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Costs of Urban Stormwater Control

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Foreword

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Abstract

This report presents information on the cost of stormwater pollution control facilities in urban areas, including collection, control, and treatment systems. Information on prior cost studies of control technologies and cost estimating models used in these studies was collected, reviewed, and evaluated. The collection phase involved identifying, screening, and consolidating publications associated with capital costs of stormwater conveyance systems and control technologies. The resulting data were evaluated to develop a critical review of costs for urban stormwater control technologies, including identification of cost information gaps and research needs.

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Chapter 1

Introduction

The purpose of this report is to provide information on the cost of stormwater quantity and quality control facilities. Information on prior cost studies of control technologies and the cost estimating models used in these studies was collected, reviewed, and evaluated as part of this effort. The collection phase involved identifying, screening, and consolidating published literature, papers, reports, etc. associated with capital costs, operation and maintenance costs, performance, and effectiveness of stormwater control technologies. The resulting data were evaluated to develop a preliminary critical review of stormwater control technologies. This review discusses cost-effectiveness, delineates technology gaps, and develops a list of research needs in these areas. The prototype cost model is presented as a spreadsheet model.

Chapter 2

Cost Estimation Methods

2.1 Forms of the Cost Equations

2.1.1 Single explanatory variable

The traditional way to present summary results of cost estimation data is to approximate the cost with a single variable power function shown in equation 2.1. This power function is linear in the log transform. Thus, the data should plot as a straight line on log-log paper. The two parameters (α_0 and α_1) can be estimated from the log-log graph or found using linear regression on the log-transformed data. Contemporary spreadsheets such as Excel fit the function automatically.

$$C = \alpha_0 x^{\alpha_1} \tag{2-1}$$

where

C = cost, $

α_0 = site specific coefficient, e.g., location and land use

x = independent variable, i.e., some measure of component size

The exponent, α_1, represents the economies of scale factor. If α_1 is less than 1.0, then unit costs decrease as size increases. A generic economies of scale factor that has been used for years is α_1 = 0.6 (Peters and Timmerhaus, 1980). When α_1 = 1, the power function simplifies to a linear relationship and no economies of scale are present. If $\alpha_1 > 1$, then diseconomies of scale are evident.

A key reason for the popularity of the power function approximation was that it was an efficient way to replace a database with a single equation. This feature was very important before the widespread use of computers. The negative side of this simple approximation is that the fit may not be that accurate. Cost is seldom a function of only one explanatory variable.

2.1.2 Multiple explanatory variables

The cost estimation problem can be expressed in a general form as:

$$C = f(x_1, x_2, \ldots x_i, \ldots x_n) \tag{2-2}$$

where

C = cost, $

x_i = independent variable that is a measure of component size

If a database of historical cost estimates as a function of n explanatory variables is available, then an approximating equation can be developed using a variety of multiple regression approaches. The most popular form of the estimating equation is simply to use multiple linear regression. However, the relationship of cost to several explanatory variables is seldom this simple.

Below is a review of historical cost relationships for materials of interest to this analysis. These sections illustrate the development of functional forms to match the cost data at the time, and the general development of cost estimation techniques. However, no attempt has been made to update these equations to the present because the results are 20-30 yr. old, and many of the key assumptions and limitations are not presented. All of the regression models presented here assume that the independent variable is exact, i.e., that all the error is in the independent variable, and that the error follows a normal distribution.

2.2 Pipe Costs

Dajani et al. (1972) estimated wastewater collection network costs by fitting regression models to data from actual construction bids. The following functional form was assumed:

$$C = a + bD^2 + cX^2 \tag{2-3}$$

Where

C = construction cost, \$
D = pipe diameter, ft
X = average depth of excavation, ft

Merritt and Bogan (1973) used a graphical relationship to estimate pipe construction cost as a function of diameter and invert depth. No database accompanied this graph. Grigg and O'Hearn (1976) present storm drainage pipe costs as a function of pipe diameter based on data for Englewood, CO. Tyteca (1976) presents cost functions for wastewater conveyance systems. For pipe systems, he uses functions of the following form:

$$C/L = K + aD^b \tag{2-4}$$

Where

C = total capital cost, \$
L = length of pipe, m
K = fixed cost, \$
D = diameter, m
a, b = parameters

According to Tyteca, values of b range from 1.2 to 1.5. For the Belgium case studied by Tyteca (1976), he developed three cost functions depending on whether the terrain is "meadows," "river banks," or a "river in urban area." A positive fixed cost was included in. each of these three equations and b ranged from 1.0 to 1.68. These regression equations have little transferability in space or time.

Han, Rao, and Houck (1980) estimated storm drainage costs as part of an optimization model they developed. They used the following equations for estimating storm sewer pipe costs:

For $H \leq 20, D \leq 36$ $$C = 1.93D + 1.688H - 12.6 \quad \textbf{(2-5)}$$

For $H > 20, D \leq 36$ $$C = .692D + 2.14H + .559DH - 13.56 \quad \textbf{(2-6)}$$

For $D > 36$ $$C = 3.638D + 5.17H - 111.72 \quad \textbf{(2-7)}$$

Where

C = installation cost of the pipe, 1980 \$/ft
D = diameter, in.
H = invert depth, ft

The U.S. Army Corps of Engineers (1979) MAPS software was the first to use a process engineering oriented approach for estimating the cost of water resources infrastructure. For gravity pipes, MAPS estimated the cost as follows:

The required input is as follows:

- Flow (maximum and minimum), MGD
- Length, ft
- Initial elevation, ft
- Final elevation, ft
- Terrain multipliers
- Design life (default = 50 yr)
- Manning's *n* (default = 0.015)
- Number and depth of drop manholes
- Rock excavation, % of total excavation
- Depth of cover, ft (default = 5 ft)
- Dry or wet soil conditions
- Cost overrides

The average annual cost is calculated as:

$$AAC = AMR + TOTOM \quad \textbf{(2-8)}$$

Where

AAC = average annual cost, \$/yr
AMR = amortized capital cost, \$/yr
$TOTOM$ = annual O&M cost, \$/yr

The amortized capital cost is:

$$AMR = CRF * PW \quad \textbf{(2-9)}$$

Where

CRF = capital recovery factor
PW = capital cost, $

The capital costs are estimated as

$$PW = CC + OVH + PLAND \tag{2-10}$$

Where

CC = construction costs, $
OVH = overhead costs, $
PLAND = land costs, $

Overhead costs are estimated as

$$OVH = 0.25 * CC \tag{2-11}$$

$$CC = AVC * WETFAC * DEPFAC * XLEN * SECI * CITY * CULT * \frac{(1 + Rock * 2)}{255.6} \tag{2-12}$$

Where

AVC = unit cost of pipe for average conditions, $/ft
WETFAC = wetness factor
= 1.2 for wet soil
= 1.0 for average soil
= 0.8 for dry soil

DEPFAC = depth of cover factor

$$= 0.725 + 0.048 * DEPTH \tag{2-13}$$

DEPTH = depth of cover, ft
XLEN = length of pipe, ft
SECI = EPA sewer index (1957-59 = 100)
CITY = city multiplier
CULT = terrain multiplier
Rock = rock excavation percent of total excavation, in decimal form

The EPA sewer index is no longer available. The Engineering News-Record (ENR) Construction Cost Index has been used in this report. The terrain multiplier is calculated as:

$$CULT = \frac{(C1 * 0.8131 + C2 * 0.6033 + C3 * 0.6985 + C4 * 0.7169 + C5 * 0.7911 + C6 * 1.3127)}{100} \tag{2-14}$$

Where

$C1$ = % open country
$C2$ = % new residential
$C3$ = % sparse residential
$C4$ = % dense residential
$C5$ = % commercial
$C6$ = % central city

The MAPS formulation is an interesting blend of regression equations and cost factors. Unfortunately, the database for the regression equations such as for estimating terrain effects was never presented. Thus, the user must take these equations at face value.

Moss and Jankiewicz (1982) promote the use of life cycle costing to determine the best type of storm sewer pipe to buy. For their case study of Winchester, Virginia, three types of sewers were being considered: reinforced concrete (service life = 75 year), aluminum coated steel (service life = 25 year), and asphalt-coated galvanized steel (service life = 20 year). As the authors point out, service life is difficult to estimate. It depends on material durability, in-place structural durability, abrasive characteristics of the drainage, and corrosive characteristics of both ground water and drainage. In the case of different service lives, the comparison should be done using a least common multiple of years, 300 yr in this case. Thus, the present worth is calculated by comparing the cost of the original installation and three replacements for the steel pipe, 11 replacements for the aluminum steel pipe, and 14 replacements for the galvanized steel pipe. The salvage value for each replacement should be included. Alternatively, the equivalent uniform annual cost of each option could be determined with the lowest annual cost used as the decision criterion.

2.3 Manholes

For individual manholes, Han, Rao, and Houck (1980) used the following equation:

$$C_m = 259.4 + 56.4h \tag{2-15}$$

Where

C_m = manhole cost, 1980 \$
h = depth of manhole, ft

Dames and Moore (1978) estimate manhole costs indirectly as 36 to 38% of the total in-place pipe cost.

2.4 Other Sewer Pipe Related Costs

Dames and Moore (1978) present estimates of added costs associated with sanitary sewer pipes. Their results are shown in Table 2-1. The above results indicate the vital importance of site-specific cost data since the total additional cost is over 100%.

Table 2-1. Average Non-Pipe Costs as Percent of Total In-Place Pipe Costs for Sanitary Sewers (Dames and Moore, 1978)

Category	Pipe Cost (%)
Sanitary sewer miscellaneous appurtenances	7
Manholes	32
Drop manholes	2
Thoroughfare crossings	13
Stream crossings	1
Rock excavation	2
Pavement removal and replacement	13
Special bedding	1
Miscellaneous costs not categorized	28
Utility reconnection and removal	1
Total	100

2.5 Storage Costs

Storage is used to detain or retain peak stormwater flows for later release at a slower rate. Storage can improve or degrade downstream water quality, depending upon how it is operated. Stahre and Urbonas (1993) present a detailed evaluation of urban stormwater storage systems. Nix and Heaney (1988) show how to find the optimal mix of storage and release or treatment rate.

Storage costs depend heavily upon land costs. Land costs range from zero, if the land is assumed part of an easement or “donated” by the developer, to “full costs,” based on the highest alternative use of the land. A summary of selected storage cost estimation equations is presented in Table 2-2.

Inspection of the storage estimating equations reveals that the economies of scale factor ranges from a low of 0.40 for large reservoirs to a high of 0.83 for a combined sewer overflow (CSO) storage basin. In addition, earthen basins cost less than 10% of the cost of the same size concrete basin.

2.6 Multipurpose Facilities

The cost of storm drainage systems is affected by other purposes that the system serves. For example, a combined sewer system provides the dual purposes of transporting both wastewater and stormwater. Storm drainage systems provide local flood control but may exacerbate water quality problems and degrade downstream receiving waters.

Stormwater detention systems may serve as both quantity and quality controls. Streets serve as traffic conduits and transport stormwater. An acceptable way to apportion the costs of a multipurpose facility to individual purposes is to design systems for each purpose independently, and then design the multipurpose system. The go-it-alone costs and the costs for the multipurpose facility are prorated to determine the apportioned costs (Heaney, 1997).

Table 2-2. Estimated Capital Cost of Storage as a Function of Volume

Type	Equation	*C* ($ Units)	*V* (Range)	*V* (Units)	Year	Reference
Reservoir	$C = 160V^{0.4}$	1,000	$10^4 - 10^6$	Acre-ft	1980	1
Covered concrete tank	$C = 614V^{0.81}$	1,000	1 –10	Mgal	1976	2
Concrete tank	$C = 532V^{0.61}$	1,000	1–10	Mgal	1976	2
Earthen basin	$C = 42V^{0.61}$	1,000	1–10	Mgal	1976	2
Clear well, below ground	$C = 495V^{0.61}$	1,000	1–10	Mgal	1980	2
Clear well, ground level	$C = 275V^{0.61}$	1,000	0.01–10	Mgal	1980	2
CSO storage basin	$C = 3637V^{0.83}$	1,000	0.15–30	Mgal	1993	2
CSO deep tunnel	$C = 4982V^{0.80}$	1,000	1.8–2,000	Mgal	1993	3

C = capital cost; *V* = volume
References: [1]U.S. Army Corps of Engineers (1981); [2]Gummerman et al. (1979); [3]U.S. EPA (1993b)

2.7 Integrated Approaches

Rawls and Knapp (1972) gathered data from 70 stormwater systems in the United States and used linear and nonlinear regression analysis to estimate total system costs as a function of the explanatory variables shown below:

- Recurrence interval, yr
- Average ground slope, ft/100 ft
- Runoff coefficient, C
- Number of manholes and inlets
- Smallest pipe size, in.
- Largest pipe size, in.
- Total capacity, ft^3/s
- Total length of lines, ft
- Total drainage area, acre
- Total developed area, acre

This approach is useful for aggregate comparative analysis among cities but the results are quite dated.

Earle and Farrell (1997) recently presented a mathematical model for estimating sanitary sewer costs. They used construction cost data from R.S. Means "Site Work and Landscape Cost Data." The output of their model is an estimate of the average cost per house for the collection system under study. The following factors are used to estimate the final cost per house:

City Cost Index	K1	.85 – 1.12
Bidding Conditions Factor	K2	.95 – 1.05
Hazen Williams "C" Factor	K3	1.0 – 1.04
Restoration Complexity	K4	.85 – 1.25
Location (in or out of right-of-way)	K5	1.0 – 1.05
Soil Conditions (influence of rock)	K6	1.0 – 1.75
Ground Water	K7	1.0 – 1.26

By selecting values of each of the above seven factors (K), the final cost per house is estimated as:

$$C_{final} = C_{base}(K1 * K2 * K3 * K4 * K5 * K6 * K7) \tag{2-16}$$

This approach is a big improvement over the regression approach. The R.S. Means database is a reliable source of current information on sewer costs. The use of factors is a way to incorporate site attributes. The major limitation of this approach is that factor selection remains subjective. For example, the Soil Conditions Factor varies from 1.0 to 1.75. Which value should we choose? The effect of rock depends not only on its presence but also on its location in the pipe network.

2.8 Process-Oriented Approaches

In a process-oriented approach, the cost estimation model is linked directly to a process simulator. In the case of urban stormwater, the cost model can be linked directly to the hydrologic and hydraulic simulators. The only current model we found that incorporates this feature is the HYDRA computer program available as part of the Federal Highway Administration's HYDRAIN program (FHWA 1991). This model only does simple links between pipe costs and an assumed design. Storm sewer optimization is not included.

2.9 Stormwater Cost Optimization

While accurate cost data are essential for cost estimation, the total project cost depends heavily upon the quality of the selected solution. Various optimization techniques for finding the optimal design for a stormwater drainage system have been proposed, but because of the inherent complexity of the problem these classical optimization approaches have had very limited success.

Literature on this subject has been reviewed by Miles and Heaney (1988) who present a spreadsheet-based trial and error approach for solving the problem. A profile view of the vertical alignment of a stormwater drainage system is shown in Figure 2-1 (Miles and Heaney, 1988). The basic tradeoff is that between pipe and excavation costs. The larger the pipe diameter, the shallower the slope that can be used, reducing excavation costs, albeit at the expense of additional pipe costs.

Miles and Heaney (1988) reanalyzed the twenty-pipe problem shown in Figure 2-2. They were able to demonstrate that the spreadsheet method provided a superior solution because it depicted the pipe hydraulics more accurately and used a relatively efficient trial and error procedure. For each trial, the spreadsheet calculates the total cost of the design and checks to see whether the design constraints have been satisfied.

The problem is actually relatively complex. Typically, the drainage network must discharge at a specified elevation at the outfall. For each section, the designer must select from 8 to 10 pipe diameters among a large range of pipe slopes. If 10 pipe diameters and 10 slopes are available at each section, then 100 possible combinations need to be checked. If one starts at the headwaters, then the calculations can proceed relatively easily until this branch intersects another branch. For example, we can design branches 12-32 and 32-42 in Figure 2-2. Similarly, we can design branches 11-22, 22-33, and 33-42. However, the two independently designed branches may result in different invert elevations at node 42. The invert elevation for node 42 affects the cost of the entire downstream pipe network. Thus, we quickly end up with thousands of possible combinations to evaluate. Conventional designers typically evaluate very few options and then stop once they have found a feasible solution.

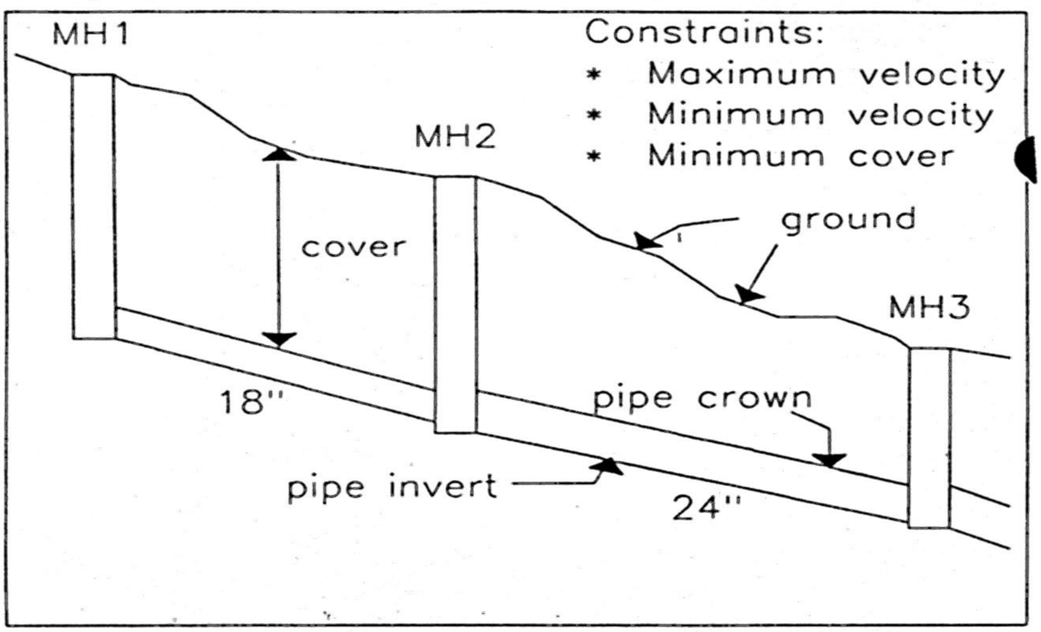


Figure 2-1. Profile view of the vertical alignment of a stormwater system (Miles and Heaney, 1988) (Reproduced with permission of the American Society of Civil Engineers).

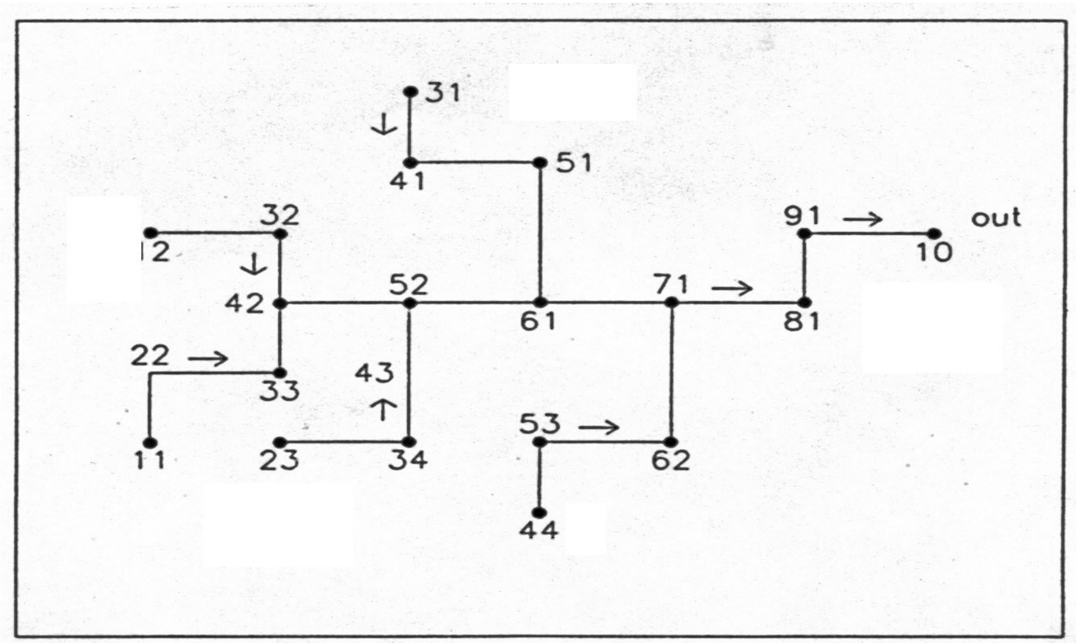


Figure 2-2. Layout of the twenty pipe stormwater problem (Miles and Heaney, 1988) (Reproduced with permission of the American Society of Civil Engineers).

Because existing designs are not optimized, it is difficult to compare them. It is also difficult to do sensitivity analysis because we don't know how good the solutions are. The lack of a systematic way to optimize sewer design is a major impediment for improved cost-effectiveness evaluations. We have developed a new way to do this evaluation using intelligent search techniques (Heaney et al., 1998d).

2.10 Summary and Conclusions

Virtually all cost estimates in the literature are based on the conventional approach of fitting regression equations to cross sectional data on "as-builts." Before the widespread availability of microcomputers, these approaches were the only viable alternative. Unfortunately, even since the advent the personal computer, little research funding has been available to develop the databases necessary for detailed cost estimation procedures. Curve fitting methods are inefficient given the available technology for computerized design calculations. An improved method is to link the cost estimator directly to the hydraulic simulator, and then develop cost estimates relative to the fundamental processes of an urban drainage system.

Chapter 3

Cost Estimates for Stormwater Systems

The goal of this section is to provide the tools and data necessary to accurately estimate the costs of conventional stormwater systems; pipeline installation; excavation; bedding, and manhole installation. Section on open channels, storage, pumps, and paving costs are included as well for future reference

3.1 Stormwater Pipelines

This section describes the cost components of pipeline installation, i.e.:

1. Pipeline Installation: The pipelines themselves, and the material, labor, and equipment necessary for installation.
2. Trench Excavation Costs: The cost of excavating and constructing the trench into which the pipeline is installed. Backfill and rock blasting are included within this category.
3. Bedding Costs: These include the material, labor, and equipment necessary to install a simple compacted bedding system prior to backfilling the trench.

3.1.1 Pipeline installation

The costs of two different types of pipe were tabulated based on the data from RS Means (1996a). All values are updated to 1/99 $ using the ENR index of 6000 for January 1999, and 5584 for July 1995. The costs include fixed operations cost and profit, and the pipe materials, labor, and equipment. Because of the relative cost of the materials, pipes typically chosen for stormwater systems are corrugated metal (CMP), and reinforced concrete (RCP). The RS Means data was chosen for this analysis because of the longevity of this source of data (the user of this spreadsheet can easily swap databases, however).

A plot of the total installed costs (excluding excavation and backfill) vs pipe diameter for the CMP and RCP pipes is shown in Figure 3-1. A nonlinear relationship is readily apparent, and a power function was fit to the data. The resulting equation below is for CMP pipe, using the updated RS Means data:

$$C_p = 0.54D^{1.3024} \tag{3-1}$$

Where

C_p = construction cost, 1/99 $/ft

D = pipe diameter, in.

Although Equation 3.1 has a relatively high correlation coefficient (R^2) of .98, it is not a close fit for larger pipe diameters. A better way to estimate pipe costs is to use a lookup table, which is a standard feature in spreadsheets. Lookup tables are particularly useful for discrete data such as pipe diameters, and avoid the problem of trying to find a single equation that fits well over a wide range of pipe sizes.

The lookup tables for the design model is shown as Tables 3-1 and 3-2 for CMP and RCP pipe, respectively. A major disadvantage of using equations instead of direct cost data can be seen in Figure 3-1. The power function, although providing a good overall fit, can deviate from the actual cost/ft data point significantly, leading to an underestimation of project costs. However, an important advantage is that the equations provide a shorthand method of storing the relationship between costs and capacity. Equations facilitate the economic analytical evaluation of the component under consideration. With the use of a spreadsheet model, however, it becomes less necessary to make simplifying assumptions necessary to make regression fits possible, because simple lookup functions can replace these approximating equations.

