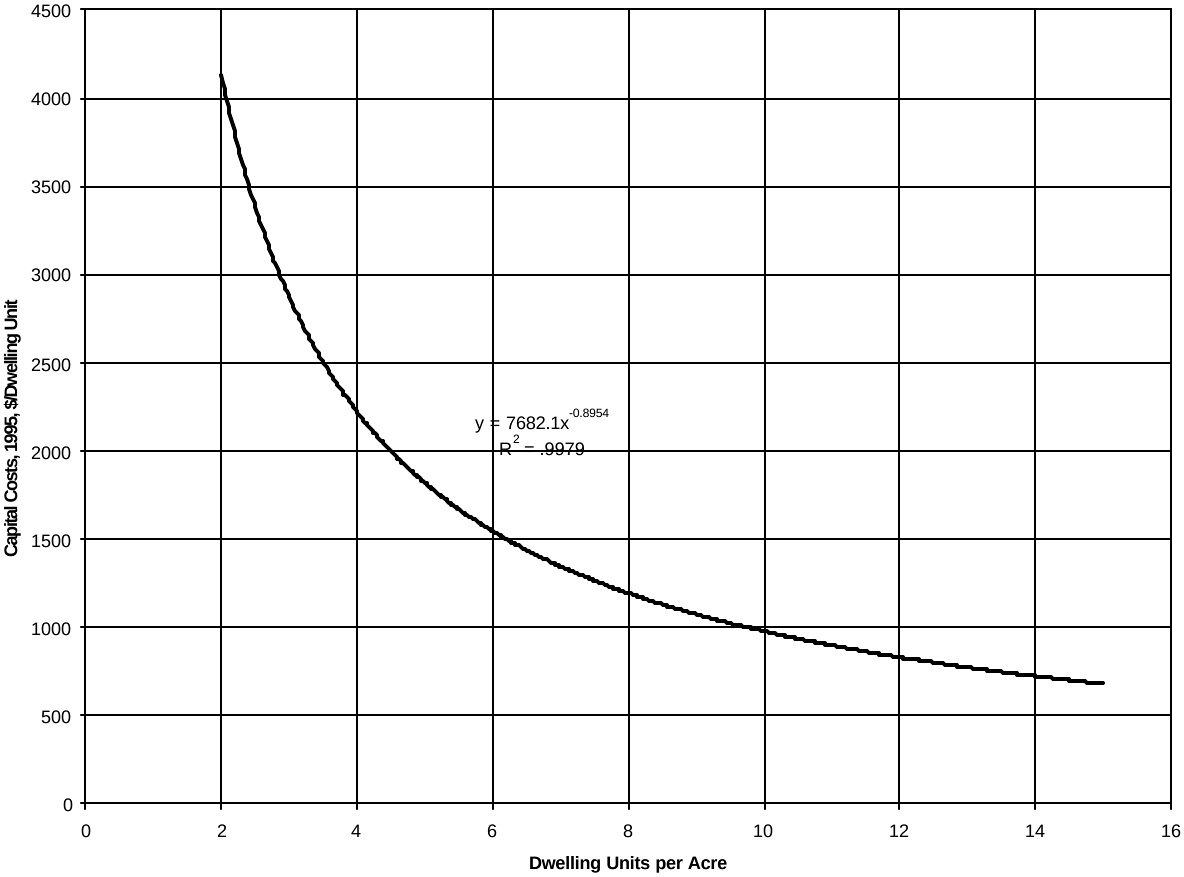

Figure 10-12. Effect of dwelling unit density on 1995 sanitary sewer construction costs in dry areas (Hassett 1995).

Table 10-9. Estimated 1998 sanitary sewer pipe costs per dwelling unit for various dwelling unit densities.

Larger/smaller Ratio:		**0.15**	**0.2**	**0.4**	**Cost of Small Pipe[1]**	**Total Pipe Cost for Various Population Sizes[1] ($/DU)**		
Dwelling Unit Density (DU/acre)	**Lot Pipe (feet/DU)**	**Added Larger Pipe (feet/DU) for Various Population Sizes**						
		1,000	**10,000**	**100,000**	**$/DU**	**1,000**	**10,000**	**100,000**
2	70	10.5	14	28	$7,000	$10,150	$11,200	$15,400
4	41	6.15	8.2	16.4	$4,100	$5,945	$6,560	$9,020
6	31	4.65	6.2	12.4	$3,100	$4,495	$4,960	$6,820
8	21	3.15	4.2	8.4	$2,100	$3,045	$3,360	$4,620
10	11	1.65	2.2	4.4	$1,100	$1,595	$1,760	$2,420

1) Assumed Unit Cost for Pipe in $/ft:

"Small Pipe"	100
"Large Pipe"	300

Cost of Treatment

The cost of treating stormwater varies widely depending on the local runoff patterns and the nature of the treatment. Cost estimates for combined sewer systems are presented in US EPA (1993) for swirl concentrators, screens, sedimentation, and disinfection. Capital costs results are shown in Figure 10-13 and Table 10-10 and operating and maintenance costs are found in Figure 10-14.

Typically, treatment will be combined with storage in order to dampen peak flows and allow bleeding water from storage to the treatment plant. This treatment-storage approach can be evaluated using continuous simulation and optimization to find the optimal mix of storage and treatment (Nix and Heaney 1988). Ambiguities in such an analysis include the important fact that treatment occurs in storage and storage occurs during treatment for some controls (e.g., sedimentation systems). As shown in Table 10-3, average stormwater flows can exceed dry weather wastewater flows for some lower DU density situations.

In order to provide a planning level estimate of stormwater treatment costs as a function of DU per acre and annual runoff, stormwater treatment is assumed to be comparable in unit cost to primary treatment. The resulting stormwater treatment unit costs in 1998 $ are shown below:

Basic primary treatment:	$0.50/1,000 gallons
Average primary treatment:	$0.75/1,000 gallons
Refined primary treatment:	$1.00/1,000 gallons

These unit treatment costs were multiplied by the estimated quantities of stormwater to get the annual cost per DU. This annual cost is then multiplied by a present worth factor of 10 to provide an estimate of the present value of this cost. The results of this cost estimate for stormwater treatment are shown in Table 10-11 that presents the estimated treatment costs per DU. These results indicate total costs per DU ranging from $129 for high density areas with relatively low runoff to $1,829 for low density developments with high runoff.

Similar analysis can be done for DWF including infiltration. A good first approximation would be to use $1.50 per 1,000 gallons for treatment cost.