Table 3-1. Lookup Table for Corrugated Metal Pipe (updated from RS Means, 1996a)

Diameter (in.)	Cost (1/99 $/ft)
8	9.40
10	11.80
12	14.40
15	18.40
18	20.90
24	30.10
30	37.20
36	54.80
48	81.60
60	118.20
72	179.50

Table 3-2. Lookup Table for Reinforced Concrete Pipe (updated from RS Means, 1996a)

Diameter (in.)	Cost (1/99 $/ft)
12	15.70
15	16.60
18	19.00
21	23.00
24	27.60
27	32.90
30	55.80
36	74.40
42	85.40
48	102.30
60	146.70
72	192.60
84	288.90
96	355.60

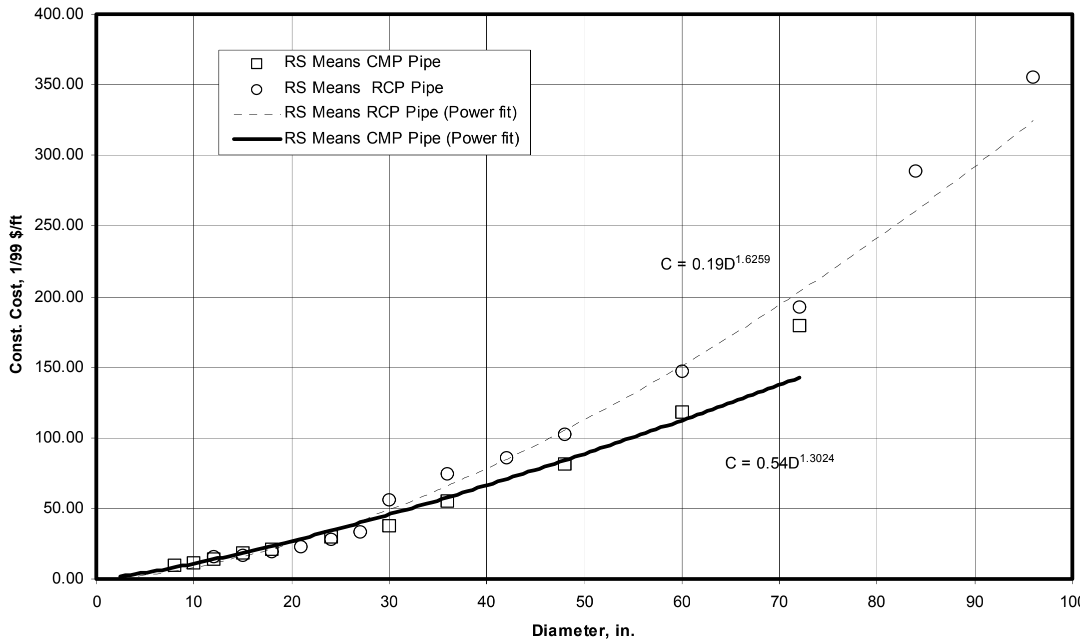


Figure 3-1. Cost of storm drainage pipe.

3.1.2 Trench excavation costs

Various trench excavation cost data were updated from RS Means (1996a) and plotted in Figure 3-2. Included are such fixed operations costs as labor, equipment, and materials costs. Although the excavation costs generally vary with depth and backhoe bucket size (not shown here), there was no statistical relationship that could explain this variation easily. For the purposes of the model, an average of this data was taken, which results an average excavation cost in $\$/yd^3$ for a "moist loam" type of soil. Then, using productivity estimates from RS Means (1996a) for various soils, the excavation costs in Table 3-3 were obtained.

Table 3-3. Trench Excavation Costs, Includes Backfill and Blasting (updated from RS Means, 1996a)

Soil Type	Horizontal	Vertical	Excavation Cost (1/99 $\$/yd^3$)
Clay	1	1	7.09
Moist loam	2	1	5.87
Rock	0	1	86.29
Sand	2	1	6.12
Silt	1.5	1	6.72

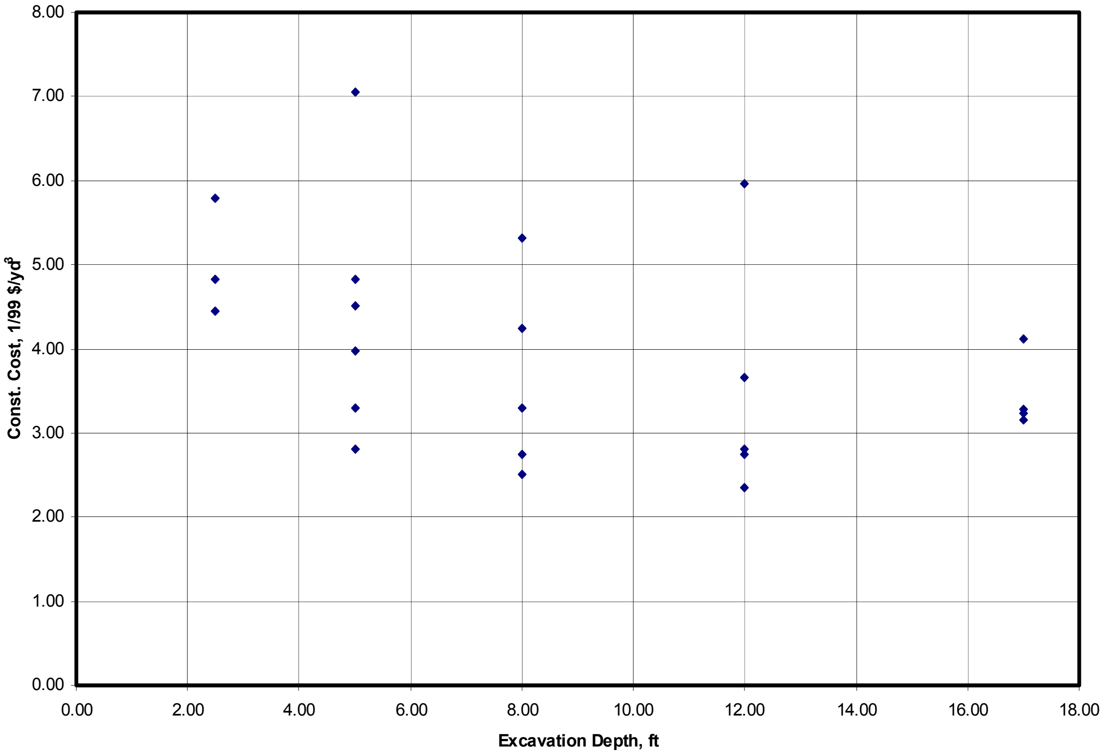


Figure 3-2. Trench excavation costs (Updated from RS Means, 1996a).

3.1.3 Bedding costs

Bedding provides sufficient compacted material necessary to protect the pipe from external loading forces. Bedding costs in the RS Means (1996a) system vary with diameter and side slope of the trench. The bedding material is compacted bank sand filled to 12 in. above the pipe. These costs were updated to 1/99 $ and can be found in Table 3-4. This table relates the horizontal and vertical side slope, the diameter, and the width to bedding costs, which include fixed operations cost and profit. Although several regression relationships were evaluated, it was decided that the most accurate model of these costs would be a two-way lookup table, relating the horizontal:vertical ratio and the pipe diameter to the projected cost.

Table 3-4. Bedding Costs (updated from RS Means, 1996a)

Horizontal	Vertical	H/V	Diameter (in.)	Trench Width (ft)	Cost (1/99 $/ft)
0	1	0	6	1	0.92
0	1	0	8	2	2.00
0	1	0	10	2	2.07
0	1	0	12	2	2.12
0	1	0	14	3	3.47
0	1	0	15	3	3.51
0	1	0	16	3	3.57
0	1	0	18	3	3.62
0	1	0	20	4	5.25
0	1	0	21	4	5.29
0	1	0	24	4	5.44
0	1	0	30	4	5.55
0	1	0	32	6	9.72
0	1	0	36	6	9.98
0	1	0	48	7	13.01
0	1	0	60	8	16.23
0	1	0	72	10	23.39
0	1	0	84	12	31.80
0.5	1	0.5	6	1	1.90
0.5	1	0.5	8	2	3.16
0.5	1	0.5	10	2	3.43
0.5	1	0.5	12	2	3.67
0.5	1	0.5	14	3	5.25
0.5	1	0.5	15	3	5.39
0.5	1	0.5	16	3	5.55
0.5	1	0.5	18	3	5.88
0.5	1	0.5	20	4	7.77
0.5	1	0.5	21	4	7.95
0.5	1	0.5	24	4	8.52
0.5	1	0.5	30	4	9.56
0.5	1	0.5	32	6	14.06
0.5	1	0.5	36	6	15.08
0.5	1	0.5	48	7	20.58
0.5	1	0.5	60	8	26.81
0.5	1	0.5	72	10	37.47
0.5	1	0.5	84	12	49.71
1	1	1	6	1	2.90
1	1	1	8	2	4.36
1	1	1	10	2	4.77
1	1	1	12	2	5.25
1	1	1	14	3	7.06
1	1	1	15	3	7.30
1	1	1	16	3	7.56
1	1	1	18	3	8.14
1	1	1	20	4	10.28
1	1	1	21	4	10.59
1	1	1	24	4	11.61
1	1	1	30	4	13.50
1	1	1	32	6	18.46
1	1	1	36	6	20.17
1	1	1	48	7	28.17
1	1	1	60	8	37.40
1	1	1	72	10	51.76
1	1	1	84	12	67.70
1.5	1	1.5	6	1	3.91
1.5	1	1.5	8	2	5.69
1.5	1	1.5	10	2	6.15
1.5	1	1.5	12	2	6.81
1.5	1	1.5	14	3	8.83

Horizontal	Vertical	H/V	Diameter (in.)	Trench Width (ft)	Cost (1/99 $/ft)
1.5	1	1.5	15	3	9.18
1.5	1	1.5	16	3	9.56
1.5	1	1.5	18	3	10.38
1.5	1	1.5	20	4	12.80
1.5	1	1.5	21	4	13.24
1.5	1	1.5	24	4	14.63
1.5	1	1.5	30	4	17.64
1.5	1	1.5	32	6	22.77
1.5	1	1.5	36	6	25.23
1.5	1	1.5	48	7	35.76
1.5	1	1.5	60	8	48.21
1.5	1	1.5	72	10	65.65
1.5	1	1.5	60	8	48.21
1.5	1	1.5	72	10	65.65
1.5	1	1.5	84	12	86.16
2	1	2	6	1	5.01
2	1	2	8	2	6.73
2	1	2	10	2	7.49
2	1	2	12	2	8.37
2	1	2	14	3	10.59
2	1	2	15	3	11.04
2	1	2	16	3	11.54
2	1	2	18	3	12.66
2	1	2	20	4	15.32
2	1	2	21	4	15.89
2	1	2	24	4	17.71
2	1	2	31	4	21.61
2	1	2	32	6	27.15
2	1	2	36	6	30.22
2	1	2	48	7	43.22
2	1	2	60	8	58.67
2	1	2	72	10	79.32
2	1	2	84	12	103.94

3.2 Manholes

Manhole cost data, updated from RS Means (1996a), are tabulated in Table 3-5. The costs include fixed operations cost and profit, and labor, equipment, and materials costs for installation of precast concrete manholes. A plot of this data can be found in Figure 3-3. A power relationship was plotted and the following equation obtained:

$$C_{mh} = 482H^{0.9317} \tag{3-2}$$

Where

C_{mh} = cost of manhole, 1/99 $

H = height of manhole, ft (maximum difference between the ground elevation and the invert elevations of sewers entering the manhole)

In general, the fit of the power equation was good, particularly at the lower heights. Some inaccuracies are introduced due to the regression relationship, however this is mitigated by the desire within the system model for a continuous function providing cost as a function of *H*. An alternative method is to use a lookup table and interpolate between the values of Table 3-5.

Table 3-5. Precast Concrete Manholes Costs (updated from RS Means, 1996a)

Riser Internal Diameter (ft)	Depth (ft)	Cost (1/99 $/ft)
4	4	1,860
4	6	2,460
4	8	3,250
4	10	3,970
4	12	4,830
4	14	6,060
5	4	2,310
5	6	3,120
5	8	3,970
5	10	5,070
5	12	6,260
5	14	7,600
6	4	3,150
6	6	4,070
6	8	5,340
6	10	6,710
6	12	8,350
6	14	9,990

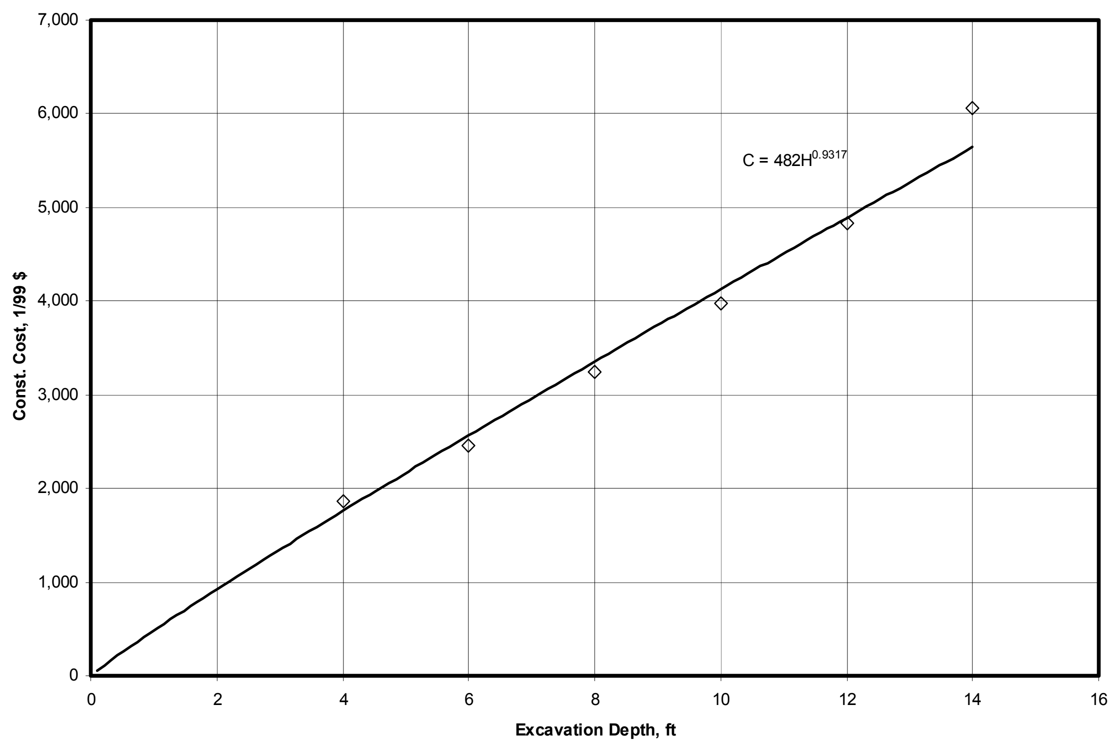


Figure 3-3. Manhole costs, as a function of excavation depth.

3.3 Open Channels

The cost of open channels needs to be estimated on a case by case basis since cut and fill calculations are required. Excavation costs are an important component of the construction of an open channel. MAPS (US Army Corps of Engineers, 1979) provides a general template for doing these calculations. The data presented in Table 3-3 on excavation costs may assist in this effort.

3.4 Pump Stations

Two different sized sewage pump stations are available in the RS Means database, as shown in Table 3-6. The costs include fixed operations cost and profit, and labor, equipment, and materials costs. An alternative method for calculating a pump station cost would be to develop a generic design of the structure that would be scaled based upon capacity and head, and include the appropriate pump costs. This work is beyond the scope of this effort.

Table 3-6. Capital Costs of Sewage Pump Stations (updated from RS Means, 1996a)

Description	Flow Rate (gpm)	Cost (1/99 $)
Sewage Pump Station	200	59,000.00
Sewage Pump Station	1000	112,000.00

3.5 Pavement and Creation of Impervious Surfaces

Fairly good data are available on the cost of various types of pavement, including porous pavement. Table 3-7 lists the main activities associated with paving and creation of impervious areas within developments. The costs include fixed operations cost and profit, and labor, equipment, and materials costs. An example of the use of this data is the following: Using a 32 ft wide subdivision street, with 6 in. crushed stone base material of 1½ in. in diameter, a primer, and a wearing course of 1½ in. of asphaltic concrete pavement, and curb and gutter (both sides) sums to a total of $58.80 per linear foot of pavement. This is shown below:

Base course: $$5.85\ \frac{\$}{yd^2} * \frac{yd^2}{9\,ft^2} * 32\,ft = 20.80\ \$/ft \tag{3-3}$$

Prime: $$2\frac{gal}{yd^2} * 1.82\frac{\$}{gal} * \frac{yd^2}{9\,ft^2} * 32\,ft = 12.94\ \$/ft \tag{3-4}$$

Paving: $$3.14\frac{\$}{yd^2} * \frac{yd^2}{9\,ft^2} * 32\,ft = 11.16\ \$/ft \tag{3-5}$$

Curb: $$6.95\ \$/ft * 2 = 13.90\ \$/ft \tag{3-6}$$

Total per linear ft: $$\$20.80 + \$12.94 + \$11.16 + \$13.90 = \$58.80 \tag{3-7}$$

Table 3-7. Paving Costs (updated from RS Means, 1996a)

Activity	Material	Diameter (in.)	Unit	Depth (in.)	Cost (1/99 $)
Prepare and Roll Subbase >2500 yd^2			yd^2		0.88
Base Course	Crushed Stone	0.75	yd^2	3	3.39
Base Course	Crushed Stone		yd^2	6	6.07
Base Course	Crushed Stone		yd^2	9	8.92
Base Course	Crushed Stone		yd^2	12	11.49
Base Course	Crushed Stone	1.5	yd^2	4	3.52
Base Course	Crushed Stone		yd^2	6	5.85
Base Course	Crushed Stone		yd^2	8	7.82
Base Course	Crushed Stone		yd^2	12	12.36
Base Course	Bank run gravel		yd^2	6	2.63
Base Course	Bank run gravel		yd^2	9	3.22
Base Course	Bank run gravel		yd^2	12	5.10
Base Course	Bituminous concrete		yd^2	4	8.37
Base Course	Bituminous concrete		yd^2	6	12.04
Base Course	Bituminous concrete		yd^2	8	15.86
Base Course	Bituminous concrete		yd^2	10	19.58
Prime and seal			gal		1.82
Asphaltic Concrete Pavement	Binder Course		yd^2	1.5	3.14
Asphaltic Concrete Pavement	Binder Course		yd^2	2	4.09
Asphaltic Concrete Pavement	Binder Course		yd^2	3	5.91
Asphaltic Concrete Pavement	Binder Course		yd^2	4	7.77
Asphaltic Concrete Pavement	Wearing Course		yd^2	1	2.31
Asphaltic Concrete Pavement	Wearing Course		yd^2	1.5	3.44
Asphaltic Concrete Pavement	Wearing Course		yd^2	2	4.52
Asphaltic Concrete Pavement	Wearing Course		yd^2	2 .5	5.47
Asphaltic Concrete Pavement	Wearing Course		yd^2	3	6.51
Curb and Gutter, machine formed	Concrete	24	LF		6.95

Note: gal = gallon; yd^2 = square yards; LF = linear foot.

This unit cost ($/ft) is for a lightly traveled subdivision street. As the projected traffic increases, the thickness used increases, thereby increasing the cost per linear foot.

This data is presented so that the cost of transportation related impervious surfaces is included in the system model.

3.6 Conclusions

In summary, detailed databases exist that can provide accurate cost information. The use of lookup tables, database functions, and regression (limited use where appropriate), a system model providing generic costing relationships can be built. Systematic evaluation of different designs through simulation enables repeated testing of various designs, leading to a method for optimization.

Chapter 4

Cost Effectiveness of Stormwater Quality Controls

4.1 Objectives of Control

Stormwater quality control is used to reduce pollutant loadings from urban runoff events. In most cases, the volume and peak flow of the event has a direct bearing on the discharge quality. Some facilities, where the local regulatory focus was on peak flow reduction are now being reevaluated for quality control as well.

4.2 Control Descriptions and Construction Costs

Predominant stormwater quality controls are outlined in the following sections and available cost information on them is provided. Detailed cost data were not available for most of these systems, and so design guidance cost curves were updated from several references. This approach would be more viable if the sample size was large. However, the sample sizes are not available for the bulk of these data.

4.2.1 Offline storage-release systems

Storage-release systems are designed to intercept effluent and retain it for a predetermined time-period prior to its discharge into receiving waters. Before the effluent is released from the storage unit, it has undergone some physical settling, and, perhaps some biological treatment. The two main types of storage systems evaluated here are surface storage and deep tunnels.

4.2.1.1 Surface storage

Surface storage units are offline storage, at or near the surface, and are typically made of concrete. Typically, large diameter culverts are used. The best source of empirical cost data on surface storage can be found in US EPA (1993), which relates cost as a function of size, or volume of the facility. This relationship has been updated to 1/99 $ and is found in equation 4.1:

$$C = 4.546V^{0.826} \tag{4-1}$$

Where

C = construction cost, millions 1/99 $

V = volume of storage system, Mgal (where $0.15 \leq V \leq 30$ Mgal)

Equation 4.1 has been plotted in Figure 4-1 for the applicable range of volumes.

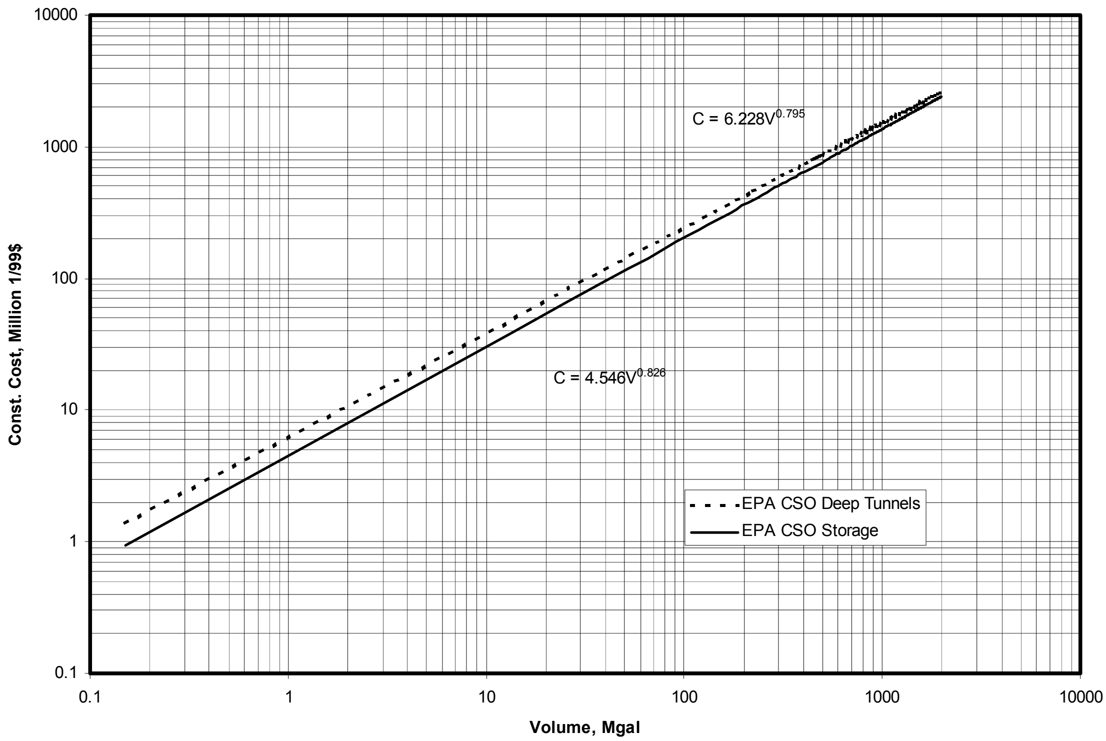


Figure 4-1. Construction costs of offline storage. (Updated to 1/99 $, ENR = 6000, Adapted from US EPA, 1993)

4.2.1.2 Deep tunnels

Deep tunnels, bored into bedrock have been used increasingly in urban areas because space is unavailable for surface storage units. Although they function similarly to surface storage units it is difficult to add biological treatment enhancements or baffling to tunnels. US EPA (1993) is currently the best source of data on the cost of deep tunnels. This source relates cost as a function of size, or storage volume. This relationship has been updated to 1/99 $ and is expressed in equation 4.2:

$$C = 6.228V^{0.795} \tag{4-2}$$

Where

C = construction cost, million 1/99 $
V = volume of storage system, Mgal (where $1.8 \leq V \leq 2{,}000$ Mgal)

Equation 4.2 has been plotted in Figure 4-1 for the applicable range of volumes.

4.2.2 Swirl concentrators

Swirl concentrators use centrifugal force and gravitational settling to remove the heavier sediment particles and floatables from urban runoff. They are typically used in CSO situations, but may also be used in general urban runoff events (US EPA 1993). These devices alone do not provide any means to reduce peak discharge, they are commonly used in conjunction with some form of storage, and their performance varies (Urbonas, 1999).

The best source of data on swirl concentrators is currently US EPA (1993), which relates cost as a function of size, or, in this case, design flow. This relationship has been updated to 1/99 $ and is expressed in equation 4.3:

$$C = 0.22Q^{0.611} \tag{4-3}$$

Where

C = construction cost, millions 1/99 \$
Q = design flow rate, MGD (where $3 \leq Q \leq 300$ MGD)

Equation 4.3 has been plotted in Figure 4-2 for the applicable range of flows.

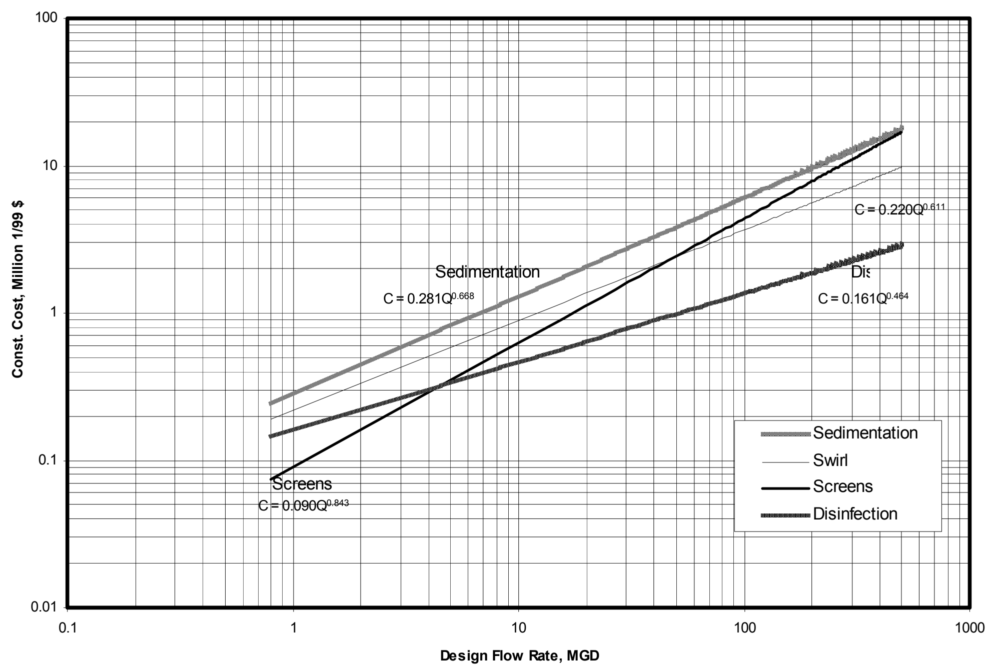


Figure 4-2. Construction costs for swirl concentrators, screens, sedimentation basins, and disinfection. (Updated to 1/99 \$, ENR = 6000, Adapted from US EPA, 1993).