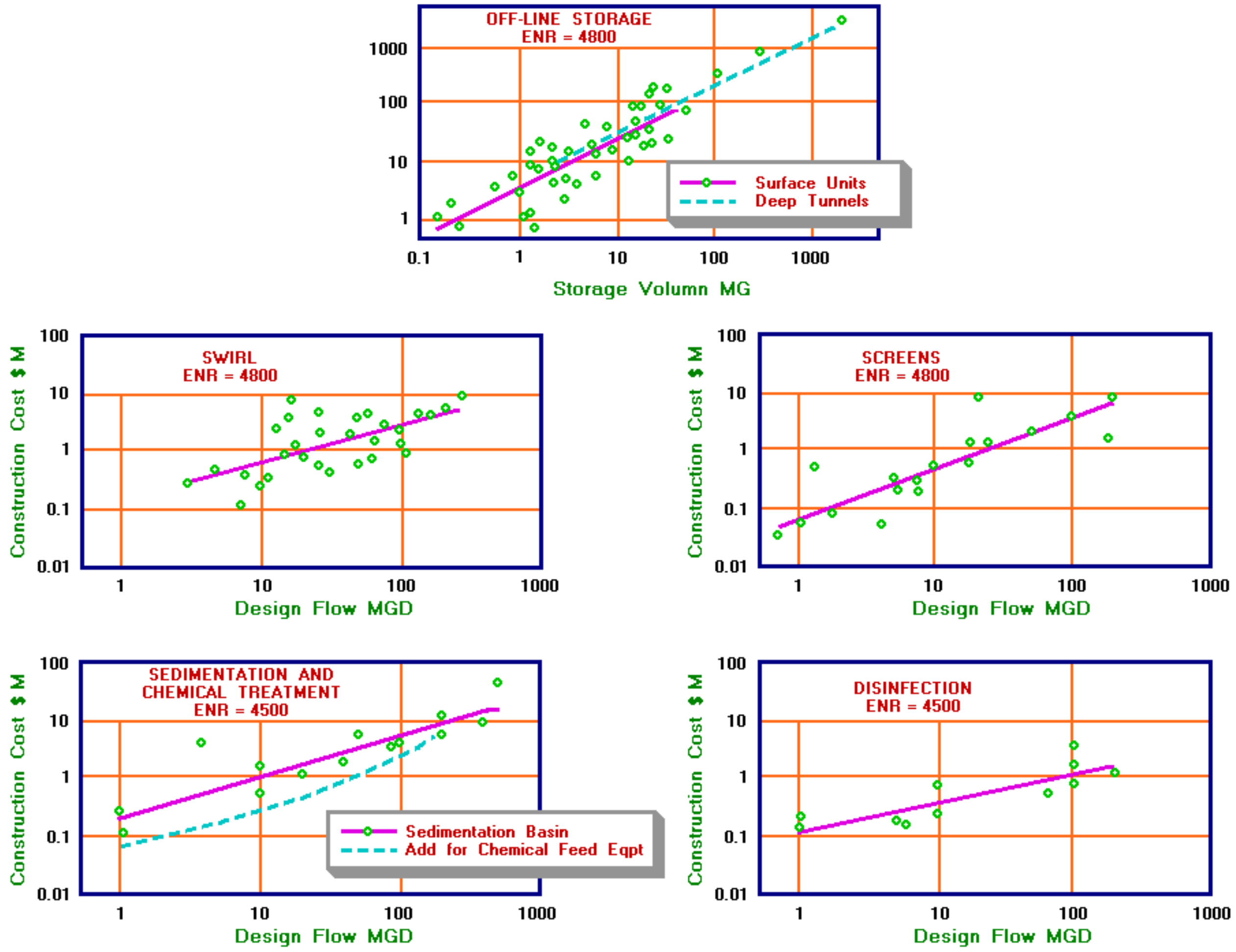

Figure 10-13. Construction costs for CSO controls (US EPA 1993).

Table 10-10. Cost equations for CSO control technology (US EPA 1993).

CSO Control Technology	Cost Equation	Applicable Design Range	ENR Index
Storage basins	$C = 3.637V^{.826}$	$0.15 \leq V \leq 30$ MG	4800
Deep tunnels	$C = 4.982V^{.795}$	$1.8 \leq V \leq 2{,}000$ MG	4800
Swirl concentrators	$C = 0.176V^{.611}$	$3 \leq Q \leq 300$ MGD	4800
Screens	$C = 0.072V^{..843}$	$0.8 \leq Q \leq 200$ MGD	4800
Sedimentation	$C = 0.211V^{.668}$	$1 \leq Q \leq 500$ MGD	4500
Disinfection	$C = 0.121V^{.464}$	$1 \leq Q \leq 200$ MGD	4500