4.2.3 Screens

Coarse screens are used to remove large solids and some floatables from CSO discharges. US EPA (1993) is the best current source of available cost data. Cost is expressed as a function of size, or design flow. This relationship has been updated to 1/99 $ and is shown in equation 4.4:

$$C = 0.09Q^{0.843} \tag{4-4}$$

Where
C = construction cost, millions 1/99 $
Q = design flow rate, MGD (where $0.8 \leq Q \leq 200$ MGD)

Equation 4.4 has been plotted in Figure 4-2 for the applicable range of flows.

4.2.4 Sedimentation basins

Sedimentation basins detain stormwater to allow physical settling prior to its discharge. These basins are usually baffled to eliminate short circuiting of the flow. US EPA (1993) is the best current source of cost data on sedimentation basins. This source relates cost as a function of size, or design flow. The relationship has been updated to 1/99 $ and is expressed in equation 4.5:

$$C = 0.281Q^{0.668} \tag{4-5}$$

Where
C = construction cost, millions 1/99 $
Q = design flow rate, MGD (where $1 \leq Q \leq 500$ MGD)

Equation 4.5 has been plotted in Figure 4-2 for the applicable range of flows.

4.2.5 Disinfection

Disinfection is used to kill off pathogenic bacteria prior to a CSO discharge. The best current source of data on disinfection (chlorination without dechlorination) is US EPA (1993). This source relates cost as a function of size, or design flow. This relationship has been updated to 1/99 $ and is expressed in equation 4.6:

$$C = 0.161Q^{0.464} \tag{4-6}$$

Where:
C = construction cost, millions 1/99 $
Q = design flow rate, MGD (where $1 \leq Q \leq 200$ MGD)

Equation 4.6 has been plotted in Figure 4-2 for the applicable range of flows.

4.2.6 Best management practices

The term "Best Management Practices" (BMPs) is used for any practice meant to control and manage the quality or quantity of urban runoff (Urbonas, 1999). This definition delineates stormwater BMPs as structural and nonstructural. Structural BMPs include such devices as detention basins, retention basins, infiltration trenches or basins. They are typically constructed as part of the urban development process to mitigate the deleterious effects of urban runoff. A key BMP, minimizing the directly connected impervious area, is not included in this analysis as very little data is available on its cost (Urbonas, 1999). The more typical, nonstructural BMPs, include such activities as street sweeping and public education on the disposal of pollutants, e.g., oils. These methods are more difficult to assess.

4.2.6.1 Detention basins

Detention basins are storage basins designed to empty after each storm. These basins are most common in rapidly developing urban areas. They use an undersized outlet which causes water to back up and fill the basin (Ferguson, 1998). The rate of discharge depends upon the outlet size and is usually set by local standard. Detention basins attenuate the peak runoff from the developed area. These basins perform well in controlling local water quantity impacts of urban runoff. If the outlet is designed appropriately, water quality can also be controlled to some extent.

The best current source of cost information is Young et al. (1996), which gives cost as a function of storage volume as shown in equation 4.7:

$$C = 55{,}000V^{0.69} \tag{4-7}$$

Where:

C = construction cost, 1/99 $

V = volume of basin, Mgal

The construction costs have been updated to 1/99 $. Land costs were excluded. This relationship is plotted in Figure 4-3. Off-line surface storage for CSO controls is plotted alongside these for comparison purposes. The basis for this relationship is a study done for the Metropolitan Washington Council of Governments (Wiegand et al., 1986).

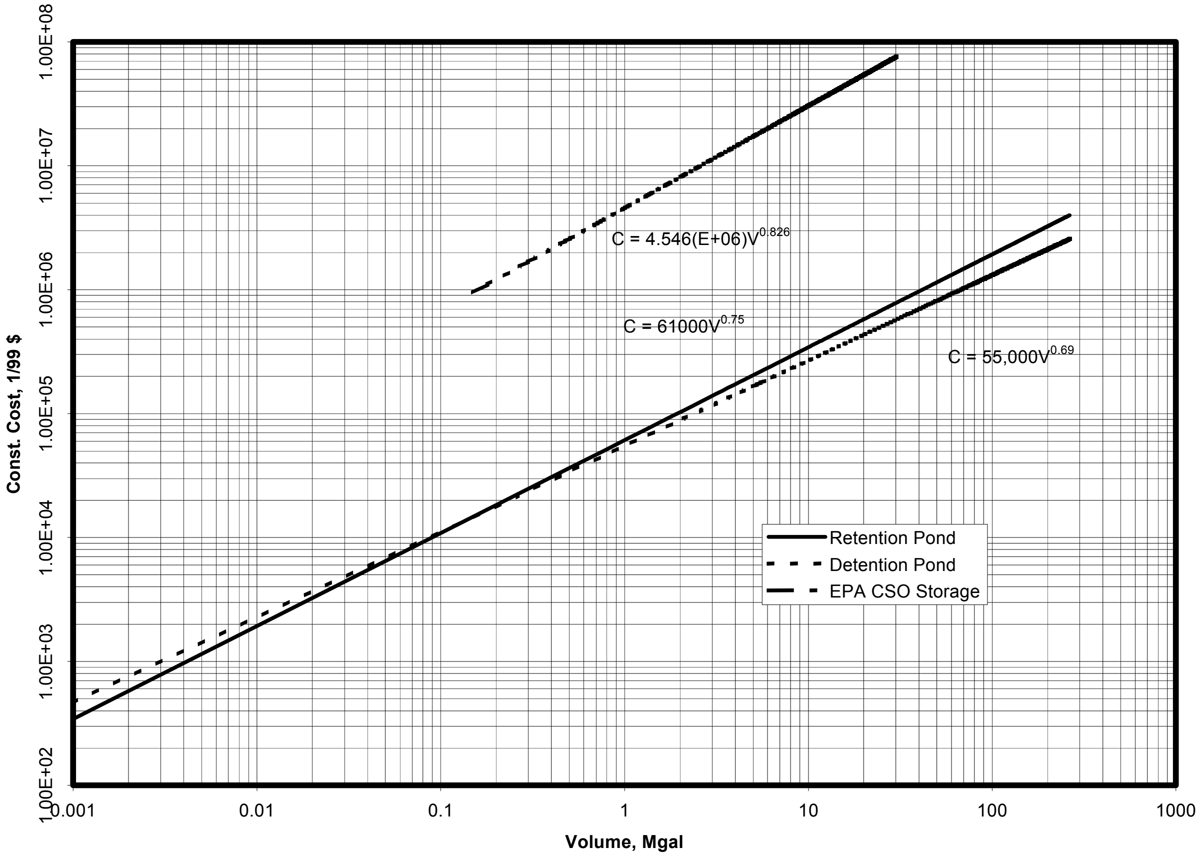


Figure 4-3. Construction costs of detention, retention, and offline surface units (Adapted from Young et al., 1996).

4.2.6.2 Retention basins

Retention basins are similar to detention basins, except that the permanent pool is increased. By increasing the permanent pool, (i.e., the point at which discharge occurs), in the storage volume (and typically increasing the storage size as well), increased physical and biological treatment occurs due to the longer residence time in the basin. These types of basins are called retention basins, or wet ponds. The amount of physical storage available is determined by the difference between the height set as the permanent pool volume and the height above the top of the weir or outlet structure available, or freeboard. Because cost depends upon volume, retention basins are more costly in controlling the same amount of peak discharge as a dry detention basin from a quantity standpoint.

The best available cost data on retention basins is found in Young et al. (1996), which gives cost as a function of the total volume of the pond (not the available storage). This relationship is:

$$C = 61{,}000V^{0.75} \tag{4-8}$$

Where:

C = construction cost, 1/99 \$
V = volume of pond, Mgal

The construction costs have been updated to 1/99 \$. Land costs were excluded. This relationship is plotted in Figure 4-3. The basis for this relationship is a study done for the Metropolitan Washington Council of Governments (Wiegand et al., 1986). The data behind this relationship was not reported.

4.2.6.3 Infiltration trenches

Infiltration is the process of runoff water soaking into the ground. Since infiltrated water is removed from surface waters, it represents a complete control for that fraction of stormwater that can be infiltrated (Ferguson, 1998). An infiltration trench is used in areas where space is a problem. It usually consists of excavating a void volume, lining the volume with filter fabric to keep out fine material, installation of conveyance piping, and filling the void with gravel or crushed stone. The trench's performance depends greatly upon the soil characteristics of the area, and operating and maintenance practices (Urbonas, 1999).

The best available cost data on infiltration trenches is found in Young et al. (1996), which gives cost as a function of the total volume of the trench. This relationship is:

$$C = 157V^{0.63} \tag{4-9}$$

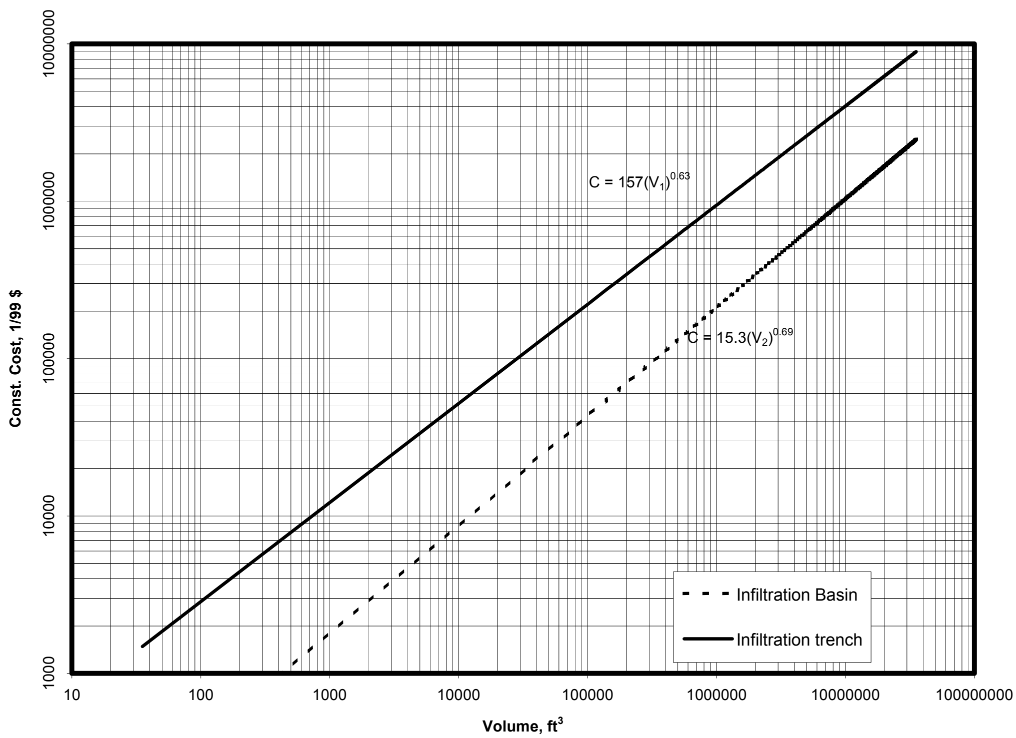
Where:

C = construction cost, 1/99 \$
V = volume of trench, ft^3

The source did not list the data for this relationship. The construction costs have been updated to 1/99 \$. Land costs were excluded. This relationship is plotted in Figure 4-4.

4.2.6.4 Infiltration basins

Infiltration basins are similar to retention ponds; however, they are typically used in flatter terrain, and discharge only in low frequency events. Permeable soils underlying the basin and high rates of evapotranspiration are the major prerequisite for using these basins. The water typically can only leave via percolation into the groundwater, or evapotranspiration. Performance in buffering runoff water quality is high; however, from a quantity standpoint, a large land area must be used to control significant runoff events. A major disadvantage is the high maintenance involved due to clogging of the basin.



Note: V_1= trench volume; V_2=basin volume
Figure 4-4. Construction cost, infiltration trenchs and basins (Adapted from Young et al., 1996).

The best available cost data on infiltration basins is found in Young et al. (1996), which gives cost as a function of the total volume of the basin. This relationship is:

$$C = 15.3V^{0.69} \tag{4-10}$$

Where:

C = construction cost, 1/99 $
V = volume of infiltration basin, ft^3

The construction costs have been updated to 1/99 $. Land costs were excluded. Equation 4.10 is plotted in Figure 4-4. The basis for this relationship is a study done by Schueler (1987). The data that this relationship was based upon were not reported.

4.2.6.5 Sand filters

Sand filters remove sediment and pollutants from runoff. Usually the filters have a presettling chamber to induce settling of the larger solids that would typically clog the sand filter itself. The filtered outflow is collected, rather than infiltrated, and either discharged, or treated further. Performance of these systems is typically good in space-limited areas and in arid climates (Young et al., 1996).

The best available cost data on sand filters is found in Young et al. (1996), which gives cost as a function of the total impervious surface area draining to the filter. This relationship is found in equation 4.11:

$$C = KA \tag{4-11}$$

Where:

C = construction cost, 1/99 \$
A = impervious surface, acres
K = constant, ranging from 11,200 to 22,400

The construction costs have been updated to 1/99 \$. Land costs were excluded. The basis for this relationship is a study done for the Metropolitan Washington Council of Governments (Schueler 1994). The data behind this relationship was not reported.

4.2.6.6 Water quality inlet

Water quality inlets are inlets modified for the control of some solids, oil, and grease. These are sometimes referred to as oil and grit separators. According to Urbonas (1999), the performance of these devices has not been very good.

The best available cost data on water quality inlets is found in Young et al. (1996). Updated to 1/99 \$, the costs range from \$7,200 to \$21,500. The basis for this relationship is a study done by Schueler (1987). The data behind this relationship was not reported.

4.2.6.7 Grassed swales

Grassed swales are vegetated channels used in lieu of the traditional concrete curb and gutter typical of urban areas. Pollutants are removed through filtration by vegetation, settling, and infiltration into the soil (Young et al., 1996). The performance of these systems is highly variable. The use of swales is not recommended in dense urban areas where space is at a premium, or in commercial/industrial areas where contamination of groundwater can occur due to oils and grease in the effluent (Urbonas, 1999).

The best available cost data on grassed swales is found in Young et al. (1996), in which cost is found to vary as follows:

$$C = KL \tag{4-12}$$

Where:

C = construction cost, 1/99 \$
L = length of swale, ft

K = constant, 5 to14

The construction costs have been updated to 1/99 \$. No land costs were included in this analysis. These costs can be significant because an increased right-of-way is needed to include the swale. The basis for this relationship is a study done by Schueler (1992). The data behind this relationship was not reported.

4.2.6.8 Vegetated filter strip

Vegetated filter strips are located adjacent to an impervious surface and gradually sloped to allow overland flow to run slowly across the vegetation. Pollutants are adsorbed and filtered by the vegetated material. High volumes or velocities are not appropriate for these types of areas (Young et al., 1996). Good removal of pollutants can be achieved, assuming the width of the strip is sufficient (Urbonas 1999). No cost information is available, because the designs are highly variable (Young et al., 1996).

4.2.6.9 Wetlands

Wetlands are a modification of the retention pond/infiltration pond to include a broad, shallow, shelf that is inundated periodically under low frequency events. Under these conditions a littoral wetland ecosystem is planted, or allowed to form. The design of wetlands is similar to that of the retention pond, but because of relatively high adsorption surfaces and high levels of biological productivity, wetland pollution removal rates tend to be better (Young et al., 1996). Cost information is not given, as the designs are highly variable (Young et al., 1996)

4.2.6.10 Porous pavements

Porous pavements are a modification to asphalt pavements to allow some infiltration to occur. A berm is used to trap water and contain it on site. Typically, porous pavement infiltration rates are much lower than rates in infiltration basins, although similar treatment characteristics can occur. This method is reserved for low traffic areas because high vehicular traffic can damage the pavement due to "pumping" of groundwater. (Young et al., 1996). Porous pavements can also be negatively affected by freezing temperatures due to frost heave. Cost information is not given, because the designs are highly variable (Young et al., 1996)

4.2.6.11 Nonstructural BMPs

Nonstructural BMPs include such management practices as street sweeping, and educational programs, e.g., on oil recycling. Although important benefits may result from these activities, they are typically difficult to measure, and when measured, usually the constituent measured may have not a causal relationship with a variable that directly affects receiving water quality (Urbonas, 1999). Because of their indirect nature, detailed cost information is not available (Heaney et al., 1998c).

4.2.6.12 Assessment of BMP control performance

An overall assessment of structural BMP control performance can be found in Table 4-1 (Urbonas, 1999). The table lists expected removal ranges for total suspended solids, total phosphorus, total nitrogen, zinc, lead, BOD, and bacteria, compiled from several different sources. Urbonas (1999) however, cautions the use of the table alone, he argues that the definition of "effectiveness is fundamentally flawed, as it is typically a snapshot in time, and ignores the performance of the control over time, and the variability of maintenance to the control." For example, porous pavement is excellent at removal of solids, but is certainly not designed to do so and will clog very quickly if a high solids loading is applied to it.

Table 4-1. BMP Pollutant Removal Ranges (Urbonas, 1999)

	Removal Range (%)						
Structural BMP	TSS	Total P	TKN	Zinc	Lead	BOD_5	Bacteria
Porous Pavement	80 - 95	65	75 - 85	98	80	80	N/A
Grass Buffer Strip	10 - 20	0 - 10	0 - 10	0 - 10	N/A	N/A	N/A
Grass Lined Swale	20 - 40	0 - 15	0 - 15	0 - 20	N/A	N/A	N/A
Infiltration Basin	0 - 98	0 - 75	0 - 70	0 - 99	0 - 99	0 - 90	75 - 98
Percolation Trench	98	65 - 75	60 - 70	95 - 98	N/A	90	98
Retention Pond	91	0 - 79	0 - 80	0 - 71	9 - 95	0 - 69	N/A
Extended Detention	50 - 70	10 - 20	10 - 20	30 - 60	75 - 90	N/A	50 - 90
Wetland Basin	40 - 94	(-)4 - 90	21	(-)29 - 82	27 - 94	18	N/A
Sand Filters (fraction flowing through filter)	14 - 96	5 - 92	(-)129 - 84	10 - 98	60 - 80	60 - 80	N/A

Note: The above-reported removal rates represent a variety of site conditions and influent-effluent concentration ranges. It is not appropriate to use the averages of these rates for any of the reported constituents as design objectives for expected BMP performance or for its permit effluent conditions. Keep in mind that influent concentrations, local climate, geology, meteorology and site-specific design details and storm event-specific runoff conditions affect the performance of all BMPs.

Urbonas (1999) advocates a more design-oriented approach in assessing control performance. An example of this approach is found in Table 4-2. While subjective, this approach does provide the designer with enough information to evaluate the control under a wider range of conditions than the regulatory approach found in Table 4.1. However, much more work needs to be done in this area to properly assess the expected benefits of the BMP control in question.

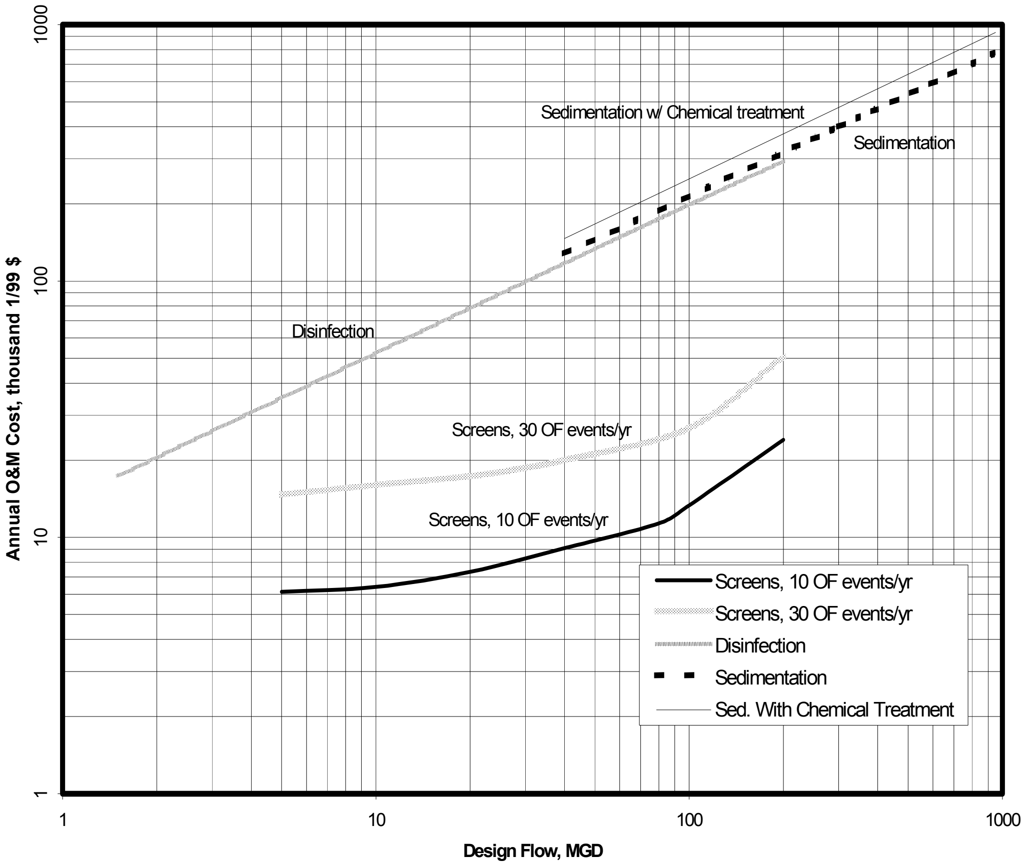
Table 4-2. An Assessment of Design Robustness Technology for Several BMPs (Urbonas, 1999.)

Structural BMP	Hydraulic Design[a]	Removal of Constituents in Stormwater		Overall Design Robustness
		TSS	Dissolved	
Swale	High	Low - Moderate	None - Low	Low
Buffer (filter) strip[b]	Low – Moderate	Low - Moderate	None - Low	Low
Infiltration basin[c]	Low – High	High	Moderate - High	Low – Moderate
Percolation trench	Low – Moderate	High	Moderate - High	Low – Moderate
Extended detention (dry)	High	Moderate - High	None - Low	Moderate - High
Retention pond (wet)	High	High	Low - Moderate	Moderate - High
Wetland	Moderate – High	Moderate - High	Low - Moderate	Moderate
Media filter	Low – Moderate	Moderate - High	None - Low	Low – Moderate
Oil separator	Low – Moderate	Low	None - Low	Low
Catch basin inserts	Uncertain	N/A	N/A	N/A
Monolithic porous pavement[b]	Low – Moderate	Moderate - High	Low - High[c]	Low
Modular porous pavement[b]	Moderate – High	Moderate - High	Low - High[c]	Low – Moderate

[a]Weakest design aspect, hydraulic or constituent removal, governs overall design robustness.
[b]Robustness is site-specific and very much maintenance-dependent.
[c]Low-to-Moderate whenever designed with an underdrain and not intended for infiltration;

4.3 Operation and Maintenance Costs for Controls

Operation and maintenance cost data for controls are only available for a limited number of CSO-type controls; i.e., sedimentation, disinfection, and screens. CSO-type controls are expected to be significantly more expensive in terms of operating and maintenance costs than those controls that handle only stormwater, however, no data were available (beyond anecdotal) for non CSO-type controls. These relationships can be found in Figure 4-5 from US EPA (1993). For a complete cost/benefit analysis of each control, one needs operating and maintenance costs to complete a life-cycle cost analysis (LCA). LCA is done by bringing all controls to the same design life (by including replacements as necessary), amortizing the control over the same period, and including in this annual cost the annual operating and maintenance cost for each control. LCA is then compared to the benefits of the control.



Note: OF = overflow
Figure 4-5. Operation and maintenance costs for CSO controls (Adapted from US EPA 1993).