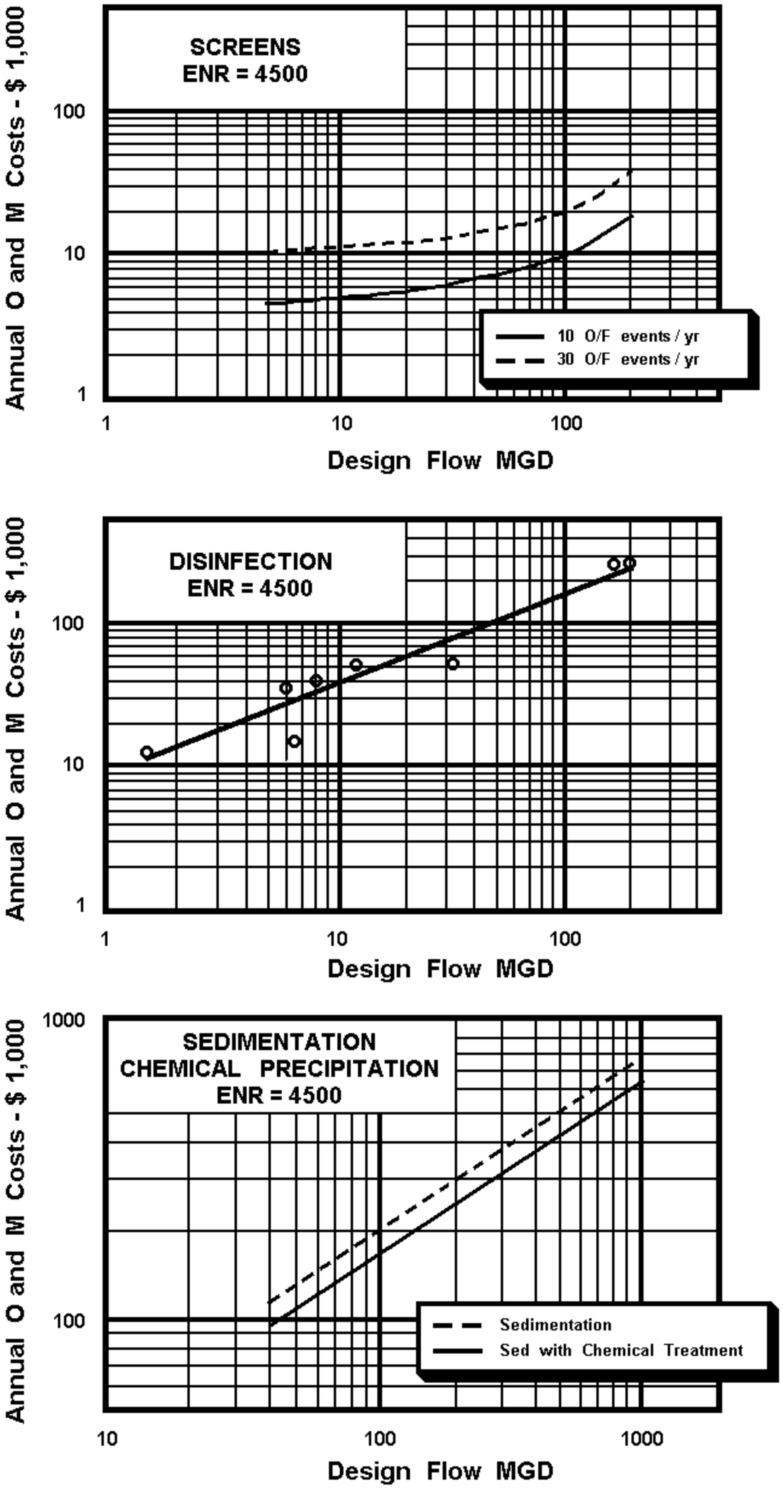

Figure 10-14. Operation and maintenance costs for CSO controls (US EPA, 1993).

Table 10-11. Present (1998) value of cost of treating stormwater runoff.

Runoff from impervious area (inches/yr.):			10	20	30	40
Dwelling Unit Density (DU/acre)	**Indoor Daily Use (gal/DU)**	**Impervious Surface (sq. ft/DU)**	**Present Value of Costs ($/DU)**			
2	180	9,780	457	914	1,372	1,829
4	180	4,690	219	439	658	877
6	180	3,760	176	352	527	703
8	180	3,445	161	322	483	644
10	180	2,756	129	258	387	515

Table 10-12. Estimated (1998) storage cost per dwelling unit[1].

Dwelling Unit Density (DU/acre)	Impervious Surface (sq. ft/DU)	Present Value of Cost ($/DU)
2	9,780	3,048
4	4,690	1,462
6	3,760	1,172
8	3,445	1,074
10	2,756	859

1) Runoff required to be stored in inches: 0.5

Cost of Storage

The total 1995 construction cost of a ground level prestressed concrete tank as a function of its volume is shown in Figure 10-15. The average unit cost ranges from $1.00/gal. for a 250,000 gallon tank to about $.25/gal. for a 10 million gallon tank.

Inspection of the cost curve indicates stronger economies of scale up to the two million gallon size. The economies of scale factor for the portion of the curve up to two million gallons in 0.51. The economies of scale factor above two million gallons is only 0.81, while the average economies of scale factor is 0.62. The estimated cost of storage for one million gallon systems using the equations in Table 10-7 indicates storage costs ranging from about $.06/gal. for earthen basins to $.90/gal. for a covered concrete storage tank.

The costs of storage reported by US EPA for CSO control projects indicate much higher unit costs as was shown in Figure 10-13. For a one million gallon facility, the unit costs range from about $4/gal. to $6/gal. in 1998 $. Recent estimates for CSO storage costs in New York City are about $9/gal. The cost of land has a major impact on the cost of storage. The reported unit costs vary from excluding land costs to valuing land at its full market value.

A preliminary estimate of the potential cost of storage per dwelling unit can be obtained using a common stormwater detention rule to store and treat the first one half inch of runoff. For the purpose of this exercise, a unit storage cost of $1.00 per gallon was used and the runoff is calculated as the runoff from the impervious area. The results are shown in Table 10-12. If on-site detention systems are used, then the cost of storage per dwelling unit ranges from $859 for 10 DU/acre to $3,048 for 2 DU/acre.