Chapter 5

Process-Level Cost Estimation

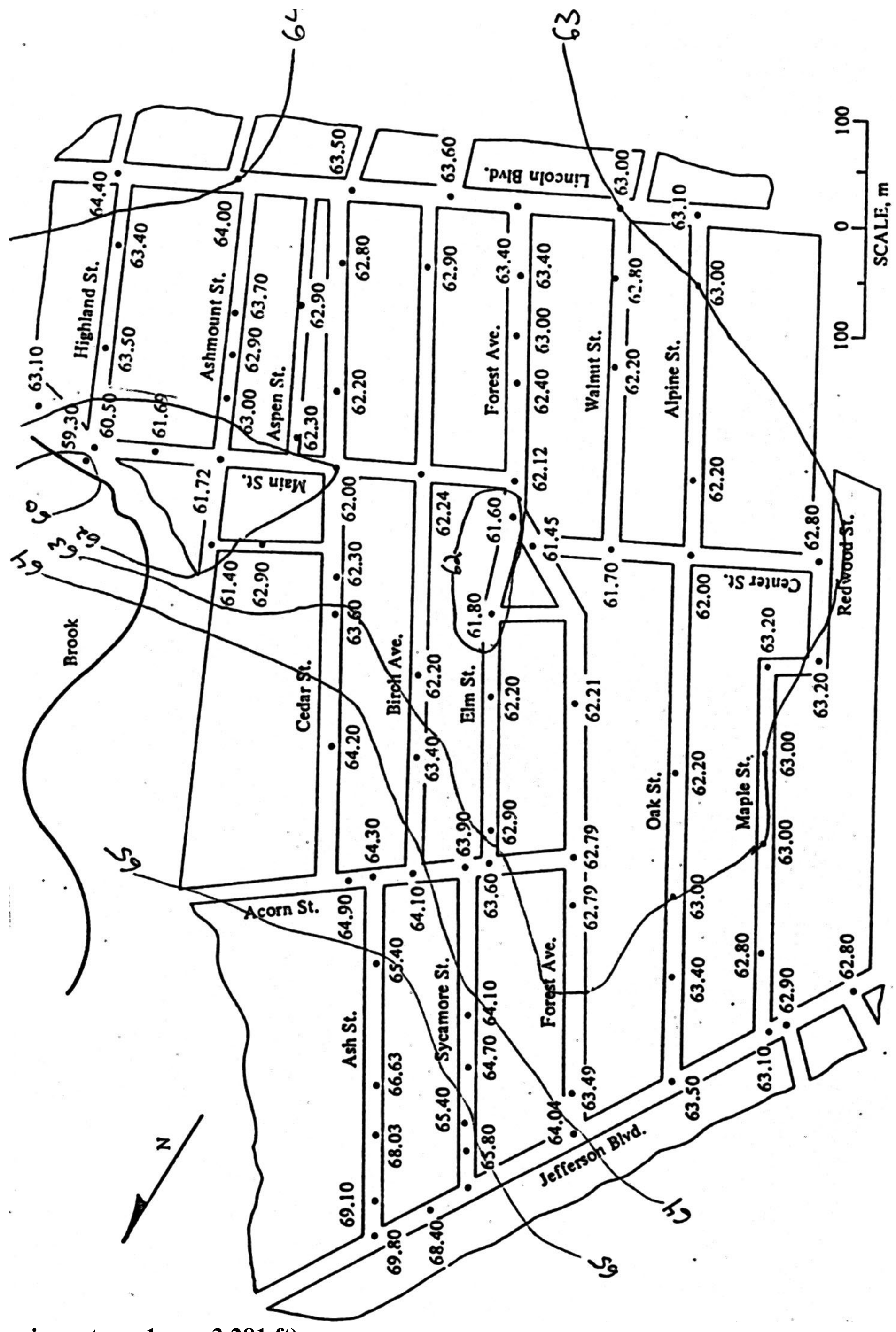
The utility of the cost estimation models presented herein can be illustrated by applying them to a proposed design. By automating the design in a spreadsheet model, many different designs can be evaluated.

5.1 Case Study

During the literature review, several urban stormwater design case studies were evaluated to determine if any of them were suitable to demonstrate process-level cost estimation. Tchobanoglous 1981 presents calculations for designing sanitary and storm sewers for the same study area. The total area is approximately 106 acres. The topography of the study area is shown in Figure 5-1. The highest part of the drainage area is on the north side. All drainage ultimately goes to a local brook. The layout of the storm sewer system is shown in Figure 5-2. The entire study area is divided into 54 sub-areas that range in size from 0.8 to 3.4 acres in size. A spreadsheet was designed to incorporate all of the necessary information for design by trial and error. The calculations are presented in tables 5.1, 5.2 and 5.3, which are described below.

5.1.1 Calculate the design flows into the drainage system

Table 5-1 consists of 69 rows and 20 columns. Each row designates a link in the drainage network. The land use for the total area is shown in Figure 5-3. Total land use consists of the mix of uses shown in Table 5-2. The dwelling units/acre for each link is listed in column 7 of Table 5-1 (except for commercial and schools, which are listed as –1 and –2, respectively). The percent imperviousness is related to land use as shown in Table 5-3. Two cases will be considered: existing zoning practices, and low impact development (LID) land use practices. If LID is used, the imperviousness for all land uses is assumed reduced by 30%. Column 8 of Table 5-1 is then computed, listing the impervious percentage for each link. Column 9 of Table 5-1 is the multiplication of the drainage area in acres from column 6 times the impervious percentage of column 8. Column 10 of Table 5-1 is the impervious coefficient of the impervious area, nominally 1.0. Column 12 of Table 5-1 is the impervious area, or column 9, totaled within each branch. Column 13 is the permeable area within the link, or the total area minus the impervious area. Based upon the land use, through a lookup table, a runoff coefficient is assigned in column 14. A cumulative runoff coefficient is calculated in column 15. Column 16 is computed by assuming an initial flow time of 20 min, and summing the previous link in the branch's time in column 17. Column 17 is calculated by dividing the distance in column 5 by the Manning velocity for the design pipe diameter. Column 18 is the sum of columns 17 and 16. Column 19 is the rainfall intensity for the given time in column 18. Column 20 is computed by the Rational Method, to be explained later.



(elevations in meters; 1 m = 3.281 ft)

Figure 5-1. Study area topography (Adopted from Tchobanoglous, 1981). (Reproduced with permission of The McGraw-Hill Companies).

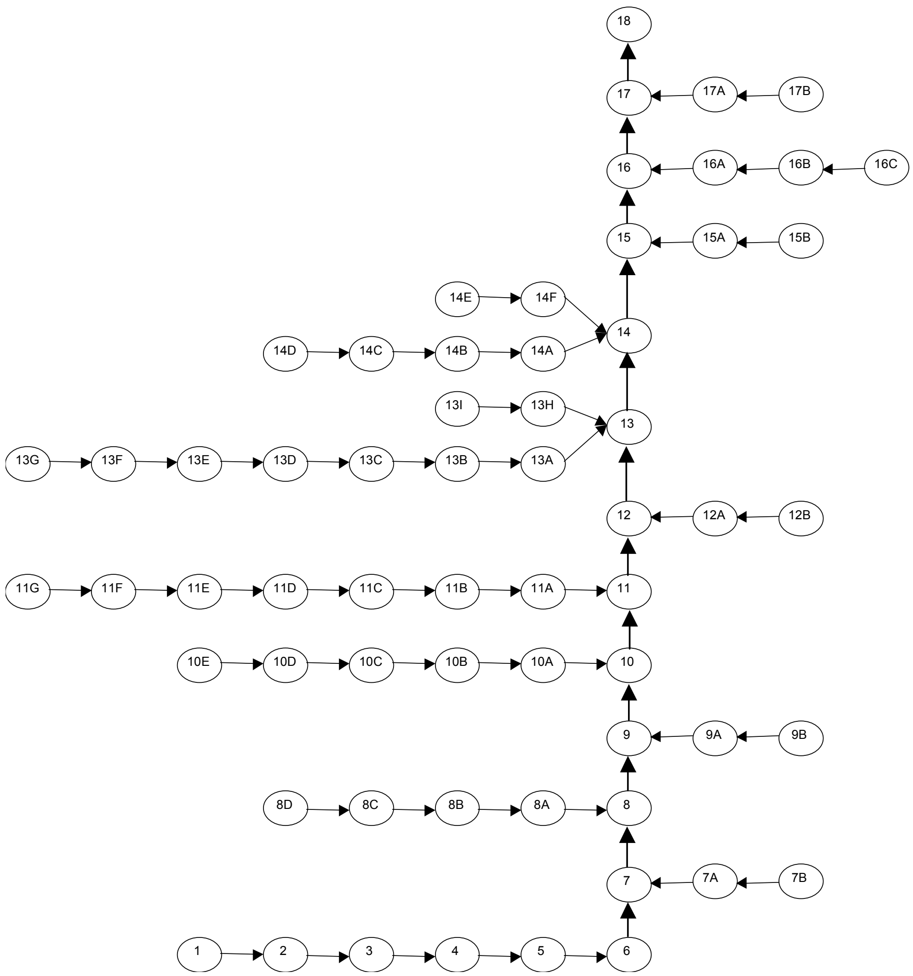


Figure 5-2. Study area sewer network.

Table 5-1. Sewer Network Design Hydrology

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Street	Type	Nodes		Sewer Length	Drainage Area	Dwelling Units/	Percent	Impervious Area, IA	IA Runoff	Cumulative Total	Cumulative Impervious	Pervious Area, PA	PA Runoff	Cumulative Runoff	Flow Time (min)			Rain Intensity	Peak Discharge
		From	To	(ft)	(ac)	acre	Impervious	(ac)	Coeff.	(ac)	(ac)	(ac)	Coeff.	Coeff.	To Upper End	In Section	Total Time	(in/hr)	(ac-in/hr)
Maple/Redwood	Branch	1	2	279	2.30	2	35	0.80	1.00	2.30	0.80	1.49	0.30	0.55	20.00	2.32	22.32		
Maple/Redwood	Branch	2	3	299	2.40	2	35	0.84	1.00	4.70	1.64	1.56	0.30	0.55	22.32	1.21	23.54	2.49	6.36
Maple/Redwood	Branch	3	4	272	2.20	2	35	0.77	1.00	6.89	2.41	1.43	0.30	0.55	23.54	1.15	24.69	2.41	9.07
Maple/Redwood	Branch	4	5	148	1.51	2	35	0.53	1.00	8.40	2.94	0.98	0.30	0.55	24.69	0.54	25.23	2.38	10.90
Maple/Redwood	Branch	5	6	325	2.20	2	35	0.77	1.00	10.60	3.71	1.43	0.30	0.55	25.23	1.26	26.49	2.31	13.35
Alpine	Branch	7B	7A	367	3.41	10	56	1.91	1.00	3.41	1.91	1.50	0.30	0.69	20.00	3.06	23.06		
Alpine	Branch	7A	7	367	2.59	10	56	1.45	1.00	6.00	3.36	1.14	0.30	0.69	23.06	1.35	24.41	2.43	10.10
Oak	Branch	8D	8C	328	2.50	3	40	1.00	1.00	2.50	1.00	1.50	0.30	0.58	20.00	2.73	22.73		
Oak	Branch	8C	8B	328	2.40	3	40	0.96	1.00	4.89	1.96	1.44	0.30	0.58	22.73	0.67	23.40	2.49	7.08
Oak	Branch	8B	8A	328	2.50	3	40	1.00	1.00	7.39	2.96	1.50	0.30	0.58	23.40	1.08	24.48	2.43	10.40
Oak	Branch	8A	8	328	2.79	3	40	1.12	1.00	10.18	4.07	1.68	0.30	0.58	24.48	0.99	25.46	2.37	13.98
Walnut	Branch	9B	9A	394	2.69	-2	35	0.94	1.00	2.69	0.94	1.75	0.30	0.55	20.00	3.28	23.28		
Walnut	Branch	9A	9	394	2.99	-2	35	1.05	1.00	5.68	1.99	1.94	0.30	0.55	23.28	1.29	24.57	2.42	7.50
W. Forest	Branch	10E	10D	394	2.89	5	46	1.33	1.00	2.89	1.33	1.56	0.30	0.62	20.00	3.28	23.28		
W. Forest	Branch	10D	10C	344	2.50	5	46	1.15	1.00	5.39	2.48	1.35	0.30	0.62	23.28	1.13	24.41	2.43	8.14
W. Forest	Branch	10C	10B	328	3.09	5	46	1.42	1.00	8.48	3.90	1.67	0.30	0.62	24.41	0.98	25.39	2.37	12.51
W. Forest	Branch	10B	10A	328	2.40	5	46	1.10	1.00	10.87	5.00	1.29	0.30	0.62	25.39	0.99	26.38	2.32	15.67
W. Forest	Branch	10A	10	246	0.99	5	46	0.45	1.00	11.86	5.46	0.53	0.30	0.62	26.38	0.74	27.12	2.28	16.81
E. Forest	Branch	12B	12A	328	1.80	12	60	1.08	1.00	1.80	1.08	0.72	0.30	0.72	20.00	2.73	22.73		
E. Forest	Branch	12A	12	328	2.20	12	60	1.32	1.00	4.00	2.40	0.88	0.30	0.72	22.73	0.84	23.58	2.48	7.16
Sycamore/Elm	Branch	11G	11F	328	2.10	5	46	0.97	1.00	2.10	0.97	1.13	0.50	0.73	20.00	2.73	22.73		
Sycamore/Elm	Branch	11F	11E	279	2.10	5	46	0.97	1.00	4.20	1.93	1.13	0.50	0.73	22.73	0.72	23.45	2.49	7.64
Sycamore/Elm	Branch	11E	11D	262	2.20	5	46	1.01	1.00	6.40	2.94	1.19	0.50	0.73	23.45	0.86	24.31	2.44	11.38
Sycamore/Elm	Branch	11D	11C	82	0.00	5	46	0.00	1.00	6.40	2.94	0.00	0.50	0.73	24.31	0.32	24.63	2.42	11.29
Sycamore/Elm	Branch	11C	11B	328	1.61	5	46	0.74	1.00	8.01	3.68	0.87	0.50	0.73	24.63	0.59	25.22	2.38	13.92
Sycamore/Elm	Branch	11B	11A	328	1.71	5	46	0.78	1.00	9.71	4.47	0.92	0.30	0.71	25.22	0.99	26.21	2.33	16.07
Sycamore/Elm	Branch	11A	11	295	1.41	5	46	0.65	1.00	11.12	5.12	0.76	0.30	0.70	26.21	1.06	27.26	2.27	17.67
Ash/Acorn/Birch	Branch	13G	13F	328	1.71	5	46	0.78	1.00	1.71	0.78	0.92	0.50	0.73	20.00	2.73	22.73		
Ash/Acorn/Birch	Branch	13F	13E	328	2.50	5	46	1.15	1.00	4.20	1.93	1.35	0.50	0.73	22.73	0.64	23.37	2.50	7.65
Ash/Acorn/Birch	Branch	13E	13D	328	1.80	5	46	0.83	1.00	6.00	2.76	0.97	0.50	0.73	23.37	0.64	24.01	2.46	10.76
Ash/Acorn/Birch	Branch	13D	13C	82	0.82	5	46	0.38	1.00	6.82	3.14	0.44	0.50	0.73	24.01	0.27	24.28	2.44	12.14
Ash/Acorn/Birch	Branch	13C	13B	394	2.00	5	46	0.92	1.00	8.82	4.06	1.08	0.50	0.73	24.28	1.02	25.30	2.38	15.31
Ash/Acorn/Birch	Branch	13B	13A	394	2.20	5	46	1.01	1.00	11.02	5.07	1.19	0.30	0.71	25.30	0.84	26.14	2.33	18.20
Ash/Acorn/Birch	Branch	13A	13	394	1.90	5	46	0.88	1.00	12.92	5.94	1.03	0.30	0.70	26.14	1.00	27.14	2.28	20.48
East Birch	Branch	13I	13H	262	2.00	-1	80	1.60	1.00	2.00	1.60	0.40	0.30	0.86	20.00	2.18	22.18		
East Birch	Branch	13H	13	262	2.30	-1	80	1.84	1.00	4.30	3.44	0.46	0.30	0.86	22.18	0.96	23.15	2.51	9.29
W. Cedar	Branch	14D	14C	262	2.00	5	46	0.92	1.00	2.00	0.92	1.08	0.50	0.73	20.00	2.19	22.19		
W. Cedar	Branch	14C	14B	262	2.50	5	46	1.15	1.00	4.50	2.07	1.35	0.50	0.73	22.19	0.87	23.06	2.52	8.26
W. Cedar	Branch	14B	14A	262	2.20	5	46	1.01	1.00	6.70	3.08	1.19	0.50	0.73	23.06	0.48	23.54	2.49	12.15
W. Cedar	Branch	14A	14	262	1.31	5	46	0.60	1.00	8.01	3.68	0.71	0.50	0.73	23.54	0.73	24.26	2.44	14.26
E. Cedar	Branch	14E	14F	262	1.11	-1	80	0.89	1.00	1.11	0.89	0.22	0.50	0.90	20.00	2.19	22.19		
E. Cedar	Branch	14F	14	262	1.61	-1	80	1.28	1.00	2.72	2.17	0.32	0.50	0.90	22.19	0.81	22.99	2.52	6.17
Aspen	Branch	15B	15A	328	1.26	-1	80	1.01	1.00	1.26	1.01	0.25	0.50	0.90	20.00	2.73	22.73		
Aspen	Branch	15A	15	262	2.05	-1	80	1.64	1.00	3.31	2.65	0.41	0.50	0.90	22.73	0.71	23.44	2.49	7.42
W. Ashmont	Branch	16C	16B	328	3.51	5	46	1.61	1.00	3.51	1.61	1.89	0.70	0.84	20.00	2.73	22.73		
W. Ashmont	Branch	16B	16A	328	2.20	5	46	1.01	1.00	5.71	2.63	1.19	0.70	0.84	22.73	0.80	23.54	2.49	11.89
W. Ashmont	Branch	16A	16	246	2.10	5	46	0.97	1.00	7.81	3.59	1.13	0.70	0.84	23.54	0.60	24.14	2.45	16.01
E. Ashmont	Branch	16E	16D	262	2.20	-1	80	1.76	1.00	2.20	1.76	0.44	0.70	0.94	20.00	2.19	22.19		
E. Ashmont	Branch	16D	16	246	1.80	-1	80	1.44	1.00	4.00	3.20	0.36	0.70	0.94	22.19	0.48	22.67	2.54	9.56
Highland	Branch	17B	17A	262	2.10	-1	80	1.68	1.00	2.10	1.68	0.42	0.70	0.94	20.00	2.18	22.18		
Highland	Branch	17A	17	246	2.00	-1	80	1.60	1.00	4.10	3.28	0.40	0.70	0.94	22.18	0.22	22.41	2.56	9.87
Maple/Redwood	Trunk	6	7	400	10.60	2	35	3.71	1.00	10.60	3.71	6.89	0.30	0.55	20.00	3.34	23.34	2.50	14.43
Alpine	Trunk	7	8	36	6.00	2	35	2.10	1.00	16.61	5.81	3.90	0.30	0.55	23.34	0.72	24.05	2.45	22.19
Oak	Trunk	8	9	220	10.18	2	35	3.56	1.00	26.79	9.38	6.62	0.30	0.55	24.05	0.06	24.12	2.45	35.74
Walnut	Trunk	9	10	230	5.68	2	35	1.99	1.00	32.47	11.36	3.69	0.30	0.55	24.12	0.31	24.43	2.43	42.99
Forest	Trunk	10	11	112	15.86	2	35	5.55	1.00	48.33	16.92	10.31	0.30	0.55	24.43	0.37	24.80	2.41	63.40
Elm	Trunk	11	12	95	11.12	2	35	3.89	1.00	59.45	20.81	7.23	0.30	0.55	24.80	0.20	25.01	2.39	77.59
Birch	Trunk	13	14	246	18.83	2	35	6.59	1.00	94.15	32.95	12.24	0.50	0.59	25.19	0.53	25.72	2.35	131.39
Cedar	Trunk	14	15	144	9.27	2	35	3.24	1.00	103.41	36.20	6.02	0.50	0.60	25.72	0.40	26.12	2.33	144.73
Aspen	Trunk	15	16	203	3.31	2	35	1.16	1.00	106.72	37.35	2.15	0.50	0.60	26.12	0.26	26.38	2.32	149.02
Ashmont	Trunk	16	17	361	11.81	2	35	4.13	1.00	118.53	41.49	7.68	0.50	0.61	26.38	0.37	26.75	2.30	166.06
Highland	Trunk	17	18	164	4.10	2	35	1.44	1.00	122.63	42.92	2.67	0.70	0.62	26.75	0.66	27.41	2.26	171.08

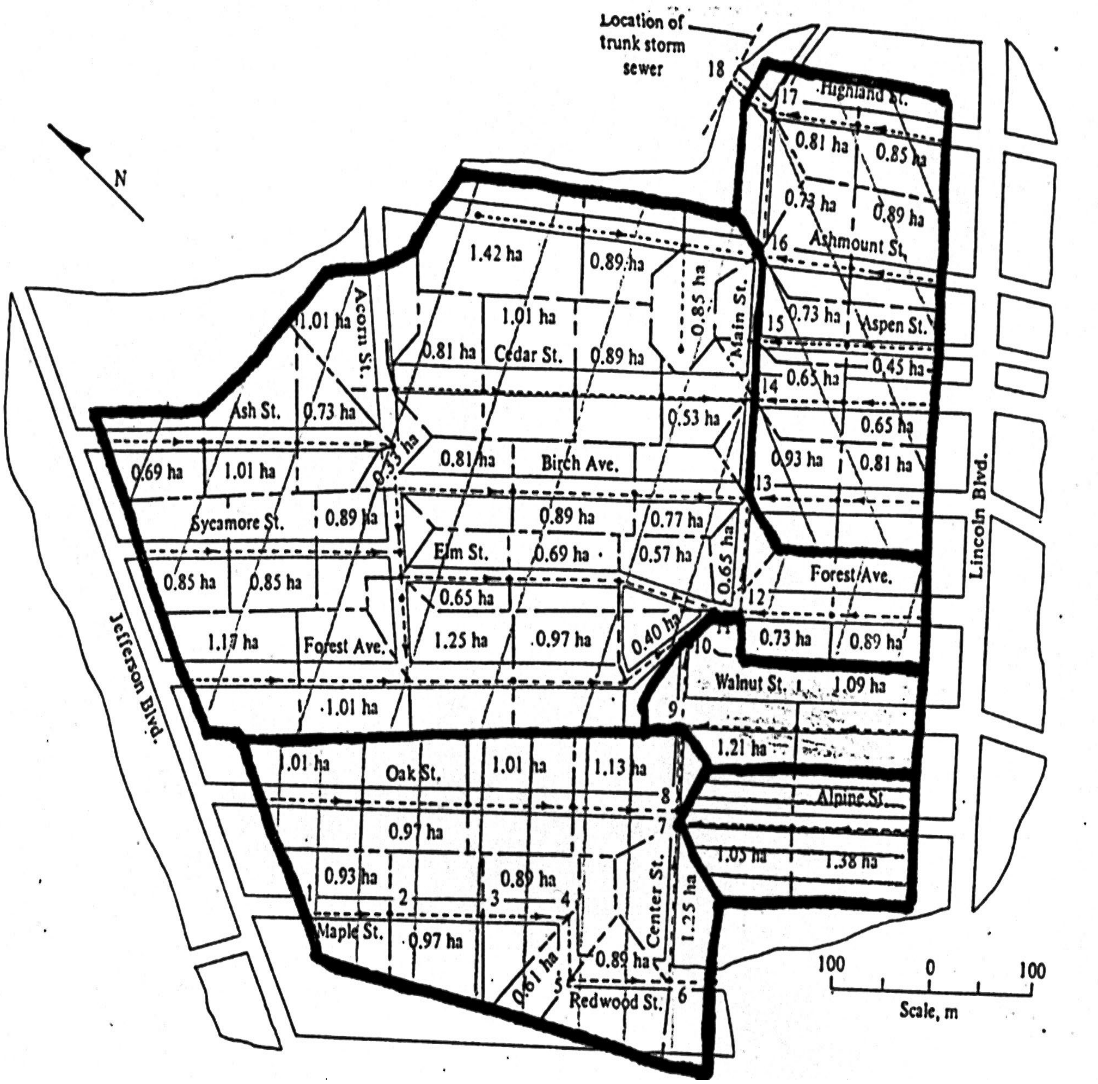


Figure 5-3. Study area land use (Adapted from Tchobanoglous, 1981).
(Reproduced with permission of The McGraw-Hill Companies).

Table 5-2. Mix of Land Uses in Happy Acres

Land Use	Area (acres)	Dwelling Density (units/acre)
Residential, low density	20.8	2 - 3
Residential, medium density	51.7	5
Apartments	10.0	10
School	5.7	N/A
Commercial	18.4	N/A
Total	106.6	

Table 5-3. Imperviousness for Various Land Uses (Heaney et al., 1998d.)

Dwelling (units/acre)	Imperviousness (%)
1	30
2	35
3	40
4	43
5	46
6	48
7	50
8	52
9	54
10	56
11	58
12	60
Commercial	80
School	35

The runoff coefficients for impervious and permeable areas are shown in Table 5-4. Runoff coefficients for permeable areas depend on the soil type.

The expected peak runoff is calculated using the Rational Method, or

$$Q = CiA \tag{5-1}$$

Where
Q = estimated peak flow, ft^3/s
C = runoff coefficient
i = rainfall intensity, in./hr
A = contributing drainage area, acres

Table 5-4. Runoff Coefficients for Various Areas

Description	Runoff Coefficient
Directly connected impervious area	1
Other impervious area	0.7
Pervious areas Soil Type:	
Sand	0.2
Silt	0.3
Clay	0.5
Rock	0.7

The runoff coefficient is calculated in Table 5-1 as the weighted average of the runoff coefficients from the impervious and permeable areas. The total drainage area is calculated by summing the contributing drainage areas. The design rainfall intensity is established by calculating the time of concentration of the runoff. The time of concentration is:

$$t_c = t_i + t_p \tag{5-2}$$

where

t_c = time of concentration, min
t_i = time to inlet, min
t_p = time in pipe, min

The flow time in the pipe is simply

$$t_p = L/v \tag{5-3}$$

where

L = length of pipe, ft
v = velocity, ft/s

However, it is less clear how to estimate the inlet time. For urban areas, inlet times from 5–20 min are used. Following the Tchobanoglous, 1981 protocol, 20 min is used here as the inlet time.

Intensity-duration-frequency (IDF) curves for Boulder, CO and Houston, TX are shown in Figures 5-4 and 5-5 (Bedient and Huber, 1989). A summary of the values of intensity for 20 min in duration for Boulder, CO and Houston, TX is presented in Table 5-5.