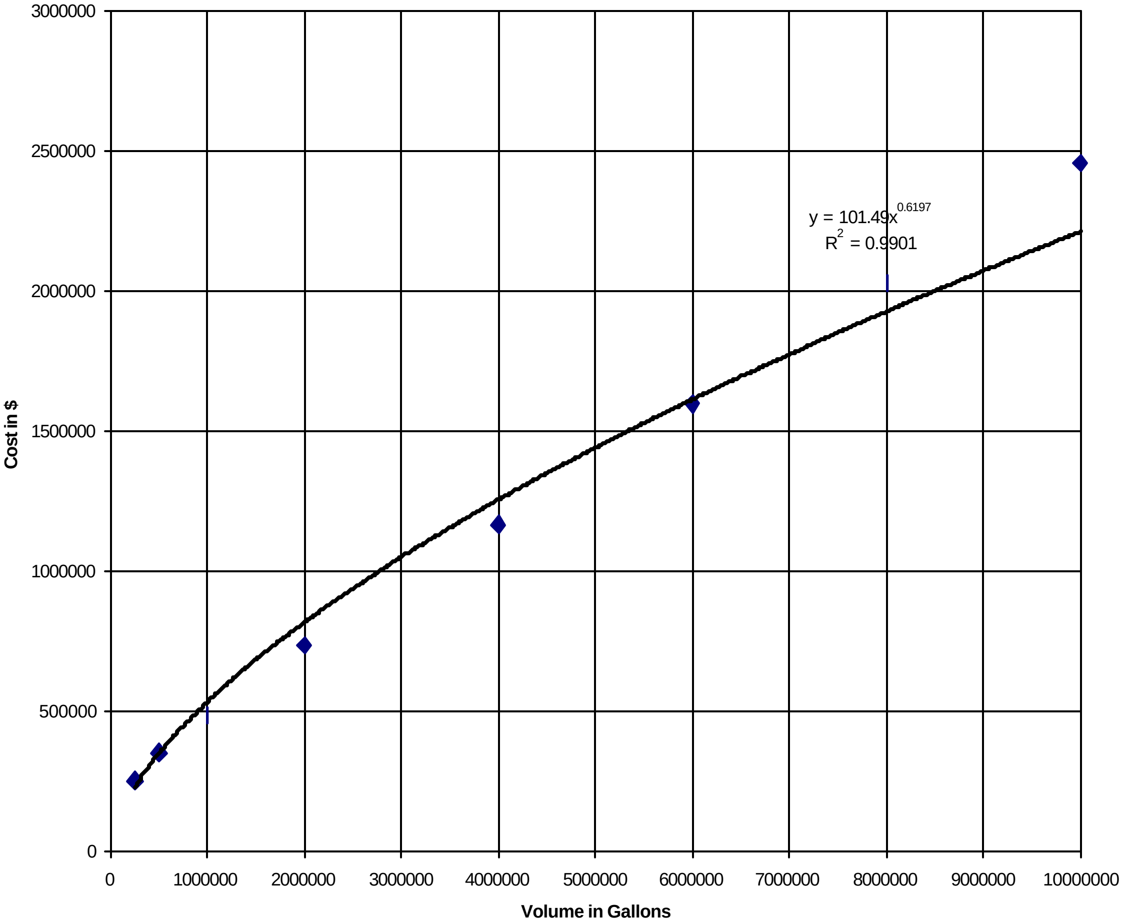

Figure 10-15. Cost of a ground level prestressed concrete storage tank in 1995 as a function of volume.

Summary of Costs for Urban Stormwater Systems

The variability in the cost per DU for urban water supply is mainly due to the amount of lawn to be watered and the need for irrigation water. In more arid parts of the U.S., most of the water entering cities is used for lawn watering. The major factor affecting the variability in wastewater treatment costs is the amount of I/I. The required lengths of pipe for water supply and wastewater systems can be approximated based on DU and ratios of the off-site pipe lengths to the on-site pipe lengths. Piping lengths per DU increase if central systems are used because of the longer collection system distances.