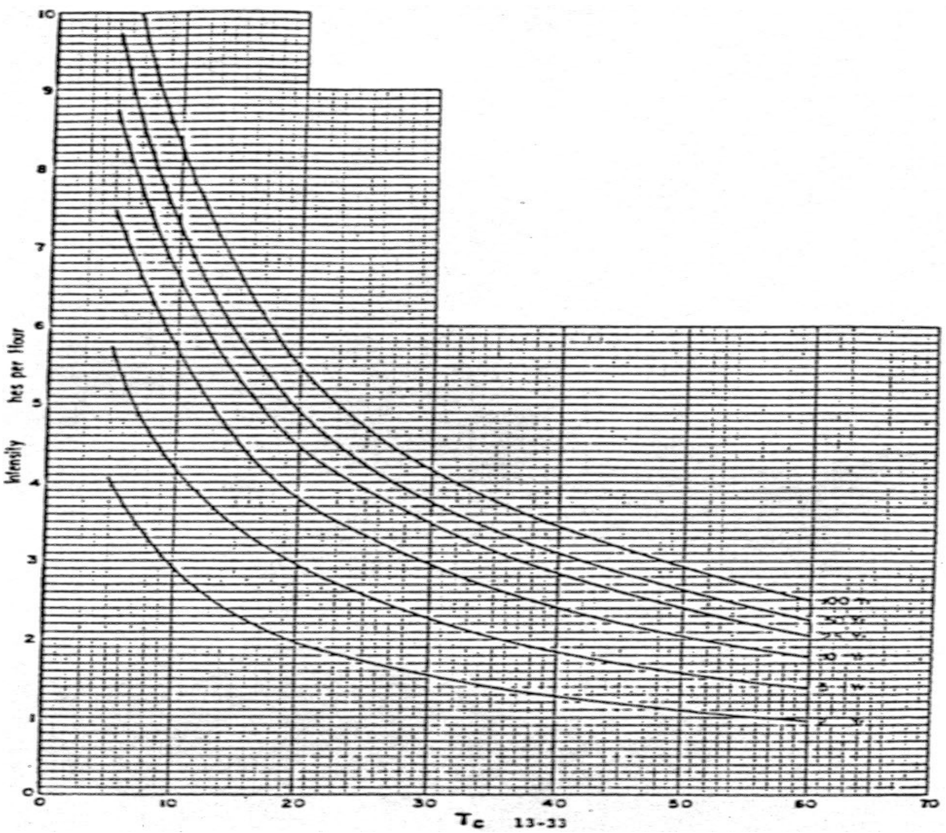


Figure 5-4. Intensity-duration-frequency curves for Boulder, CO (From US SCS, 1973).

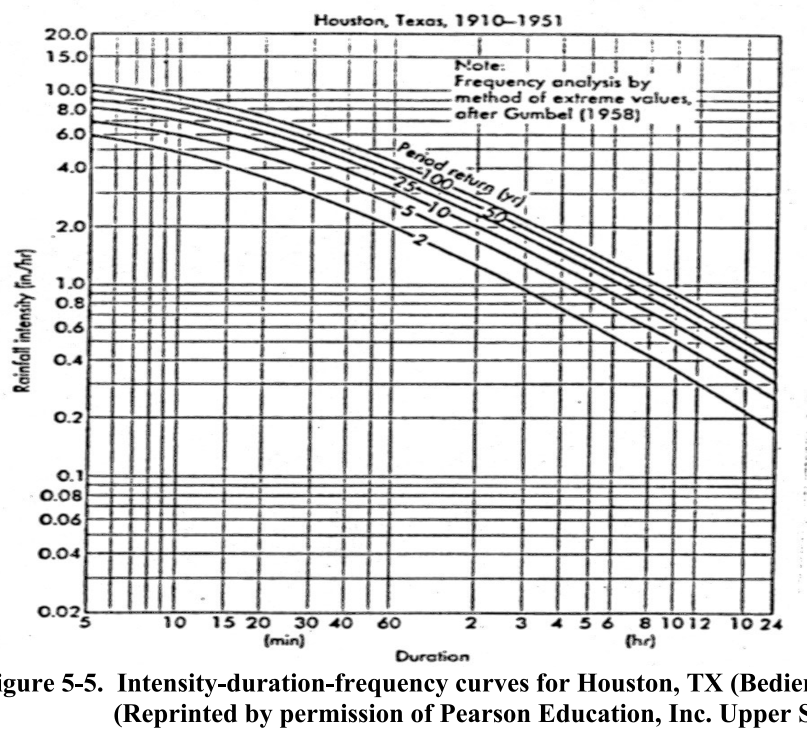


Figure 5-5. Intensity-duration-frequency curves for Houston, TX (Bedient and Huber 1989). (Reprinted by permission of Pearson Education, Inc. Upper Saddle River, New Jersey).

Table 5-5. **Comparison of Design Rainfall Intensities for 20-min Duration Storms in Boulder, CO, and Houston, TX**

Recurrence Interval (yrs)	Boulder, CO (in./hr)	Houston, TX (in./hr)
2	2	3.6
5	2.9	4.7
10	3.9	5.6
25	4.5	6.1
50	4.9	6.8
100	5.5	7.3

These two cities will be used for the cost analysis as representing a wet area with annual precipitation greater than 40 in. and a semi-arid area with annual precipitation of less than 20 in.

A plot of the intensities vs. recurrence intervals is shown in Figure 5-6. Several observations can be made. First, intensities are about 1.8× larger in Houston, TX than in Boulder, CO. Second, the design intensities increase at a decreasing rate as the recurrence intervals increase. Urban storm drainage designs are usually sized to handle a 5-yr or 10- yr storm. Flood control systems are typically designed to provide protection for the 100-yr storm. For this example, a 5-yr recurrence interval will be used for the initial calculations. The design recurrence interval can then be varied to see its effect on total cost.

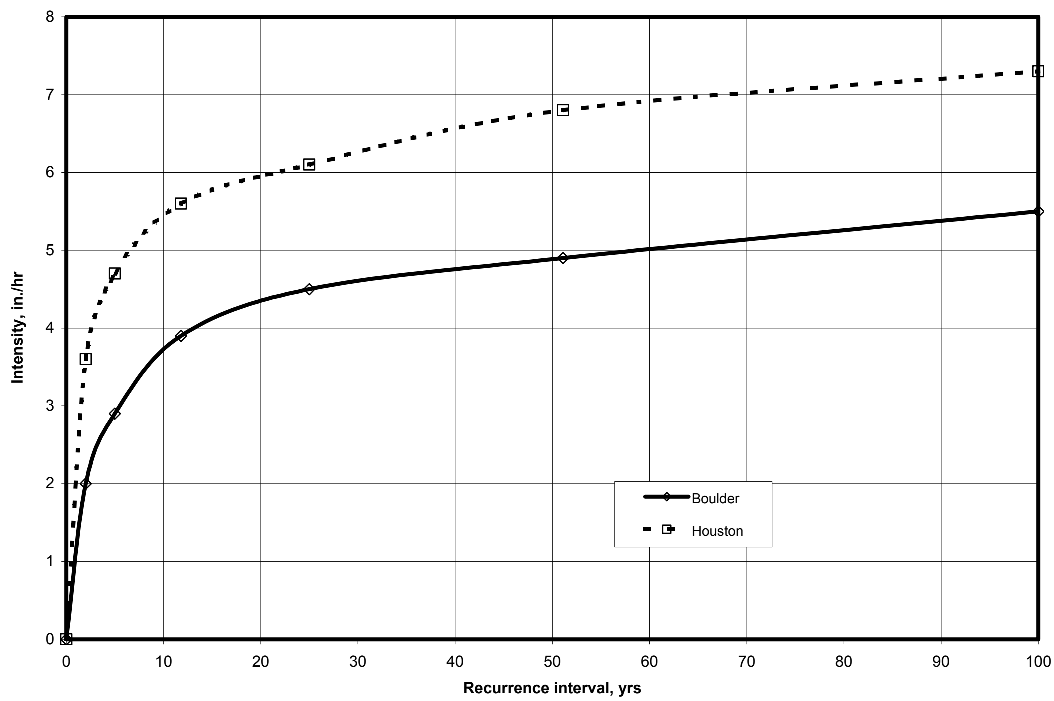


Figure 5-6. Intensities vs. recurrence interval for Boulder, CO and Houston, TX for a 20-min duration.

Intensity-Duration-Frequency (IDF) curves can be approximated by equations of the form:

$$i = kt^{b} \tag{5-4}$$

where

i = rainfall intensity, in./hr
t = time of concentration, min
k, b = parameters

The parameters of the IDF equation can be determined by forcing the curve through two points. Using Boulder, CO as an example, intensities for durations of 10 min and 60 min were estimated from the IDF graphs for various recurrence intervals. These estimates of two data points yield the necessary two equations and two unknowns. The two parameters can be calculated using:

$$b = \frac{\ln\left({}^{i_1}\!/_{i_2} \right)}{\ln\left({}^{t_1}\!/_{t_2} \right)} \tag{5-5}$$

$$k = {}^{i_1}\!/_{t_1} \tag{5-6}$$

Values of k and b for Boulder, CO are shown in Table 5-6.

Table 5-6. IDF Curve Parameters for Boulder, CO

Recurrence Interval (yrs)	*k*	*b*
2	12.169	–0.6228
5	17.234	–0.6131
10	25.072	–0.6433
25	29.655	–0.6526
50	33.127	–0.6569
100	38.796	–0.6697

Using approximating equations allows the design intensity to be easily recalculated as the time of concentration changes.

The estimated peak flow rates using the Rational Method are shown in the last column of Table 5-1. A much better way to estimate peak flows is to use real storm hydrographs and route these hydrographs through the drainage system using a simulator such as the Stormwater Management Model (SWMM) developed by the US EPA. However, this example will use the “standard practice” of the simpler Rational Method approach.

Table 5-7. Sewer Network Design Hydraulics

1	2	3	4	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Street	Type	Nodes From	To	Trial Slope ID #	Trial Slope (ft/ft)	Trial Pipe ID #	Trial Pipe Dia. (in)	Diameter Check Dia? (2 = OK)	Upstream Depth to top of pipe (ft)	Downstream Depth to top of pipe (ft)	Minimum Cover Check (2=OK)	Q_f (cfs)	Required Q (cfs)	Capacity Check Q_f>=Q? (2 = OK)	Q/Q_f	V/V_f	Full Velocity V_f (ft/sec)	Design Velocity V (ft/sec)	Velocity Check 10>V≥3 (2 = good)
Maple/Redwood	Branch	1	2																
Maple/Redwood	Branch	2	3	4	0.004	3	18	2	4.0	5.2	2	7.24	6.36	2	0.88	1.02	4.10	4.19	2
Maple/Redwood	Branch	3	4	3	0.003	4	21	2	4.9	6.4	2	9.46	9.07	2	0.96	1.02	3.93	4.02	2
Maple/Redwood	Branch	4	5	4	0.004	4	21	2	6.4	7.0	2	10.92	10.90	2	1.00	1.00	4.54	4.56	2
Maple/Redwood	Branch	5	6	3	0.003	5	24	2	6.8	7.7	2	13.50	13.35	2	0.99	1.01	4.30	4.35	2
Alpine	Branch	7B	7A																
Alpine	Branch	7A	7	4	0.004	4	21	2	4.0	5.5	2	10.92	10.10	2	0.92	1.03	4.54	4.66	2
Oak	Branch	8D	8C																
Oak	Branch	8C	8B	13	0.013	4	21	2	4.0	4.3	2	19.69	7.08	2	0.36	0.80	8.19	6.54	2
Oak	Branch	8B	8A	5	0.005	4	21	2	4.3	5.6	2	12.21	10.40	2	0.85	1.02	5.08	5.17	2
Oak	Branch	8A	8	5	0.005	5	24	2	5.4	6.7	2	17.43	13.98	2	0.80	1.01	5.55	5.59	2
Walnut	Branch	9B	9A																
Walnut	Branch	9A	9	5	0.005	4	21	2	4.0	4.3	2	12.21	7.50	2	0.61	0.94	5.08	4.77	2
W. Forest	Branch	10E	10D																
W. Forest	Branch	10D	10C	5	0.005	4	21	2	4.0	4.4	2	12.21	8.14	2	0.67	0.96	5.08	4.90	2
W. Forest	Branch	10C	10B	6	0.006	4	21	2	4.4	4.4	2	13.38	12.51	2	0.93	1.03	5.56	5.70	2
W. Forest	Branch	10B	10A	5	0.005	5	24	2	4.2	5.1	2	17.43	15.67	2	0.90	1.02	5.55	5.68	2
W. Forest	Branch	10A	10	5	0.005	5	24	2	5.1	4.4	2	17.43	16.81	2	0.96	1.02	5.55	5.67	2
E. Forest	Branch	12B	12A																
E. Forest	Branch	12A	12	10	0.01	3	18	2	4.0	4.3	2	11.45	7.16	2	0.63	0.95	6.48	6.14	2
Sycamore/Elm	Branch	11G	11F																
Sycamore/Elm	Branch	11F	11E	10	0.01	3	18	2	4.0	4.5	2	11.45	7.64	2	0.67	0.96	6.48	6.25	2
Sycamore/Elm	Branch	11E	11D	5	0.005	4	21	2	4.2	5.2	2	12.21	11.38	2	0.93	1.03	5.08	5.21	2
Sycamore/Elm	Branch	11D	11C	3	0.003	5	24	2	5.0	4.2	2	13.50	11.29	2	0.84	1.02	4.30	4.37	2
Sycamore/Elm	Branch	11C	11B	14	0.014	5	24	2	4.2	4.2	2	29.17	13.92	2	0.48	0.87	9.29	8.11	2
Sycamore/Elm	Branch	11B	11A	5	0.005	5	24	2	4.2	4.6	2	17.43	16.07	2	0.92	1.03	5.55	5.69	2
Sycamore/Elm	Branch	11A	11	3	0.003	6	27	2	4.3	4.5	2	18.49	17.67	2	0.96	1.02	4.65	4.76	2
Ash/Acorn/Birch	Branch	13G	13F																
Ash/Acorn/Birch	Branch	13F	13E	16	0.0175	3	18	2	4.0	4.5	2	15.14	7.65	2	0.51	0.89	8.57	7.61	2
Ash/Acorn/Birch	Branch	13E	13D	16	0.0175	3	18	2	4.5	4.7	2	15.14	10.76	2	0.71	0.98	8.57	8.39	2
Ash/Acorn/Birch	Branch	13D	13C	5	0.005	4	21	2	4.4	4.2	2	12.21	12.14	2	0.99	1.01	5.08	5.13	2
Ash/Acorn/Birch	Branch	13C	13B	8	0.008	4	21	2	4.2	5.0	2	15.45	15.31	2	0.99	1.01	6.42	6.50	2
Ash/Acorn/Birch	Branch	13B	13A	10	0.01	5	24	2	4.8	4.8	2	24.65	18.20	2	0.74	0.99	7.85	7.76	2
Ash/Acorn/Birch	Branch	13A	13	7	0.007	5	24	2	4.8	7.5	2	20.63	20.48	2	0.99	1.01	6.57	6.64	2
East Birch	Branch	13I	13H																
East Birch	Branch	13H	13	4	0.004	4	21	2	4.0	4.1	2	10.92	9.29	2	0.85	1.02	4.54	4.62	2
W. Cedar	Branch	14D	14C																
W. Cedar	Branch	14C	14B	6	0.006	3	18	2	4.0	4.3	2	8.87	8.26	2	0.93	1.03	5.02	5.15	2
W. Cedar	Branch	14B	14A	17	0.02	3	18	2	4.3	4.6	2	16.19	12.15	2	0.75	0.99	9.16	9.11	2
W. Cedar	Branch	14A	14	7	0.007	4	21	2	4.3	5.2	2	14.45	14.26	2	0.99	1.01	6.01	6.09	2
E. Cedar	Branch	14E	14F																
E. Cedar	Branch	14F	14	7	0.007	3	18	2	4.0	4.2	2	9.58	6.17	2	0.64	0.95	5.42	5.17	2
Aspen	Branch	15B	15A																
Aspen	Branch	15A	15	9	0.009	3	18	2	4.0	4.1	2	10.86	7.42	2	0.68	0.97	6.15	5.96	2
W. Ashmont	Branch	16C	16B																
W. Ashmont	Branch	16B	16A	11	0.011	3	18	2	4.0	4.3	2	12.01	11.89	2	0.99	1.01	6.79	6.88	2
W. Ashmont	Branch	16A	16	9	0.009	4	21	2	4.1	5.3	2	16.38	16.01	2	0.98	1.02	6.81	6.94	2
E. Ashmont	Branch	16E	16D																
E. Ashmont	Branch	16D	16	16	0.0175	3	18	2	4.0	4.0	2	15.14	9.56	2	0.63	0.95	8.57	8.15	2
Highland	Branch	17B	17A																
Highland	Branch	17A	17	20	0.0401	7	30	2	4.0	4.02	2	89.52	9.87	2	0.11	0.54	18.24	9.93	2
Maple/Redwood	Trunk	6	7																
Alpine	Trunk	7	8	14	0.014	5	24	2	4.0	7.0	2	29.17	22.19	2	0.76	1.00	9.29	9.25	2
Oak	Trunk	8	9	13	0.013	8	36	2	6.0	5.5	2	82.88	35.74	2	0.43	0.84	11.73	9.91	2
Walnut	Trunk	9	10	10	0.01	8	36	2	5.5	6.7	2	72.69	42.99	2	0.59	0.93	10.28	9.60	2
Forest	Trunk	10	11	8	0.008	8	36	2	6.7	9.2	2	65.02	63.40	2	0.98	1.02	9.20	9.38	2
Elm	Trunk	11	12	6	0.006	9	42	2	8.7	11.0	2	84.93	77.59	2	0.91	1.03	8.83	9.05	2
Forest	Trunk	12	13	5	0.005	10	48	2	10.5	11.3	2	110.70	102.79	2	0.93	1.03	8.81	9.03	2
Birch	Trunk	13	14	5	0.005	11	60	2	10.3	11.0	2	200.71	131.39	2	0.65	0.96	10.22	9.79	2
Cedar	Trunk	14	15	4	0.004	11	60	2	11.0	12.7	2	179.52	144.73	2	0.81	1.01	9.14	9.22	2
Aspen	Trunk	15	16	4	0.004	11	60	2	12.7	11.6	2	179.52	149.02	2	0.83	1.01	9.14	9.27	2
Ashmont	Trunk	16	17	4	0.004	11	60	2	11.6	8.5	2	179.52	166.06	2	0.93	1.03	9.14	9.38	2
Highland	Trunk	17	18	4	0.004	11	60	2	8.5	5.2	2	179.52	171.08	2	0.95	1.02	9.14	9.36	2

5.1.2 Sizing the sewer pipes and their slopes

The calculations for selecting a feasible solution to the storm drainage design are shown in Table 5-7. Using this template, the engineer selects from among 20 available sewer sizes and 20 assumed slopes. It is convenient to number these options 1–20 and then use a lookup table to input the associated pipe diameters and slopes. The design requirements for this sewer network are as follow:

1. The minimum depth of cover is 4 ft.
2. Stormwater can flow in the street for the first section only.
3. The flow capacity of the pipe must exceed the estimated peak flow.
4. No downstream pipe can be smaller in diameter than its upstream pipe.
5. Where multiple pipes enter a single manhole, the depth of the manhole is the maximum required depth.
6. The minimum velocity of flow in the sewer under design conditions is 3.0 ft/s. The model computes the velocity for full or partially full pipes as appropriate.

Using a trial and error procedure, the pipe diameters and slopes are varied until all of the above conditions are satisfied. This spreadsheet template is an advanced way to do storm sewer design. In a typical design, only a few scenarios are evaluated before settling on a final design. The feasible solution shown in Table 5-7 is based on several trials that included evaluation of the system cost. Thus, diameters and slopes were varied in order to reduce the total cost. The basic tradeoff in conventional storm sewer design is that a larger pipe can be laid at a flatter slope. Thus, added pipe costs are offset by reduced excavation costs.

Column 8 of Table 5-7 is the design diameter in inches, which is restricted to a given set of diameters within a lookup table. Column 6 is the slope of the pipe, which is also restricted to a group of slopes from a lookup table. Column 10 is the computed upstream crown elevation. Column 11 is the computation of the downstream crown elevation. Each of the calculations within each link (row) is matched to subsequent downstream elevations, and a check is made for the minimum cover constraint in column 11. Column 18 is the computation of the full flow within the pipe, and column 19 is the computation of the pipe flowing under the design conditions. The choice of pipe diameter is restricted such that the capacity of a pipe is not exceeded. Next the ratios of Q/Q_f are calculated in column 16, which then leads to the v/v_f in column 17 using the ratios for a partially full pipe. The velocity of the pipe flowing full is calculated by dividing the full flow rate in column 12 by the cross sectional area of the pipe(function of the pipe diameter) and is listed in column 17. Column 18 is velocity of the partially full pipe, calculated from the ratio in column 16. Details of the pipe hydraulics are described in Miles and Heaney (1988).