The costs of stormwater systems per dwelling unit vary widely as a function of the impervious area per DU and the precipitation in the area. The required stormwater pipe length per DU is about equal to sanitary sewer lengths for higher density areas in wetter climates. At the other extreme, very little use is made of storm sewers in arid areas and runoff is routed down the streets to local outlets. Also, tradeoffs exist between pipe size and the amount of storage provided. Consequently, generalizing the expected total cost of stormwater systems is difficult. The following conclusions can be reached for stormwater systems:

1. Urban sprawl has greatly increased the cost per DU for stormwater because of the large increase in impervious area per dwelling unit. Early in the 20th century, DU densities of 8-10 per acre were common. The associated impervious area per DU was about 3,000 square feet. With contemporary low density development in the range of two to four DU/acre, the square feet per DU is about 7,500. Thus, the volume of runoff per DU has increased dramatically.

2. If detention systems are needed, then storage costs per DU range from about $850 for 10 DU/acre to over $3,000 per DU for 2 DU/acre.

3. If stormwater receives primary treatment, then the costs range from $129/DU to $1,829/DU depending on runoff and DU density.

4. For wetter, higher density areas, stormwater piping costs range from $1,100/DU to $15,400/DU depending upon density and population size.

5. The development of neighborhood stormwater management systems with potential for reusing some of this water for non-potable purposes should be explored.

Financing Methods

Stable funding is an essential ingredient in developing and maintaining viable urban water organizations, whether they are stormwater utilities, watershed organizations, or some other organizational form. Integrated management offers the promise of improved economic efficiency and other benefits from combining multiple purposes and stakeholders. However, the benefits from integrated watershed management exacerbate problems of financing these more complex organizations because ways must be found to assess a “fair share” of the cost of this operation to each stakeholder (Heaney 1997). Nelson (1995) provides a current overview of utility financing in the water, wastewater, and storm water areas.

The main financing methods for urban stormwater systems are (Debo and Reese, 1995):

1. Tax funded systems
2. Service charge funded systems
3. Exactions and impact fee funded systems
4. Special assessment districts

Urban stormwater utilities have been a successful way to fund wet weather flow pollution control systems (Benson 1992, Reese 1996). Roesner, Mack, and Howard (1996) describe a wet weather flow master plan that formulates an integrated way to finance necessary stormwater infrastructure for a new development near Orlando, FL. Henkin and Mayer (1996) describe how EPA’s Environmental Financial Advisory Board (EFAB) and Environmental Financing Information Network (EFIN) can be used to create a financing strategy for implementing comprehensive conservation and management.

One of the most promising financing alternatives for wet weather flow infrastructure needs has been the development of a stormwater utility that can assess user fees (Ferris 1992, Reese 1996, and Benson 1992). A good overview of stormwater utility financing is provided in Debo and Reese (1995). Collins (1996) describes the formation of a county-wide stormwater utility in Sarasota, FL. EPA used this county as its first stormwater NPDES permit in the state.

Pasquel et al. (1996) describe the multifaceted funding mechanisms used by Prince William County, VA to fund the county’s watershed management program. The sources include a stormwater management fee based upon density and area of impervious surface, and development impact fees. The authors include a detailed discussion of the major components of the fee structure. Nelson (1995) describes alternative methods for calculating system development charges for a stormwater utility. Most systems use a combination of these methods. The following sections briefly describe the fundamentals of financing such systems.

Tax Funded System

Usually, the Public Works Department of a city is charged with maintaining and improving stormwater systems. Projects are funded through the budget of the department, whose source is mainly property tax revenue. However, if property taxes are used, then the stormwater system must compete for funds directly with public safety, schools, and other popular programs.

Service Charge Funded System

The service charge funded system uses an algorithm that divides the budget for the stormwater system by some weighting of the demand for service, (e.g., impervious areas possibly with some reduction if the area is not directly connected). This new funding method is being implemented because it has the advantage of separating the funding needs according to the function on a user pays basis. Example fees/month per acre of impervious surface from cities across the nation are shown in Figure 10-16 (Debo and Reese 1995). Debo and Reese (1995) suggest the following monthly cost ranges per residential customer for various levels of service:

1. $1.25-$2.00 for an incidental program
2. $2.50-$4.25 for a minimum level program
3. $3.33-$6.00 for a moderate level program
4. $6.00-$12.00 for an advanced level program
5. >$16.00 for an exception level program

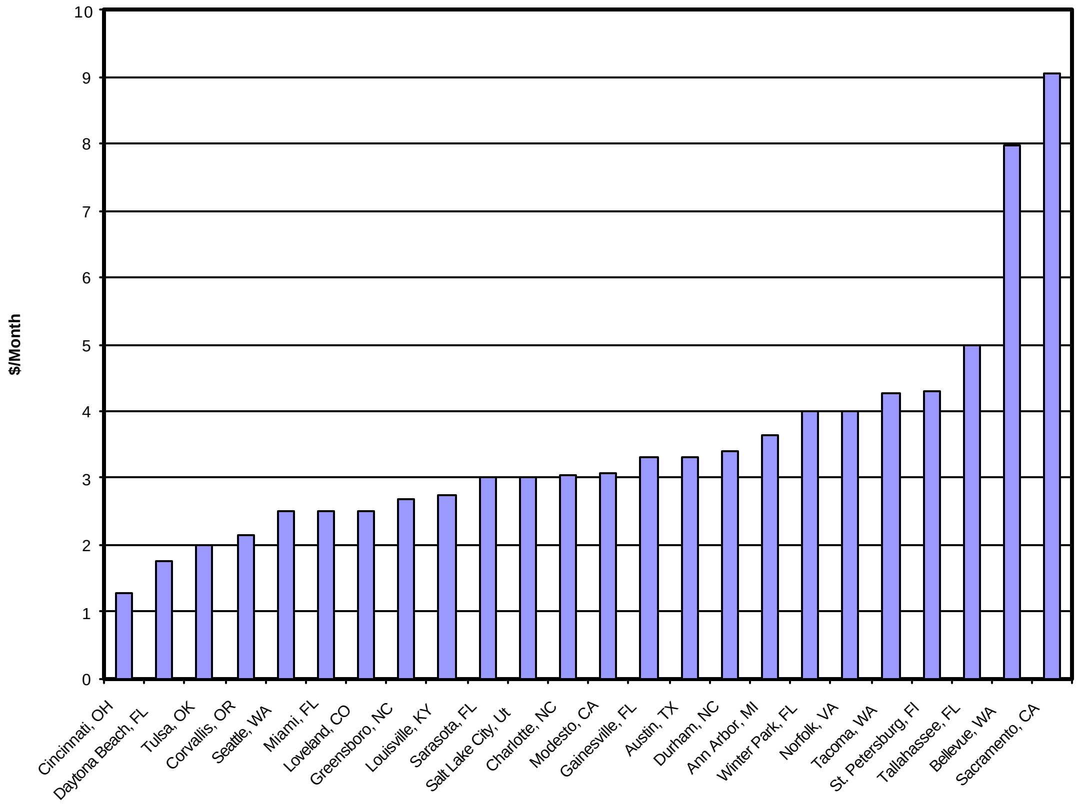

Figure 10-16. Monthly stormwater management fees (adapted from Debo and Reese 1995).

Exactions and Impact Fees

System development charges (SDC's) have emerged as the way to calculate the charges to be levied against new developments. This system charges the developer or builder an up-front fee that represents his equity buy-in to the stormwater system. Usually this fee is calculated as a measure of the depreciated value of the system, plus system-wide funding needs minus the existing users' share. The fee must be reasonable to avoid court challenges. Nelson (1995) defines the rational nexus test of reasonableness of SDCs. This tests requires:

- A connection be established between new development and the new or expanded facilities required to accommodate such development. This establishes the rational basis of public policy.
- Identification of the cost of those new or expanded facilities needed to accommodate new development.
- Appropriate apportionment of that cost to new development in relation to benefits it reasonably receives.

Care must be taken where new development results in an increase in the level of service for existing users. An important feature of this method is the ownership, or equity issue, of existing users. Usually existing users are grouped into one class for ease of calculation, however, in actuality, different groups joined at different points in time. At the time of joining, some contractual agreement (written or unwritten) was initiated. Keeping track of these agreements over time and space when setting impact fees is extremely difficult and, if not carefully done, is a key weakness of the impact fee system. Because of this added database need, and the wide variation in cost allocation methods for apportioning costs, there can be wide fluctuations in impact fee calculations. These shortcomings can be overcome, however, with better accounting and tracking of information.

Special Assessment Districts

This system funds needs within a designated geographic area by dividing the funds, usually equally, among the parcels within the area. Special assessment districts have a unique advantage in that they can follow watershed or basin boundaries. The calculation methods are inherently simple and, usually, the benefits and costs are roughly equally distributed. The disadvantage to this method is that, usually, unless a flooding disaster has occurred recently, the prospects for passage of such a district are usually very slim.

Conclusions on Finance

A variety of ways of financing stormwater management systems are available. They can enable a community to manage both the traditional flooding and drainage problem and also address issues of stormwater quality.

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