Table 5-8. Sewer Network Design Cost

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Street	Type	Nodes From	To	Length (ft)	Ground Elev. Upper (ft)	Lower (ft)	Soil	Pipe Diameter (in)	Pipe Slope	Side Slope Horz./Vert.	Upper Invert Elev. (ft)	Lower Invert Elev. (ft)	Pipe Cost ($)	Avg. Depth (ft)	Avg. Width (ft)	Total Volume (yd^3)	Excavation Cost ($\$/yd^3$)	Total ($)	Bedding Cost ($)	Manhole Depth (ft)	Manhole Cost ($)	Total Cost ($)
Maple/Redwood	Branch	1	2	279	207.0	206.7	Silt															
Maple/Redwood	Branch	2	3	299	206.7	206.7	Silt	18	0.004	1.50	201.19	200.00	5,673	6.10	10.65	718	6.72	4,821	3,099	5.5	2,360	15,953
Maple/Redwood	Branch	3	4	272	206.7	207.3	Silt	21	0.003	1.50	200.00	199.18	6,263	7.43	12.02	901	6.72	6,052	3,605	6.69	2,834	18,754
Maple/Redwood	Branch	4	5	148	207.3	207.3	Silt	21	0.004	1.50	199.18	198.59	3,396	8.46	33.65	1557	6.72	10,461	1,954	8.17	3,411	19,221
Maple/Redwood	Branch	5	6	325	207.3	207.3	Silt	24	0.003	1.50	198.59	197.61	8,964	9.25	14.91	1658	6.72	11,136	4,753	8.76	3,640	28,494
Alpine	Branch	7B	7A	367	207.0	206.0	Silt			1.50							6.72					
Alpine	Branch	7A	7	367	206.0	206.0	Silt	21	0.004	1.50	200.28	198.81	8,451	6.48	10.60	936	6.72	6,286	4,864	5.75	2,459	22,061
Oak	Branch	8D	8C	328	208.3	208.0	Silt			1.50							6.72					
Oak	Branch	8C	8B	328	208.0	204.1	Silt	21	0.013	1.50	202.25	197.99	7,544	5.91	9.75	700	6.72	4,703	4,342	5.75	2,459	19,049
Oak	Branch	8B	8A	328	204.1	203.7	Silt	21	0.005	1.50	197.99	196.35	7,544	6.73	10.97	898	6.72	6,030	4,342	6.08	2,589	20,506
Oak	Branch	8A	8	328	203.7	203.4	Silt	24	0.005	1.50	196.35	194.71	9,053	8.04	13.07	1277	6.72	8,579	4,800	7.39	3,107	25,538
Walnut	Branch	9B	9A	394	207.0	204.1	Silt			1.50							6.72					
Walnut	Branch	9A	9	394	204.1	202.4	Silt	21	0.005	1.50	198.32	196.35	9,062	5.91	9.75	841	6.72	5,652	5,216	5.75	2,459	22,389
W. Forest	Branch	10E	10D	394	210.0	207.3	Silt			1.50							6.72					
W. Forest	Branch	10D	10C	344	207.3	206.0	Silt	21	0.005	1.50	201.60	199.87	7,923	5.96	9.81	745	6.72	5,006	4,560	5.75	2,459	19,949
W. Forest	Branch	10C	10B	328	206.0	204.1	Silt	21	0.006	1.50	199.87	197.91	7,546	6.16	10.12	757	6.72	5,086	4,343	6.16	2,622	19,598
W. Forest	Branch	10B	10A	328	204.1	203.4	Silt	24	0.005	1.50	197.91	196.27	9,055	6.65	10.98	887	6.72	5,961	4,801	6.16	2,622	22,440
W. Forest	Branch	10A	10	246	203.4	201.4	Silt	24	0.005	1.50	196.27	195.03	6,791	6.78	11.16	689	6.72	4,630	3,601	7.14	3,011	18,033
E. Forest	Branch	12B	12A	328	208.3	206.7	Silt			1.50							6.72					
E. Forest	Branch	12A	12	328	206.7	203.7	Silt	18	0.01	1.50	201.19	197.91	6,232	5.66	9.25	636	6.72	4,273	3,405	5.50	2,360	16,269
Sycamore/Elm	Branch	11G	11F	328	215.9	212.3	Clay			1.00							7.09					
Sycamore/Elm	Branch	11F	11E	279	212.3	210.0	Clay	18	0.01	1.00	206.77	203.98	5,298	5.75	6.50	386	7.09	2,732	2,269	5.50	2,360	12,660
Sycamore/Elm	Branch	11E	11D	262	210.0	209.6	Clay	21	0.005	1.00	203.98	202.67	6,037	6.48	7.36	464	7.09	3,287	2,778	5.99	2,556	14,658
Sycamore/Elm	Branch	11D	11C	82	209.6	208.7	Clay	24	0.003	1.00	202.67	202.42	2,264	6.61	7.61	153	7.09	1,082	952	6.98	2,945	7,243
Sycamore/Elm	Branch	11C	11B	328	208.7	204.1	Clay	24	0.014	1.00	202.42	197.83	9,055	6.24	7.24	549	7.09	3,888	3,809	6.24	2,653	19,406
Sycamore/Elm	Branch	11B	11A	328	204.1	202.8	Silt	24	0.005	1.50	197.83	196.19	9,055	6.40	10.60	825	6.72	5,541	4,801	6.24	2,653	22,051
Sycamore/Elm	Branch	11A	11	295	202.8	202.1	Silt	27	0.003	1.50	196.19	195.30	9,714	6.68	11.15	814	6.72	5,471	4,321	6.57	2,783	22,289
Ash/Acorn/Birch	Branch	13G	13F	328	229.0	221.8	Clay			1.00							7.09					
Ash/Acorn/Birch	Branch	13F	13E	328	221.8	216.5	Clay	18	0.0175	1.00	216.28	210.54	6,234	5.75	6.50	454	7.09	3,214	2,670	5.50	2,360	14,477
Ash/Acorn/Birch	Branch	13E	13D	328	216.5	211.0	Clay	18	0.0175	1.00	210.54	204.80	6,234	6.07	6.82	504	7.09	3,570	2,670	5.99	2,556	15,029
Ash/Acorn/Birch	Branch	13D	13C	82	211.0	210.3	Clay	21	0.005	1.00	204.80	204.39	1,886	6.03	6.91	127	7.09	897	868	6.16	2,621	6,273
Ash/Acorn/Birch	Branch	13C	13B	394	210.3	208.0	Clay	21	0.008	1.00	204.39	201.24	9,055	6.34	7.21	666	7.09	4,722	4,167	5.91	2,523	20,468
Ash/Acorn/Birch	Branch	13B	13A	394	208.0	204.1	Silt	24	0.01	1.50	201.24	197.30	10,866	6.76	11.14	1099	6.72	7,383	5,761	6.76	2,861	26,871
Ash/Acorn/Birch	Branch	13A	13	394	204.1	204.1	Silt	24	0.007	1.50	197.30	194.55	10,866	8.14	13.21	1568	6.72	10,535	5,761	6.76	2,861	30,023
East Birch	Branch	13I	13H	262	208.7	205.7	Silt			1.50							6.72					
East Birch	Branch	13H	13	262	205.7	204.7	Silt	21	0.004	1.50	199.96	198.91	6,026	5.78	9.55	536	6.72	3,599	3,468	5.75	2,459	15,552
W. Cedar	Branch	14D	14C	262	212.9	210.6	Clay			1.00							7.09					
W. Cedar	Branch	14C	14B	262	210.6	209.3	Clay	18	0.006	1.00	205.13	203.55	4,987	5.63	6.38	349	7.09	2,476	2,136	5.50	2,360	11,958
W. Cedar	Branch	14B	14A	262	209.3	204.4	Clay	18	0.02	1.00	203.55	198.30	4,987	5.93	6.68	385	7.09	2,726	2,136	5.76	2,464	12,313
W. Cedar	Branch	14A	14	262	204.4	203.4	Clay	21	0.007	1.00	198.30	196.47	6,037	6.52	7.39	468	7.09	3,319	2,778	6.09	2,595	14,729
E. Cedar	Branch	14E	14F	262	208.3	205.1	Clay			1.00							7.09					
E. Cedar	Branch	14F	14	262	205.1	203.4	Clay	18	0.007	1.00	199.55	197.71	4,987	5.60	6.35	345	7.09	2,449	2,136	5.50	2,360	11,931
Aspen	Branch	15B	15A	328	207.3	206.4	Clay			1.00							7.09					
Aspen	Branch	15A	15	262	206.4	204.1	Clay	18	0.009	1.00	200.86	198.50	4,978	5.53	6.28	337	7.09	2,389	2,132	5.50	2,360	11,858
W. Ashmont	Branch	16C	16B	328	213.3	206.7	Rock			0.00							86.29					
W. Ashmont	Branch	16B	16A	328	206.7	203.4	Rock	18	0.011	0.00	201.19	197.58	6,232	5.66	0.75	52	86.29	4,452	1,189	5.50	2,360	14,233
W. Ashmont	Branch	16A	16	246	203.4	202.4	Rock	21	0.009	0.00	197.58	195.37	5,659	6.44	0.88	51	86.29	4,433	1,302	5.83	2,490	13,885
E. Ashmont	Branch	16E	16D	262	210.0	206.7	Rock			0.00							86.29					
E. Ashmont	Branch	16D	16	246	206.7	202.4	Rock	18	0.0175	0.00	201.19	196.88	4,675	5.52	0.75	38	86.29	3,256	892	5.50	2,360	11,182
Highland	Branch	17B	17A	262	211.3	208.3	Rock			0.00							86.29					
Highland	Branch	17A	17	246	208.3	198.5	Rock	30	0.0401	0.00	201.83	191.97	13,727	6.51	1.25	74	86.29	6,398	1,339	6.50	2,757	24,221
Maple/Redwood	Trunk	6	7				Silt															
Alpine	Trunk	7	8	400	206.0	203.4	Silt	24	0.014	1.50	200.03	194.43	11,047	7.49	12.23	1358	6.72	9,125	5,857			26,029
Oak	Trunk	8	9	36	203.4	202.4	Silt	36	0.013	1.50	194.43	193.96	2,685	8.72	14.58	170	6.72	1,142	528			4,355
Walnut	Trunk	9	10	220	202.4	201.4	Silt	36	0.01	1.50	193.96	191.76	16,354	9.07	15.11	1116	6.72	7,494	3,217			27,065
Forest	Trunk	10	11	230	201.4	202.1	Silt	36	0.008	1.50	191.76	189.93	17,086	10.92	17.89	1662	6.72	11,165	3,361			31,612
Elm	Trunk	11	12	112	202.1	203.7	Clay	42	0.006	1.00	189.93	189.26	9,526	13.33	15.08	830	7.09	5,882	1,295			16,704
Forest	Trunk	12	13	95	203.7	204.1	Clay	48	0.005	1.00	189.26	188.78	9,733	14.88	16.88	885	7.09	6,275	1,105			17,113
Birch	Trunk	13	14	282	204.1	203.4	Clay	60	0.005	1.00	188.78	187.37	41,391	15.66	18.16	2973	7.09	21,066	3,276			65,734
Cedar	Trunk	14	15	246	203.4	204.1	Clay	60	0.004	1.00	187.37	186.39	36,097	16.86	19.36	2974	7.09	21,081	2,857			60,035
Aspen	Trunk	15	16	144	204.1	202.4	Clay	60	0.004	1.00	186.39	185.81	21,177	17.15	19.65	1801	7.09	12,767	1,676			35,620
Ashmont	Trunk	16	17	203	202.4	198.5	Rock	60	0.004	0.00	185.81	185.00	29,840	15.06	2.50	284	86.29	24,466	1,107			55,414
Highland	Trunk	17	18	164.04	198.5	194.6	Rock	60	0.004	0.00	185.00	184.34	24,065	11.85	2.50	180	86.29	15,534	893			40,492

5.1.3 Sewer system cost evaluation

Finally, Table 5-8 does the cost estimation for the entire system. Column 10 is the pipe slope from Table 5-7. Based upon the soil type of column 8, and a lookup table, a side slope ratio of horizontal to vertical is chosen in column 11. Column 12 is the upstream invert elevation, computed by multiplying the slope of column 10 by the pipe length of column 5 and subtracting this from column 13. Column 13 is the downstream invert elevation, computed by using the pipe diameter, the previous link invert elevation, and the slope from column 10.

The ground elevations, soil types, cost of the pipes and manholes, and excavation costs are calculated for a mix of selected pipe diameter and slope scenarios. Pipe costs are estimated using lookup table values in Tables 5.9 or 5.10 for CMP or RCP pipe, respectively. These costs are computed in column 14 of Table 5-8.

Table 5-9. Lookup Table for Corrugated Metal Pipe (Adapted from RS Means, 1996a)

Diameter	CMP Pipe Cost (1/99 $/ft)
8	9.40
10	11.80
12	14.40
15	18.40
18	20.90
24	30.10
30	37.20
36	54.80
48	81.60
60	118.20
72	179.50

Excavation costs depend on the volume of excavation and the unit excavation costs. The lookup table values for these costs are listed in Table 5-11. The volume of excavation is calculated as follows:

$$V = \frac{LWH}{27} \tag{5-7}$$

Where

V = excavation volume, yd^3

L = distance between manholes, ft

W = the average of the trench top and bottom widths (bottom is D+1.5), ft

H = average excavation depth, ft

Table 5-10. Lookup table for reinforced concrete pipe (Adapted from RS Means, 1996a).

Diameter (in.)	RCP Pipe Cost (1/99 $/ft)
12	15.70
15	16.60
18	19.00
21	23.00
24	27.60
27	32.90
30	55.80
36	74.40
42	85.40
48	102.30
60	146.70
72	192.60
84	288.90
96	355.60

The average depth of the excavation is computed in column 15 of Table 5-8. The average width of the excavation is calculated as an average of the top and bottom widths, and is listed in column 16 of Table 5-8. The total volume is computed using equation 5.8 and results listed in column 17.

Excavation costs, C_{ex}, are calculated as:

$$C_{ex} = c_{ex} V \tag{5-8}$$

The unit excavation cost, c_{ex}, is a function of the soil type, which were explained in Table 3-2, and are listed again in Table 5-9. These costs are computed in column 18 and 19 of Table 5-8.

Table 5-11. Excavation Costs (Adapted from RS Means, 1996a)

Soil Type	Horizontal	Vertical	Excavation Cost (1/99 $/yr^3)
Clay	1	1	7.09
Rock	0	1	86.29
Sand	2	1	6.12
Silt	1.5	1	6.72

Bedding costs are evaluated based upon a two variable lookup function that uses side slope and diameter to determine costs. The lookup values are presented in Table 5-12, and the results are presented in column 20 of Table 5-8.

Manhole costs are estimated using the following equation:

$$C_{mh} = 482H^{0.9317} \tag{5-9}$$

Where

C_m = cost of manhole, 1/99 \$
H = height of manhole, ft
(maximum difference between the ground elevation and the invert elevations of sewers entering the manhole)

These costs are computed in column 22 of Table 5-8.

5.2 Scenario Analysis

The results shown in Tables 5-1, 5-7, and 5-8 reflect the costs for sets of such assumed input conditions as topography, land use, design storm, performance criteria, and pipe cost. The power of the spreadsheet is its ability to enable what-if design analysis. By systematically changing one or more of the input variables the impact of these variables on the total cost is more easily assessed. The classic approach is to change and assess one variable at a time. However, sensitivity analysis may be performed for a finite number of scenarios wherein many, if not all, of the input assumptions are allowed to vary, and to find the cost for each scenario. The potential number of scenarios for this problem is huge. For this initial effort, only a very small number of scenarios were selected, in order to show the impact of various scenarios on the total cost. An important caveat in this sensitivity analysis is that the base solution's effectiveness is unknown. Thus, the sensitivity analysis is done for a solution of unknown quality. This limitation can be removed in future work by using intelligent search techniques to find very good, if not optimal, solutions for each scenario. The following sub-sections describe a limited number of input variables that can be assessed to test the sensitivity of the final cost to various assumptions.

Table 5-12. Bedding Costs (Adapted form RS Means, 1996a)

Horizontal	Vertical	H/V	Diameter (in.)	Trench width (ft)	Cost (1/99 $/ft)
0	1	0	6	1	0.92
0	1	0	8	2	2.00
0	1	0	10	2	2.07
0	1	0	12	2	2.12
0	1	0	14	3	3.47
0	1	0	15	3	3.51
0	1	0	16	3	3.57
0	1	0	18	3	3.62
0	1	0	20	4	5.25
0	1	0	21	4	5.29
0	1	0	24	4	5.44
0	1	0	30	4	5.55
0	1	0	32	6	9.72
0	1	0	36	6	9.98
0	1	0	48	7	13.01
0	1	0	60	8	16.23
0	1	0	72	10	23.39
0	1	0	84	12	31.80
0.5	1	0.5	6	1	1.90
0.5	1	0.5	8	2	3.16
0.5	1	0.5	10	2	3.43
0.5	1	0.5	12	2	3.67
0.5	1	0.5	14	3	5.25
0.5	1	0.5	15	3	5.39
0.5	1	0.5	16	3	5.55
0.5	1	0.5	18	3	5.88
0.5	1	0.5	20	4	7.77
0.5	1	0.5	21	4	7.95
0.5	1	0.5	24	4	8.52
0.5	1	0.5	30	4	9.56
0.5	1	0.5	32	6	14.06
0.5	1	0.5	36	6	15.08
0.5	1	0.5	48	7	20.58
0.5	1	0.5	60	8	26.81
0.5	1	0.5	72	10	37.47
0.5	1	0.5	84	12	49.71
1	1	1	6	1	2.90
1	1	1	8	2	4.36
1	1	1	10	2	4.77
1	1	1	12	2	5.25
1	1	1	14	3	7.06
1	1	1	15	3	7.30
1	1	1	16	3	7.56
1	1	1	18	3	8.14
1	1	1	20	4	10.28
1	1	1	21	4	10.59
1	1	1	24	4	11.61
1	1	1	30	4	13.50
1	1	1	32	6	18.46
1	1	1	36	6	20.17
1	1	1	48	7	28.17
1	1	1	60	8	37.40
1	1	1	72	10	51.76
1	1	1	84	12	67.70
1.5	1	1.5	6	1	3.91
1.5	1	1.5	8	2	5.69
1.5	1	1.5	10	2	6.15
1.5	1	1.5	12	2	6.81

Horizontal	Vertical	H/V	Diameter (in.)	Trench width (ft)	Cost (1/99 $/ft)
1.5	1	1.5	14	3	8.83
1.5	1	1.5	15	3	9.18
1.5	1	1.5	16	3	9.56
1.5	1	1.5	18	3	10.38
1.5	1	1.5	20	4	12.80
1.5	1	1.5	21	4	13.24
1.5	1	1.5	24	4	14.63
1.5	1	1.5	30	4	17.64
1.5	1	1.5	32	6	22.77
1.5	1	1.5	36	6	25.23
1.5	1	1.5	48	7	35.76
1.5	1	1.5	60	8	48.21
1.5	1	1.5	72	10	65.65
1.5	1	1.5	84	12	86.16
2	1	2	6	1	5.01
2	1	2	8	2	6.73
2	1	2	10	2	7.49
2	1	2	12	2	8.37
2	1	2	14	3	10.59
2	1	2	15	3	11.04
2	1	2	16	3	11.54
2	1	2	18	3	12.66
2	1	2	20	4	15.32
2	1	2	21	4	15.89
2	1	2	24	4	17.71
2	1	2	31	4	21.61
2	1	2	32	6	27.15
2	1	2	36	6	30.22
2	1	2	48	7	43.22
2	1	2	60	8	58.67
2	1	2	72	10	79.32
2	1	2	84	12	103.94

5.2.1 Management of the demand for imperviousness

Imperviousness can be reduced by designing narrower streets and driveways, reducing parking requirements, etc. Two cases are:

Case	Imperviousness
1	Present values
2	0.7 * Present values

5.2.2 Management of land use

The assumed land use for this example is representative of a typical mix of residential, commercial, and public land use. Two other scenarios are all low density and all high density. Thus, the three land use scenarios are:

Case	Land Use
1	Mixed
2	All residential at 2 dwelling units/acre-commercial and school are the same.
3	All residential at 10 dwelling units/acre-commercial and school are the same.

5.2.3 Effect of recurrence interval

The selected design storm recurrence intervals are assumed to range from 2 to 100 yr. A 2 yr level represents a minimum level of service, whereas a 100 yr level would represent an upper limit on drainage systems. Three cases can be considered:

Case	**Recurrence Interval (yrs)**
1	2
2	5
3	100

5.2.4 Effect of climate

The sophistication of the drainage system is expected to vary widely from the wetter areas of the country with high intensity storms to very arid areas with low intensities. For this analysis, IDF curves from Boulder, CO and Houston, TX are used. Peak intensities in Houston are about 40% higher than in Boulder. Thus, two cases are:

Case	**City**
1	Boulder, CO
2	Houston, TX

5.2.5 Effect of assumed minimum inlet flow time

Our preliminary simulations indicate the importance of the assumed inlet time. Inlet time should be calculated. In our case, the calculated inlet time was only 2–3 min. If this inlet time is used, then very high intensities result. The usual assumption in stormwater manuals is to use a 5 – 20 min inlet time. For the base case, a 20 min inlet time was used. Two other cases can be considered:

Case	**Inlet Time (min)**
1	Calculated
2	5
3	20

5.2.6 Required minimum depth of cover

The minimum depth of cover is a function of local climate, groundwater conditions, the presence of basements, etc. For this example, two minimum depths can be used:

Case	Minimum Depth of Cover (ft)
1	4
2	6

5.2.7 Effect of pipe material

The unit cost of pipe depends on the type of material. The optimal type of pipe is a complex issue and a life cycle cost analysis should be done to decide which pipe material is better for a given location. Pipe cost information has been developed for corrugated metal pipe and reinforced concrete pipe. These two options provide two sets of scenarios.

Case	Pipe Material
1	Corrugated Metal
2	Reinforced Concrete

5.2.8 Possible number of scenarios

The number of cases enumerated above are just a small percentage of the possible cases that could be considered. The combinations are listed below:

Input Variable	Cases
Imperviousness	2
Land Use	3
Recurrence Interval	3
Climate	2
Inlet Flow Time	3
Depth of Cover	2
Pipe Material	2

The number of possible combinations is the product of the above seven cases, or 432 possible scenarios, far more than we can deal with in this introductory evaluation. The selected initial five scenarios are presented below:

Scenario 1. Boulder, CO typical

Input Variable	Value
Imperviousness	Present imperviousness
Land Use	Existing mixed land use
Recurrence Interval	5 yrs
Climate	Boulder, CO
Inlet Flow Time	20 min
Depth of Cover	4 ft
Pipe material	RCP

Scenario 2. Houston, TX typical

Input Variable	Value
Imperviousness	Present imperviousness
Land Use	Existing mixed land use
Recurrence Interval	5 yrs
Climate	Houston,TX
Inlet Flow Time	20 min
Depth of Cover	4 ft
Pipe material	RCP

Scenario 3. Boulder, CO major flood

Input Variable	Value
Imperviousness	Present imperviousness
Land Use	Existing mixed land use
Recurrence Interval	100 yrs
Climate	Boulder, CO
Inlet Flow Time	20 min
Depth of Cover	4 ft
Pipe material	RCP

Scenario 4. Boulder, CO 5-yr storm with calculated inlet time

Input Variable	Value
Imperviousness	Present imperviousness
Land Use	Existing mixed land use
Recurrence Interval	100 yrs
Climate	Boulder, CO
Inlet Flow Time	Calculated
Depth of Cover	4 ft
Pipe material	RCP

Scenario 5. Boulder, CO typical with different pipe material

Input Variable	Value
Imperviousness	Present imperviousness
Land Use	Existing mixed land use
Recurrence Interval	5 yrs
Climate	Boulder, CO
Inlet Flow Time	20 min
Depth of Cover	4 ft
Pipe material	CMP

5.3 Results for the Selected Scenarios

Upon selection of the assumed scenario parameters (land use, design event, inlet time, minimum depth of cover), appropriate design variables (pipe diameter, pipe slope) are entered into the spreadsheet in a trial and error fashion. For the first scenario, a 5-yr. storm was selected from the IDF relationship for the local Boulder, CO area. The inlet flow time was assumed 20 min for all sub-basins. After these hydrologic and hydraulic assumptions were made, a feasible design was found by entering slopes and pipe diameters for each section. The feasibility of the design is established through design constraints built into the spreadsheet template (i.e., minimum pipe velocity, minimum cover depth).

The cost for this design is calculated based on the selected feasible design parameters of slope and pipe diameter. It is likely that this problem will have many feasible solutions, that can be improved upon only by further trial and error. The final cost for the first scenario is $975,000, including a geographic location factor of 92% to account for local deviation from the national average (the cost functions are based on national averages). This total is broken into pipe costs, excavation costs, bedding costs, and manhole costs in Table 5-13 and Figure 5-7.

Table 5-13. Summary of Cost Scenarios

	1. Boulder 5-Yr (1/99 $)	2. Houston 5-Yr (1/99 $)	3. Boulder 100-Yr (1/99 $)	4. Boulder 5-Yr Calculated Inlet Time (1/99 $)	5. Boulder 5-Yr With Corrugated Steel (1/99 $)	6. Scenario 1 5-Yr With Uncertain Costs (1/99 $)
Total	975,000	1,174,000	1,264,000	1,444,000	1,029,000	975,000
Pipe	439,000	556,000	600,000	749,000	456,000	439,000
Excavation	287,000	338,000	374,000	386,000	319,000	287,000
Bedding	161,000	187,000	193,000	216,000	163,000	161,000
Manhole	88,000	93,000	97,000	93,000	91,000	88,000
					Min. Total	538,000
					Max. Total.	1,299,000
					Std. Dev.	111,000

Scenario 1 was then altered to reflect an identical design done for the Houston, TX area. The Houston, TX area receives approximately 80% more rainfall than Boulder, CO so the design must reflect a higher 5-yr peak flow rate. The selected feasible design for Houston, TX had steeper slopes and larger pipe diameters to convey the increased flow. This resulted in an increase of 20% over the Boulder, CO design, including the reduced location factor of 90.2% for Houston, TX. The final Houston design costs were calculated to be $1,174,000.

The rainfall intensities for the Houston, TX Scenario increased by 66% over the Boulder, CO 5-yr storm scenario. The product of length of sewer (ft) and the diameter of sewer (in.) increased by 15%, and the average slope increased 10%, from .0082 to .0090. Pipe costs increased 27%, from $439,000 to $556,000. Excavation costs increased 18%, from $287,000 in scenario 1 to $338,000 in Houston, TX.

The third scenario reflected an increased level of service for the Boulder, CO 5-yr design in Scenario 1. A 100-yr design storm was selected, resulting in a larger capacity design over the 5-yr design Boulder, CO design storm. The rainfall intensity increased 91% from the 5-yr storm to the 100-yr design storm. Consequently, the final costs increased by 30% to $1,264,000. The excavation costs increased 30% over the 5-yr design storm scenario. For the selected design, pipe costs increased 37%. The average slope of the system increased from 0.0082 to 0.098.

The fourth scenario demonstrates the dependence of the final design cost on initial hydrologic assumptions. The first three scenarios assumed a 20 min rainfall inlet time. In a basin with developed land use, the flow paths taken to the first drainage inlet may be over permeable or impervious surfaces, with widely different slopes, roughness factors, etc. For this scenario, the inlet design time was calculated based on the actual dimensions of the sub-basin, and substituted for the assumed 20 min inlet time in scenario 3. The average calculated inlet time was 10.5 min for this scenario. The altered hydrologic assumptions increased the total cost 48%, from $975,000 to $1,444,000. The majority of the cost increase was in increased pipe costs; however, a cheaper solution may exist that uses smaller pipes and steeper slopes.

The selected design also failed to meet design constraints for one pipe section. Because of a steep ground surface slope for one section, a severe slope was necessary to maintain the minimum depth of cover of 4 ft over the crown of the pipe. This severe slope caused maximum design velocities to exceed the maximum velocity constraint of 10 ft/s by 1 ft/s.

A fifth scenario was included to demonstrate the use of different pipe materials. A design using corrugated steel pipe was done for the Boulder, CO 5-yr storm. This scenario also included the increased head loss in the pipe caused by the higher roughness coefficient of the steel pipe. The Manning coefficient was increased from 0.013 for reinforced concrete pipe to 0.025 for corrugated steel pipe. This change in hydraulic performance resulted in a need for larger pipes and steeper slopes. Also, for diameters greater than 18 in. steel pipes are more expensive than concrete pipes, therefore, the final cost increased 5.5% to $1,029,000. It is likely that this design can be improved upon by further trial and error. The results of the five design scenarios are shown in Figure 5-7.

5.4 Effect of Uncertainty in the Estimates

Once the design is fixed, the uncertainty in the cost for that design can be estimated using Monte Carlo simulation. In this initial evaluation, we consider only uncertainty in the assumed input cost parameters since these values do not affect the final design when one is doing what-if analysis. Changes in the assumed cost would affect the design in an optimization or what's best analysis. When using risk analysis software such as @Risk or Crystal Ball, it is straightforward to introduce uncertainty into the cost estimates and then run, say 1,000 simulations to estimate the variability in the final cost estimate that is attributable to the uncertainty in the input cost estimates. In order to do Monte Carlo simulation, one needs to input a probability distribution for each input variable that is assumed to have uncertainty. For this evaluation, Scenario 1 will be used, and the

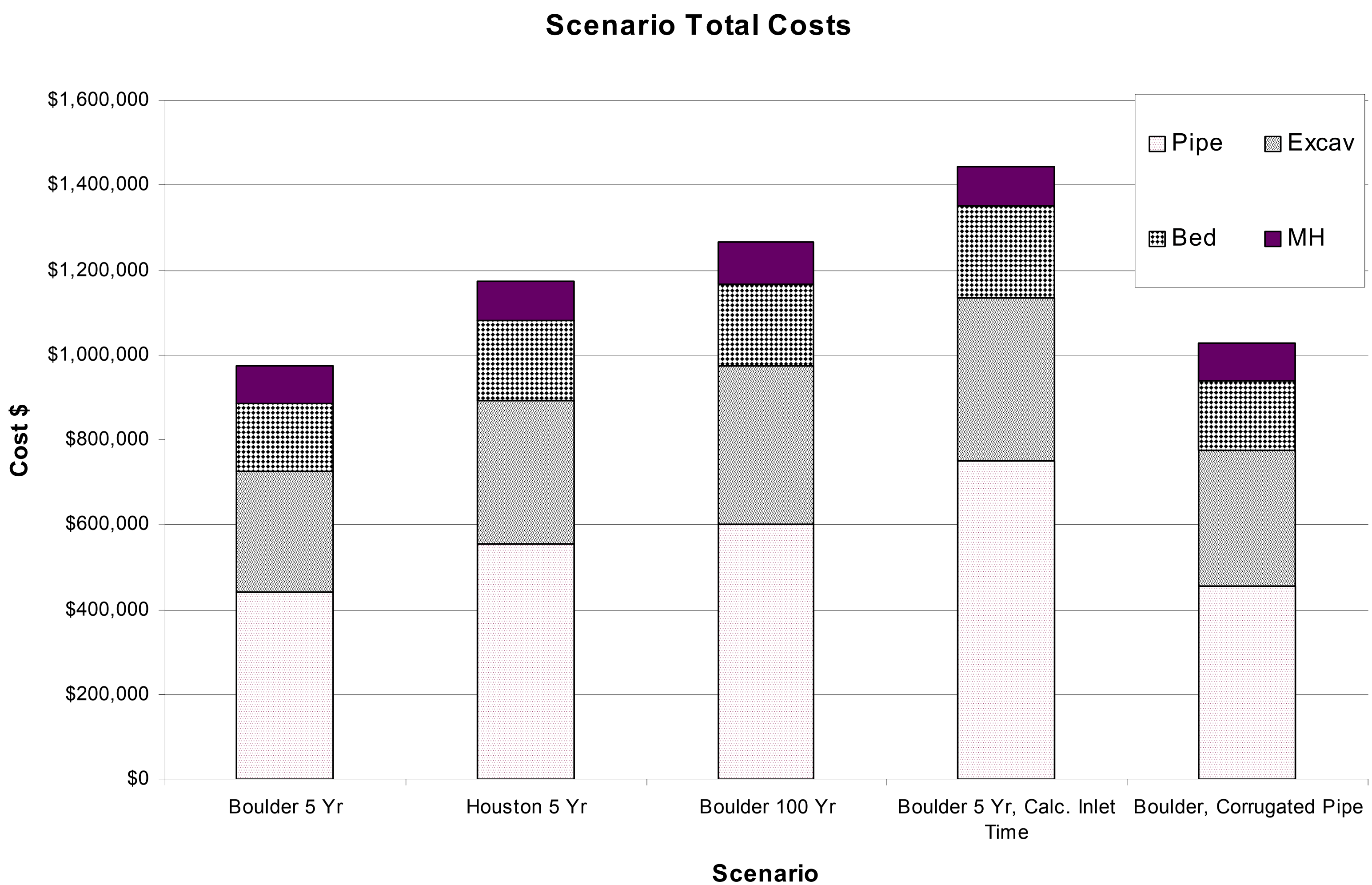


Figure 5-7. Results of the five design scenarios.

Pipe cost per inch diameter per foot: A normal distribution of the form, Normal (1, 0.25), is used to define a coefficient with a mean of one and standard deviation of .25. This coefficient is then multiplied by the mean pipe unit cost ($/ft). The following table shows the unit excavation cost for different type of soils:

Soil	Unit Excavation Cost (1/99 $/yd^3)
Clay	Triangular* (5.67; 7.09; 8.50)
Sand	Triangular* (4.87; 6.12; 7.34)
Silt	Triangular* (5.38; 6.72; 8.06)
Rock	Uniform** (69; 104)

* Triangular (minimum; mean; maximum)
**Uniform (minimum; maximum)

Monte Carlo simulation is done by repeatedly sampling from the above distributions. Each trial is a set of assumed values of the inputs. The output is the system cost for that realization. The process is repeated 1,000 times resulting in 1,000 estimates of the system cost. Finally, the cumulative distribution of these costs is determined and the results reported. Monte Carlo simulation allows us to see how uncertainty in inputs affects the final answer. It is assumed that there is no covariance between the variables.

The minimum cost recorded in the 1,000 Monte Carlo simulations was $538,000 and the maximum was $1,299,000. The mean cost of $974,867 compared well with the cost of scenario 1, $975,000. The standard deviation of the 1,000 simulation results was $111,000. The cumulative distribution of total costs is shown in Figure 5-8. The source of the variance is shown in a tornado plot depicted in Figure 5-9. The majority of the uncertainty in the final cost is due to the uncertainty assumed for the pipe costs, despite being a smaller fraction of the total costs.

5.5 Summary and Conclusions on Scenarios

The results of the five scenarios and the uncertainty analysis are shown in Table 5-13. The effect of design assumptions and initial conditions on the final outcome of the design is evident. However, hidden within these what-if analyses is the fact that the selected designs are merely one feasible solution of the many possible designs that satisfy the design constraints. When a design assumption was changed, say from the 5-yr event in scenario 1 to the 100-yr event in scenario 3, the physical design was altered greatly to convey the added flowrate. It is possible that a nearly optimal solution is compared against a sub-optimal solution in Table 5-13. Therefore, direct comparisons of design costs are impossible. While valuable, the what-if analysis does little to illuminate the optimal solution.

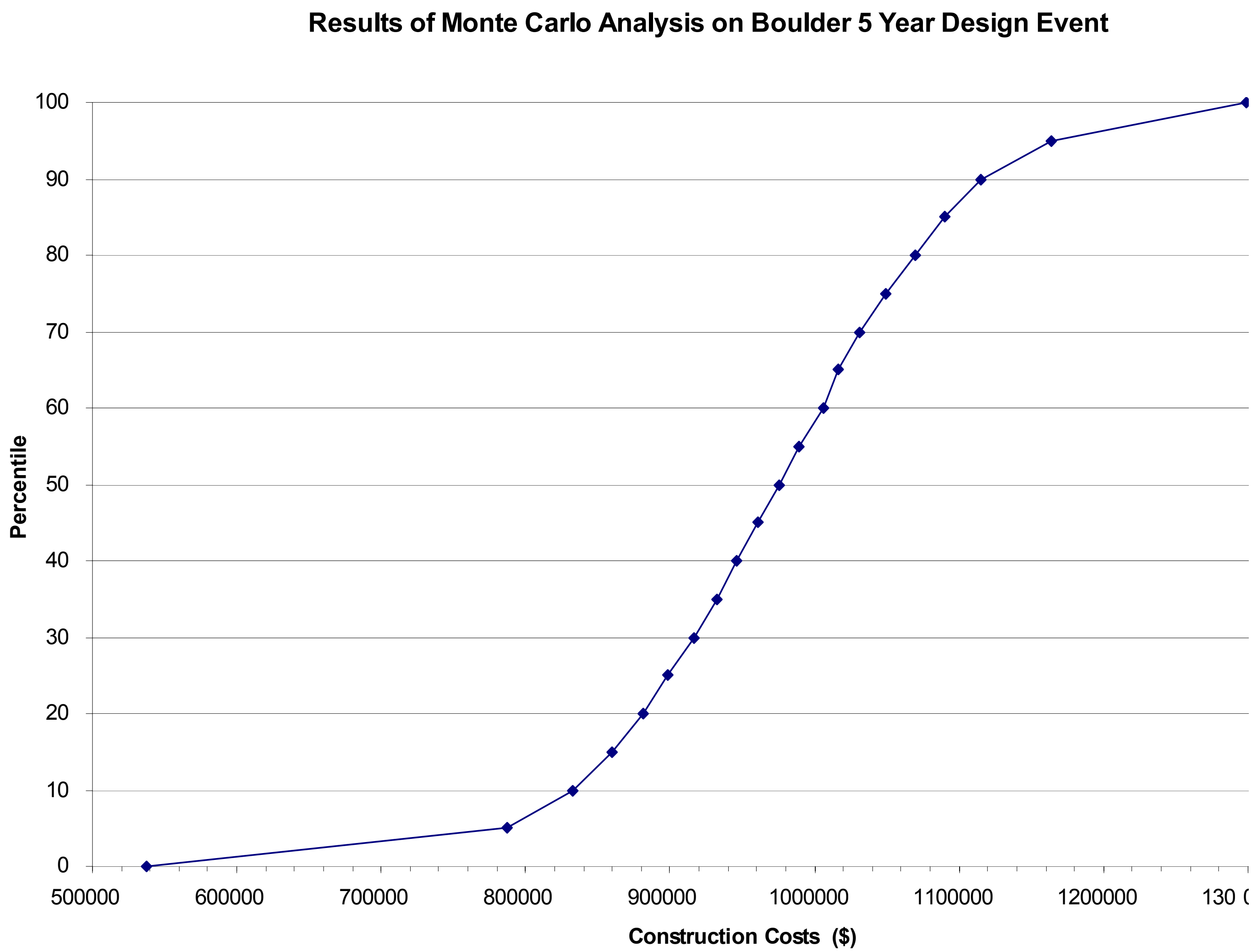


Figure 5-8. Cumulative total cost distribution

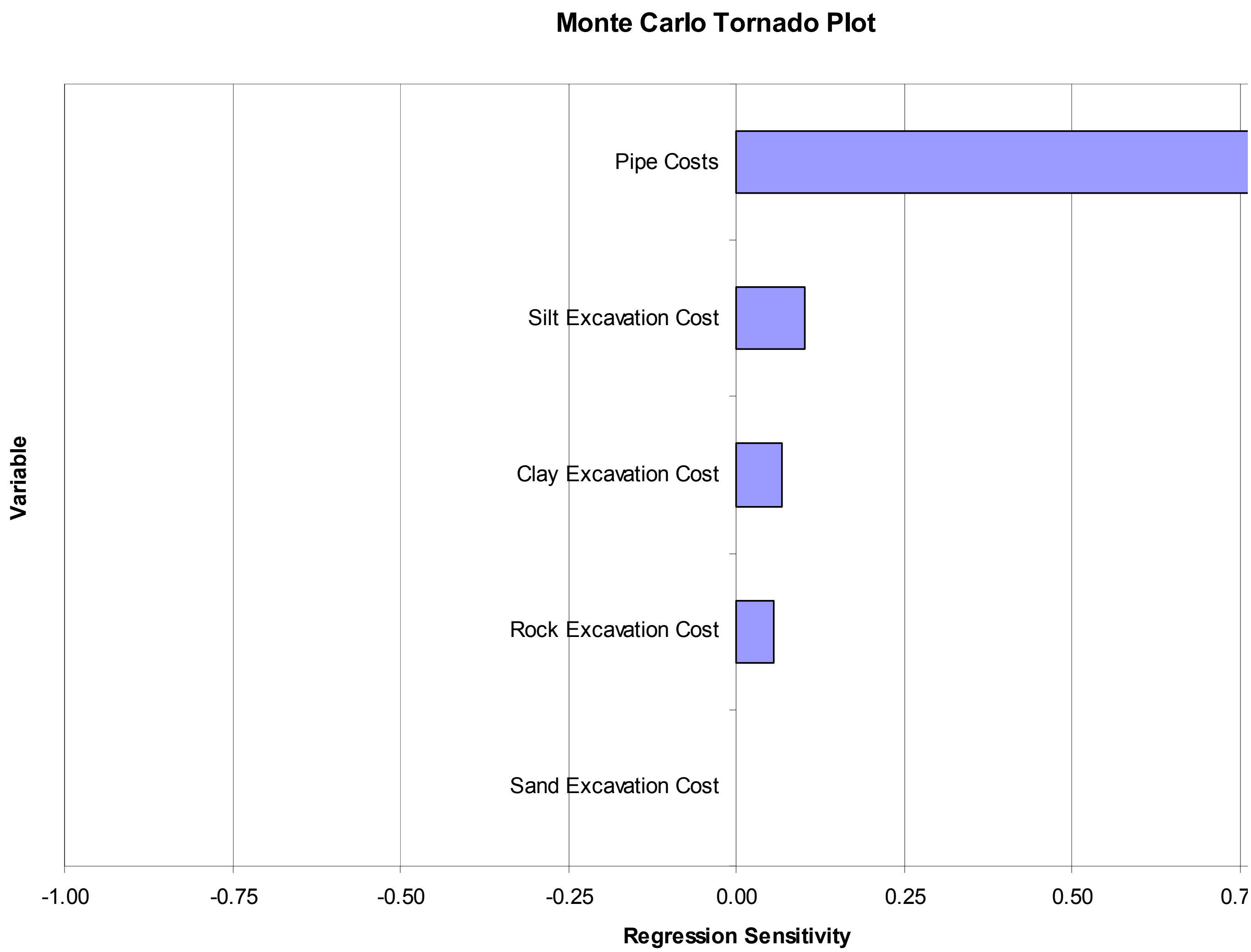


Figure 5-9. Tornado plot of uncertainty in scenario.

A more robust comparison of design costs would include optimization techniques to find optimal designs for each scenario. Then the true costs of increasing the level of service from a 5-yr storm to a 100-yr storm could be measured. To illustrate this point, assume that the design selected for Scenario 1 is very nearly optimal and the design for Scenario 3 is grossly over designed. For illustrative purposes, assume that the optimal design for the 100-yr storm in Scenario 3 is $1,000,000, and that the increased benefit from flood damage is estimated to be $250,000. That is, an estimated $250,000 will be saved over the life of the project if the drainage system is designed for a 100-yr event instead of only a 5-yr event. Under the designs found in Scenarios 1 and 3, the increased level of service ($1,264,000 – $975,000 = $289,000) would not be warranted because the costs of the increased project exceed the estimated benefits ($250,000). However, if optimal solutions were to be found for each scenario, the increased level of service in Scenario 3 would be worthwhile, because the costs of increasing the level of service from Scenario 1 to Scenario 3 ($1,000,000 – $975,000 = $25,000) would be exceeded by the expected increase in benefits ($250,000). While the example is simplified by the exclusion here of such variables as possible increased maintenance costs and uncertainty in increased benefits, it does illustrate the importance of obtaining optimal design solutions to enable direct comparison among alternatives.

Chapter 6

Cost-Effectiveness of Alternative Micro-storm Management Options

6.1 Introduction

In a recently completed project sponsored by the U.S. Environmental Protection Agency titled *Innovative Urban Wet-Weather Flow Management Systems* (Heaney et al., 1999a), many methods for improving urban stormwater quality were described. Approaches range from traditional end-of-pipe treatment methods, to sophisticated source control BMPs, including land use controls. A summary of many of these approaches is presented by Heaney et al. (1999b). However, innovative wet weather flow (WWF) quality management programs must be designed in concert with the need to provide adequate flood protection and drainage. Interestingly, innovative methods for flood control and drainage focus similarly on source controls and non-structural options (Heaney et al., 1998c). The resulting new paradigm for WWF management is that the analyst will need to evaluate a very large variety of management options that include land use modifications. Fundamental questions arise regarding how to develop effective methods for the evaluation of alternatives and how to prioritize among them. In one report, Heaney et al. (1998c) describe the optimization methods used to prioritize among options, While in another (Heaney et al., 1999b) they evaluates the role of geographical information systems (GIS) in providing the essential spatial information for these new approaches. The interested reader is referred to the other cited reports for a more complete description of these other aspects.

In this section we describe some preliminary results in developing cost estimates for land-intensive BMP urban stormwater control systems. Developing reliable cost estimates is also complicated because many BMPs are designed to serve multiple purposes. For example, if the yard of a house is retrofitted to replace one half of the lawn with infiltration and wooded areas, does the homeowner perceive a loss of the use of this yard, or welcome the fact that there will be less lawn to maintain? Controls for stormwater quality management using micro-storm (i.e., storms of a low return period of say, two months) design criteria also have value for larger design storms for drainage and flood control. Thus, these costs need to be allocated among purposes. A robust solution is one that works well over the entire spectrum of future scenarios. Traditional stormwater management systems have been designed to function well under a single design condition, e.g., the 100-yr flood (major storm) or the 10-yr storm (minor storm). Unfortunately, designing a control systems around a single extreme event is myopic because the design may not perform well under other scenarios. Major floodways designed for the 100-yr event degrade the natural stream system, overdrain the system during more frequent storms, and degrade downstream water quality by transporting pollutants rapidly through urban areas. Concern for water quality and receiving stream integrity in urban stormwater systems demonstrates the importance of a stormwater system that performs well in managing the runoff from frequent, or “micro” storms that occur on a regular basis, e.g., weekly or monthly. Lippai and Heaney (1998) present principles for doing cost allocations across purposes (micro, minor, and major storms) and groups (residential, commercial, transportation, etc.) for water supply systems. The same principles can be applied to stormwater systems. What is needed for WWF systems is an efficient method for optimizing stormwater control systems for micro to major storms. The companion report by Heaney et al. (1998c) shows how this can be done for simpler cases. More research is needed to develop fully functional models for more realistic scenarios.

Below we review previous efforts to evaluate micro-storm systems, present methods for estimating the unit costs of these BMPs, and display the results of using these cost estimates for finding the optimal mix of BMPs.

6.2 Literature Review

Pitt (1987) showed the importance of evaluating smaller storms with regard to urban stormwater quality protection. He initiated the development of the Source Loading and Management Model (SLAMM) used to estimate the efficacy of various urban nonpoint source water quality management options (Pitt and Voorhees, 1995). SLAMM emphasizes small storm hydrology and its associated particulate washoff. The predictive equations in SLAMM are based on extensive field data. Below is a brief description of the relevant components of SLAMM.

6.2.1 Land use/control options

SLAMM depicts urban land use as falling into the following major categories:

1. Residential Areas
2. Institutional Areas
3. Commercial Areas
4. Industrial Areas
5. Open Space Areas
6. Freeways

The first five of these areas contain up to the 14 source area types shown in Table 6-1.

The area in acres is needed for each of these source areas. Finally, the additional information shown in Table 6-2 is needed for some of the source areas.

Table 6-1. Source Areas in SLAMM (Pitt and Voorhees 1995)

Source Area	Number Available in Each Land Use
Roofs	5
Paved Parking/Storage	3
Unpaved Parking/Storage	2
Playgrounds	2
Driveways	3
Sidewalks	2
Street Areas/Alleys	3
Large Landscaped Areas	2
Undeveloped Areas	1
Small Landscaped Areas	3
Isolated Areas	1
Other Permeable Area	1
Other Directly Connected Impervious Area	1
Other Partially Connected Impervious Area	1
Paved Freeway and Shoulder Area (F)*	5
Large Turf Area (F)*	1

* (F) indicates available in Freeway Land Use only

Table 6-2. Other Information Needed in a Source Area (Pitt and Voorhees 1995)

Type of roof-pitched or flat
Source area connectedness-unconnected or draining to a permeable area.
Soil type-sandy (A/B) or Clayey (C/D).
Building density – low or medium/high
Pavement of alleys – yes or no
Pavement texture – smooth to very rough
Total street length – curb miles
Street dirt accumulation equation coefficients
Initial street dirt loading
Average daily traffic – vehicles/day

While SLAMM uses far more detail and represents a significant improvement over other stormwater models, it still uses a highly aggregate representation of soil and land use conditions, e.g., only two soil classifications are used, building densities are either low or medium/high. An example printout of the input file for an analysis in Toronto, shown in Table 6-3, gives a general idea of the amount of spatial aggregation. Thirty source area categories are shown, 12 of which have positive amounts of acreage. Small landscaped areas account for 436 out of a total of 730 acres

Table 6-3. Sample SLAMM Output for Toronto, ON, Canada (Pitt and Voorhees, 1995) (Reproduced with permission of Dr. Robert Pitt)

Data file name: EXAMPL3.DAT
Rain file name: LW80.RAN
Runoff Coefficient file name: RUNOFF.RSV
Study period starting date: 04/10/80
Date: 04-07-1989
Site information: WET POND WITH STANDARD CONTROLS

Particulate Solids Concentration file name: TORONTO.PSC
Pollutant Relative Concentration file name: TORONTO.POL
Study period ending date: 04/30/80
Time: 06:51:55

Areas for each Source (acres)

Source Area	Resi-dential Areas	Institu-tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas
Roofs 1	53.20	0.00	0.00	0.00	0.00
Roofs 2	61.56	0.00	0.00	0.00	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00
Paved Parking/Storage	1.52	0.00	0.00	0.00	0.00
Paved Parking/Storage	0.00	0.00	0.00	0.00	0.00
Paved Parking/Storage	0.00	0.00	0.00	0.00	0.00
Unpaved Parking/Storag	0.76	0.00	0.00	0.00	0.00
Unpaved Parking/Storag	0.00	0.00	0.00	0.00	0.00
Playground 1	0.00	0.00	0.00	0.00	0.00
Playground 2	0.00	0.00	0.00	0.00	0.00
Driveways 1	28.12	0.00	0.00	0.00	0.00
Driveways 2	28.12	0.00	0.00	0.00	0.00
Driveways 3	0.00	0.00	0.00	0.00	0.00
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00
Street Area 1	28.88	0.00	0.00	0.00	0.00
Street Area 2	58.52	0.00	0.00	0.00	0.00
Street Area 3	0.00	0.00	0.00	0.00	0.00
Lrg Lndscpd Area 1	1.52	0.00	0.00	0.00	0.00
Lrg Lndscpd Area 2	0.00	0.00	0.00	0.00	0.00
Undeveloped Area	0.00	0.00	0.00	0.00	0.00
Smll Lndscpd Area 1	436.24	0.00	0.00	0.00	0.00
Smll Lndscpd Area 2	0.00	0.00	0.00	0.00	0.00
Smll Lndscpd Area 3	0.00	0.00	0.00	0.00	0.00
Isolated Area	1.52	0.00	0.00	0.00	0.00
Other Pervious Area	30.40	0.00	0.00	0.00	0.00
Other Directly Connect	0.00	0.00	0.00	0.00	0.00
Other Partially Connec	0.00	0.00	0.00	0.00	0.00
	....	....	....	....	....
Total	730.36	0.00	0.00	0.00	0.00

Freeway Source Area	Area (acres)
Paved Lane & Shoulder Area 1	0.00
Paved Lane & Shoulder Area 2	0.00
Paved Lane & Shoulder Area 3	0.00
Paved Lane & Shoulder Area 4	0.00
Paved Lane & Shoulder Area 5	0.00
Large Turf Areas	0.00
Undeveloped Areas	0.00
Other Pervious Areas	0.00
Other Directly Connected Imperv Area	0.00
Other Partially Connected Imperv Area	0.00
	....
Total	0.00

6.2.2 Hydrology in SLAMM

Using field measurements, a rainfall-runoff relationship is established for the study area. Such a relationship for clean, rough streets is shown in Figure 6-1. The $45°$ line represents a 1:1 rainfall-runoff relationship. Losses can be partitioned as follows:

1. Initial losses, also known as initial abstraction, and
2. Maximum variable losses.

Three stages of rainfall-runoff response can be identified:

1. The amount of rainfall before any runoff is produced.
2. The rainfall range between no runoff and all of the losses being satisfied, the nonlinear portion of the runoff curve.
3. The rainfall beyond stages 1and 2, wherein the rainfall and runoff rates are equal.

Our main concern for water quality is with stages 1 and 2. Urbanization reduces the initial abstraction. It also tends to reduce the total infiltration since the infiltration capacity has been reduced by development.

6.2.3 NRCS method and initial abstraction

Pitt (1987) provided an excellent review of the literature on the nature of the initial abstraction. Initial abstraction includes the following:

- Detention storage, e.g., on flat roofs
- Infiltration into the soil
- Interception by vegetation, particularly trees
- Evaporation from impervious surfaces such as streets.

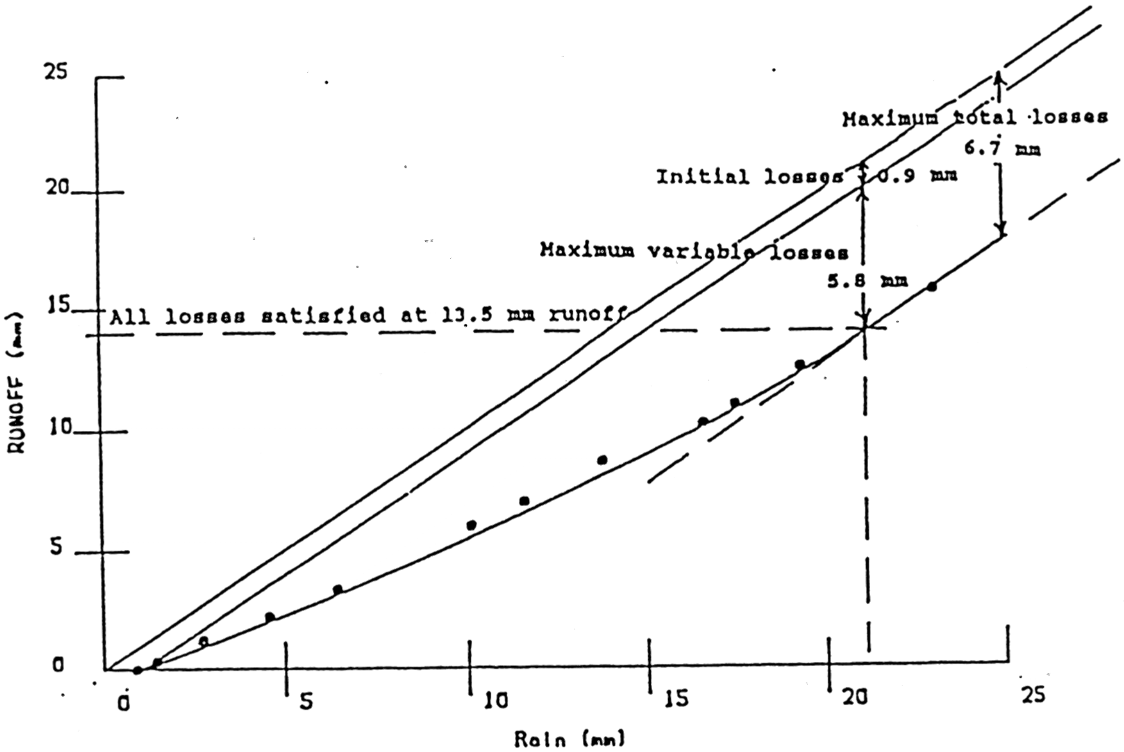
Recognizing the uncertainty of the estimates of the total initial abstraction, we will use this concept to illustrate our methodology.

6.2.4 Costs of controls in Pitt's work

Pitt (1987) estimated the following costs (as 1986 Canadian $) and needed to be revised.

- Street cleaning: $50 per curb-km cleaned
- Catchbasin cleaning: $50 per catchbasin cleaned
- Redirecting roof drains to permeable areas: $125 per house
- Infiltration trenches: $40,000 per ha paved area or roof
- Detention ponds: $200,000 per ha pond surface
  Annual maintenance costs are 4% of initial construction costs

**Figure 6-1. Illustrative rainfall-runoff relationship (Pitt, 1987).
(Reproduced with permission of Dr. Robert Pitt)**



6.2.5 Control devices in SLAMM

SLAMM evaluates the following control devices (Pitt and Voorhees, 1995):

- Wet detention ponds
- Porous pavement
- Infiltration devices
- Other devices for source areas
- Street cleaning
- Catchbasin cleaning
- Grass swales
- Other outfall devices

6.2.6 Limitations of SLAMM

SLAMM is an improvement over other approaches that neglect the dynamics of small storms. It also uses more refined spatial information and breaks land uses down into functional units, or source areas. However, its cost evaluation is limited and has not been updated since 1987. More importantly, it only does what-if analysis and cannot be used to find optimal solutions.

6.2.7 Low impact development

Some design guidelines are available for micro-storms. Extensive work has been done by Prince George's County (1999) Maryland to develop designs for Low Impact Development. They use the Natural Resources Conservation Service (NRCS) Curve Number (CN) approach to evaluate the percentage of the development that must be set aside in order to provide storage. Other design guidelines suggest capturing the first part of the runoff, typically the first 0.5 to 1 in. of runoff.

6.3 Proposed Approach

6.3.1 Introduction

Heaney et al. (1998c) describe a proposed method for using the NRCS CN method for evaluating micro-storms. The fundamental principle for the proposed approach is that development should not reduce the initial soil moisture storage that existed prior to development. This initial soil moisture storage is equivalent to the initial abstraction as calculated using the NRCS CN method. The initial abstraction is a good measure of the ability of the soil system to filter the stormwater. The initial abstraction, as a function of CN, is shown in Table 6-4. Inspection of Table 6-4 reveals the importance of CN. A low CN of 30 corresponds to an initial abstraction of 4.67 in. Even at a CN of 80, the initial abstraction is still 0.5 in. If the original CN is fairly low, then a significant amount of soil moisture storage is lost if this area is rendered impervious by development.

Table 6-4. Initial Abstraction as a Function of Curve Numbers (CN)

CN	I_a (in.)	CN	I_a (in.)
20	8	70	0.86
30	4.67	80	0.5
40	3	90	0.22
50	2	100	0.02
60	1.33		

Note: Ia = initial abstraction

The method presented here uses the concept of modifying the CN for the developed condition so that the modified CN is the same as the natural CN. The more cost-effective controls tend to focus on using the permeable area for more intensive infiltration. Alternatively, we seek to design hydrologically functional landscapes as described in the next section.

6.3.2 Hydrologically functional landscaping

Traditional landscaping relies on covering most, if not all, of the permeable area with grass. The lot is graded so that stormwater drains to the street and/or the rear of the lot as shown in Figure 6-2 (Dewberry and Davis, 1996). An example of a hydrologically functional landscape is shown in Figure 6-3 (Prince George's County, 1999). The general idea is to maximize the infiltration of stormwater by providing depressions, draining runoff from impervious areas to permeable areas, providing more circuitous routes for the stormwater to increase the time of concentration.

6.3.3 Cost of CN modifications

If the cost of modifying the CN can be determined, then cost-effective strategies can be developed for maintaining the undeveloped CN for each parcel or combination of parcels. Most BMPs are land intensive. Thus, if a BMP is installed within a right-of-way, or in a backyard, or in open space land, should the cost of the land be included in the calculation? What is the value of this land? This important topic is discussed below.

6.3.4 Land valuation

Land valuation is of critical importance for many controls because it constitutes a significant, if not major, component of total costs. Traditional urban storm drainage designs relied on subsurface sewer systems to carry WWF from the service area. Thus, land costs were not an important factor because no land was used in the process. However, once requirements for detention and retention systems were included in the WWF designs, then the cost of the land became an issue. Various perspectives on the cost of land are summarized below:

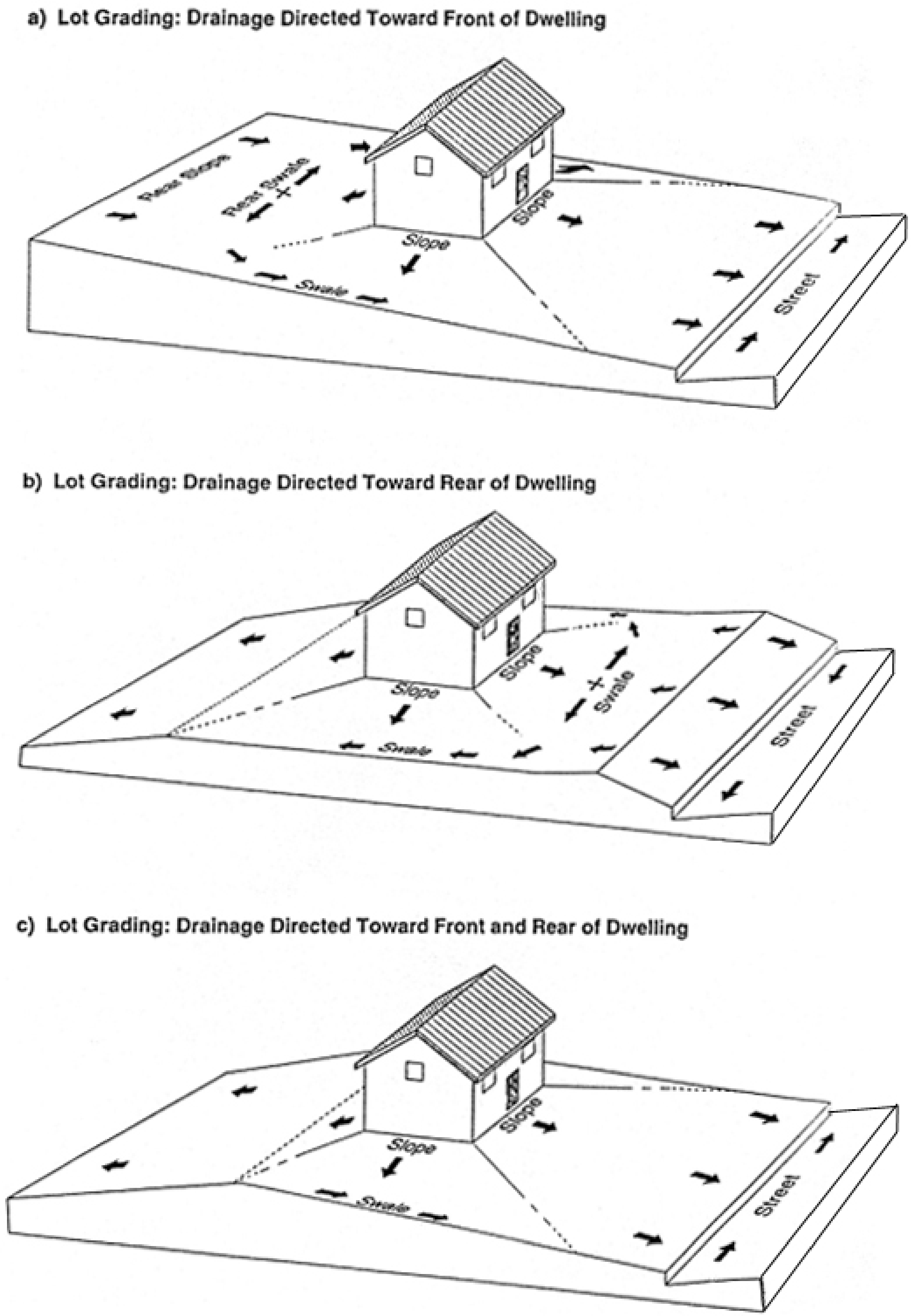


**Figure 6-2. Conventional storm drainage (Dewberry and Davis, 1996).
(Reproduced with permission of The McGraw-Hill Companies)**

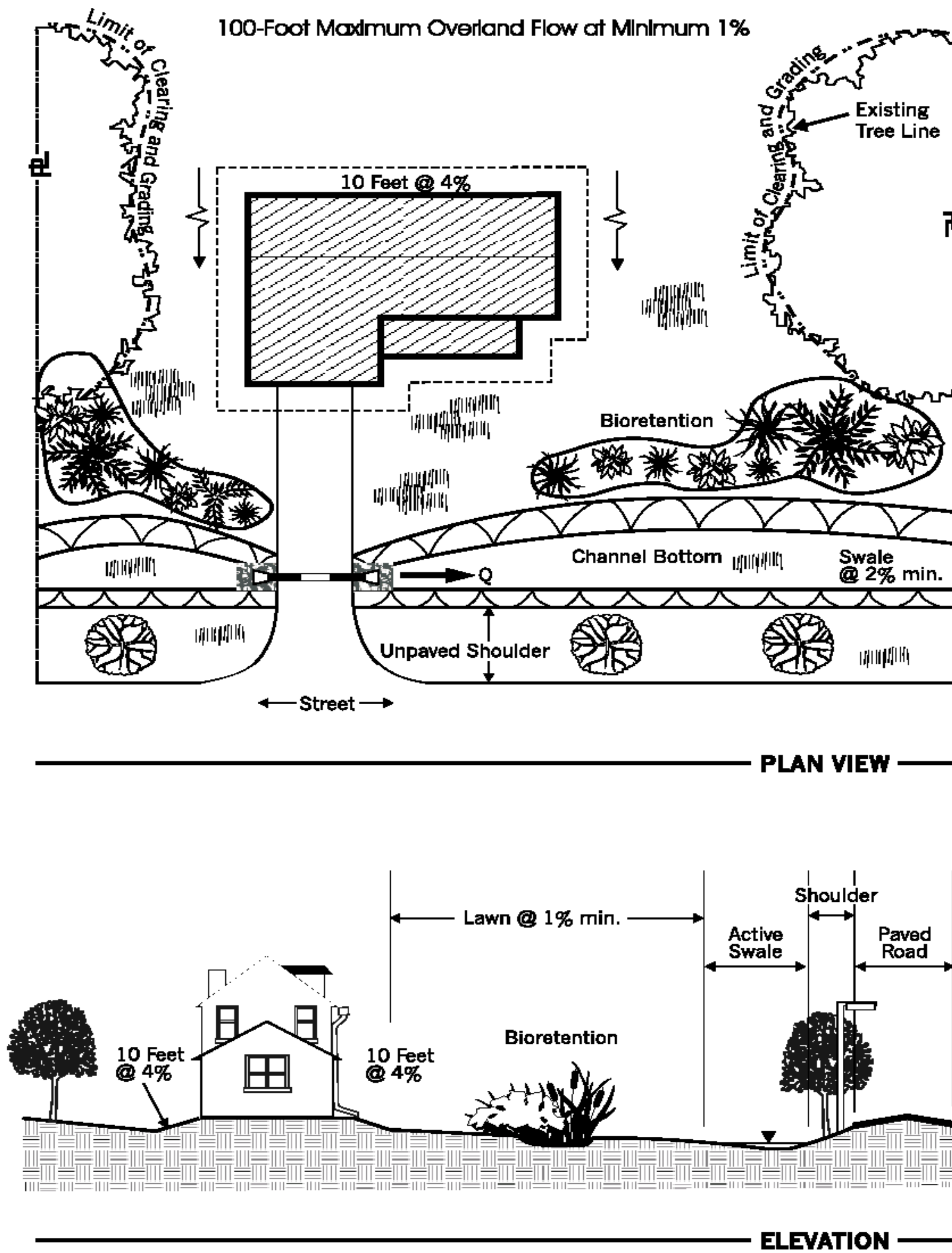


Figure 6-3. Illustration of hydrologically functional landscape (Prince George's County, 1999) (Reproduced with permission of the Prince George's County).

- The land should be valued at zero because it is part of the required right-of-way that the developer must provide along with the traditional right-of-way for streets and sidewalks, schools, and parks. If the land is on private property and is being used as landscaping, then it is viewed as being free for this other purpose.
- The land should be valued at full market value since the developer would otherwise be able to use this land for additional development of houses, commercial development, and/or other uses.

This issue is of paramount importance in estimating the "true cost" of land-intensive urban WWF BMPs whether they are located onsite or offsite. While little literature is available on this subject for urban stormwater systems, this topic has been discussed extensively with regard to evaluating the cost of transportation systems. This related literature is reviewed in the next section.

6.3.4.1 Value of land for transportation

A relatively large body of literature exists that is directed at estimating the true costs of various forms of transportation, particularly automobile-related transportation. Litman (1998) summarizes this literature and recommends methods for properly estimating the cost of transportation. Heaney et al. (1999a) quantify the impact of the automobile on urban land use in general and urban stormwater systems in particular. Accommodating the automobile requires committing a major portion of contemporary urban systems for such constructs as streets, driveways, parking lots, and garages. Some of the cost of providing land for transportation is paid by external subsidies from the state and federal governments. Much of the cost of local street and parking systems are paid by property and sales taxes. Thus, virtually none of these costs are directly assessed on the user. This approach is in stark contrast to a water utility wherein the total cost is assigned to the users, much of it in the form of commodity charges, so that they are aware of the full cost and have direct incentives to reduce their demand. For the purposes of this section, assume that a transportation utility exists in the urban area. This utility is responsible for all aspects of transportation and parking. It must pay full cost for its network, and it levies this cost directly on the transportation users. Litman (1998) defines roadway land value as follows:

Roadway land value costs include the value of land used for rights-of-way and other public facilities dedicated for automobile use. This cost could also be defined as the rent that users would pay for roadway land if it were managed as a utility, or at a minimum, the taxes that would be paid if road rights-of-way were taxed.

6.3.4.2 Rate of return on land investments

Real estate appraisers estimate market value, which can be defined as (Boyce 1981):

The highest price in terms of money which a property will bring in a competitive and open market under all conditions requisite in a fair sale, to the buyer and seller each acting prudently, knowledgeably, and assuming the price is not affected by undue stimulus.

The present value of a series of future annual income is:

$$PV = A\left[\frac{1-(1+i)^{-n}}{i}\right]$$

(6-1)

Where

PV = present value, \$
A = annual income, \$/yr
n = number of yrs
i = annual interest rate

As n tends to infinity, equation 6.1 becomes capitalized present value of an infinite stream of future benefits (PVC):

$$PVC = \frac{A}{i}$$

(6-2)

The present value of an infinite future stream of earnings is called the capitalized value of the future income stream. For example, a detailed investigation of the rate of return for muck farms north of Lake Apopka in Florida revealed an expected annual return of about $460/acre (Heaney et al. 1998d). Using a discount rate of 10%, the expected value of this land would be $4,600/acre. Detailed studies of comparable muck farmland indicated an average selling price of $4,500/acre, very close to the farm budget analysis.

For urban land use, there is no similar simple metric of land value in terms of crop productivity. However, a reliable estimate of the value of urban land can be obtained by viewing the urban development as an investment opportunity. The first step is to calculate the investment in raw land and its improvements exclusive of the building. Then, a reasonable return on investment, say 8%, is assumed. Thus, the annual benefit of committing this parcel of land to this use is 8% of the investment. The land is assumed to hold its value over time. Thus, the present value of the future sales price equals the original purchase price. Then, the cost of committing land to this use is the opportunity cost as estimated as the investment cost times the rate of return.

It is instructive to trace the development of raw land into housing or other uses, and then estimate the investment in raw and improved land. Dion (1993) provides a breakdown on the components of cost for a typical house built in 1992 as shown in Table 6-5. Finished land and labor/materials constitute 73% of the total cost. If the overhead and financing are prorated to the land and the house then the land cost constitutes about 27% of total cost, or 38% of construction costs.

Table 6-5. Breakdown of the Cost of a Typical House (Dion 1993)

Item	% of Total	Cost ($)
Overhead	20	24,000
Financing	5	6,000
Finished land	20	24,000
Labor/materials	53	63,600
Total	98	120,000

The Urban Land Institute (1989) presents another breakdown of land development costs for 1984 and 1988 as shown in Table 6-6. For 1988, land costs are about 76% of construction costs while they are 51% of construction costs in 1984. A rule of thumb in the home construction industry is that the house costs should be about twice the land costs. Thus, we will use land costs to be 50% of construction costs.

Table 6-6. Breakdown of the Cost of Housing in 1984 and 1988 (Urban Land Institute 1989)

Item	% of development (1988 $)	% of development (1984 $)
Raw land	19.3	17
Land improvements	12.6	7
Financing	4.4	6
Labor	17.4	18
Marketing	4.3	4
Materials	24.1	29
Overhead	6.5	7
Profit	8.1	9
Advertising	1.2	2
Other	0.4	2
Total	98.3	101

Note: The totals do not sum to 100 in the source

A breakdown of housing costs by function for a typical house is shown in Table 6-7. The total construction cost for the house is about $118,200. The total land value is estimated to be 50% of the cost of the house. Each component is then allocated its value based upon the proportion of area that it occupies. Unimproved land is assumed to be 2/3 of the total land value. The costs of improvements for water, wastewater, and stormwater are estimated for each functional unit. For example, all of the wastewater costs are assigned to the house. The result is a total land value attributable to the yard of $29,702. The capital and operation and maintenance costs for the yard are shown in Table 6-7. Capital costs consist of the initial preparation of topsoil plus landscaping, typically sod. Also, a sprinkler system is included. This option can be dropped as appropriate. Operation and maintenance costs consist of irrigation water, maintenance of the yard and the sprinkler system, and the opportunity cost of the land. The total present value of these costs is $87,880 or $6.76 per ft^2 of yard area.

Table 6-7. Estimated Housing Costs

Component	Area (ft^2)	% of total	Cost ($\$/ft^2$)	Construction Cost (1/99 $)	Total Land Cost (1/99 $)	Unimproved Land Cost (1/99 $)
Roof-house	1600	12.3%	56.25	90,000	7,274	4,849
Roof-garage	400	3.1%	34.00	13,600	1,818	1,212
Driveway	800	6.2%	4.00	3,200	3,637	2,425
Yard	9800	75.4%	1.00	9,800	44,552	29,702
Patio	400	3.1%	4.00	1,600	1,818	1,212
Total	13000	100.0%		118,200	59,100	39,400

Item	Input Data	Good (1/99 $\$/ft^2$)	Fair (1/99 $\$/ft^2$)	Poor (1/99 $\$/ft^2$)
A. Initial Capital Investment				
1. Soil preparation				
Initial cost of sod		0.43	0.34	0.26
Initial cost of topsoil, 6 in.		0.50	0.40	0.30
Spreading topsoil, 6 in.		0.64	0.51	0.38
Soil conditioners		0.03	0.02	0.01
Sprinkler system		0.62	0.44	0.00
		2.22	1.71	0.95
2. Opportunity Cost of Land				
Land Investment Cost, $	44,552			
Opportunity cost investment rate	6%			
Annual cost, $/yr	2,673			
Interest rate per yr	0.06			
Present worth over 25 yr, $	34,172			
Cost in $\$/ft^2$		3.49	3.49	3.49
Total of initial capital investment		5.71	5.20	4.44
B. Operation & Maintenance Costs, $				
Lawn watering				
In./yr	20			
% of permeable area that is irrigated	80%			
Cost of water, $/1,000 gal.	1.50			
Present worth factor	12.78			
Present worth, $\$/ft^2$		0.24	0.15	0.09
Lawn maintenance				
Weeks/yr.	26			
$/week	17			
Maintenance area, ft^2	7840			
Present worth, $\$/ft^2$		0.72	0.50	0.35
Sprinkler system maintenance		0.25	0.15	0.00
Total operation and maintenance costs, $		1.21	0.80	0.44
C. Total Cost, $\$/ft^2$		6.92	6.00	4.88
Portion attributable to stormwater				
Assumed %	10%			
D. Cost for Stormwater		0.69	0.60	0.49

6.3.4.3 Value of land for WWF systems

We support the view that land value should be included in the cost of WWF systems. The amount to be charged should be based on the opportunity cost of this land. This charge is an essential part of the analysis because most of the onsite or neighborhood BMPs are land intensive, e.g., detention systems, functional landscapes. The incidence of these costs is also critical in order to reward customers for onsite controls and to properly assess all users for their fair share of the total cost.

6.3.4.4 Customers in the WWF system

The customers of the urban WWF system can be viewed as the individual parcels served by the system. However, this taxonomy ignores perhaps the largest generator of urban WWFs, especially during micro-storms. This large customer is transportation that takes place in the rights-of-way of cities. This right-of-way consists of about 25% of total land use. However, it constitutes a disproportionately large amount of the directly connected impervious area that is critical in reducing the natural initial abstraction. Transportation systems also constitute a major portion of the WWF quality loads. Thus, they should be included as separate customers in order to evaluate their share of the cost of the WWF system.

6.4 Hypothetical Study Area

The study area shown in Figure 5-3 was digitized, and a parcel level GIS developed based upon each graphic object. The available themes are the following:

1. Land Use
2. Parcels
3. Storm Sewer Lines
4. Manholes
5. Soils
6. Spot Elevations
7. Street Right-of-way
8. Rooflines
9. Driveways

The study area GIS is shown in Figure 6-4. The land use classifications of the study area are shown in shaded colors. Rights of way are shown in shaded blue, rooflines are outlined in purple, driveways are in solid magenta, the storm sewer system is outlined in red, manholes for the storm sewers are in solid black, and the parcel boundaries are in black outline.

A representation of the soils for the site is shown in Figure 6-5. The three soil classifications are shown as green for rock, light brown for clay, and dark brown for silt. The soil classification is based upon the values given in Table 5-8.

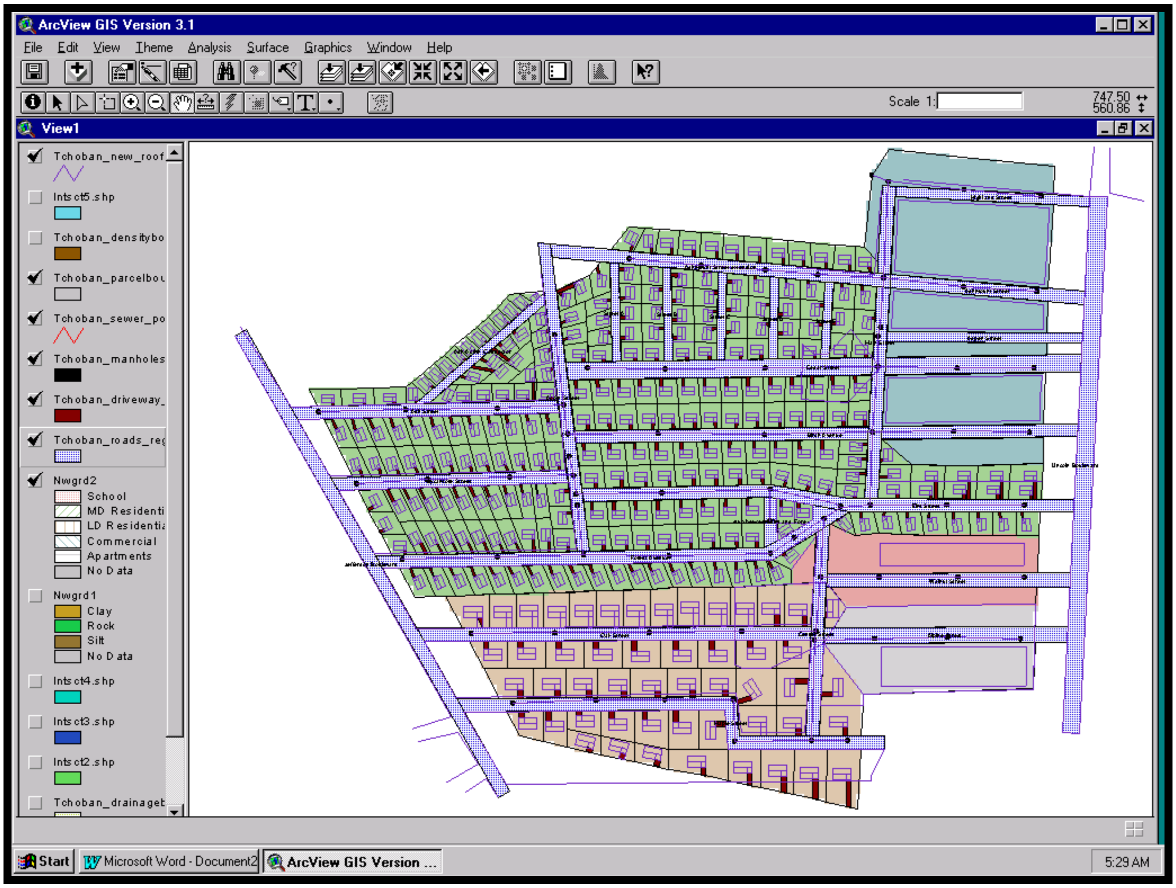


Figure 6-4. Study area GIS.

Associated with each graphic object, grouped according to type, is a relational database. Attributes associated with parcels are address and land area; and with streets are right-of-way width, length, land area, and street name. Soils and land use exist in separate tables, and this information is combined with the parcel and street databases by performing an intersection query on the two themes. The results of the query can also be output to an Excel spreadsheet by using ArcView's Avenue® script language and Microsoft's Dynamic Data Exchange® (DDE). This procedure was used to extract the relevant attribute information for parcels and streets.

6.4.1 Study area attributes

The rights-of-way identified in Figures 6.4 and 6.5 were assigned widths based upon the following criteria. Most streets within the development have a 50 ft right-of-way, a minor arterial is given a 60 ft right-of-way, and a major arterial a 70 ft right-of-way. The profile for each right-of-way is given in Table 6-8.

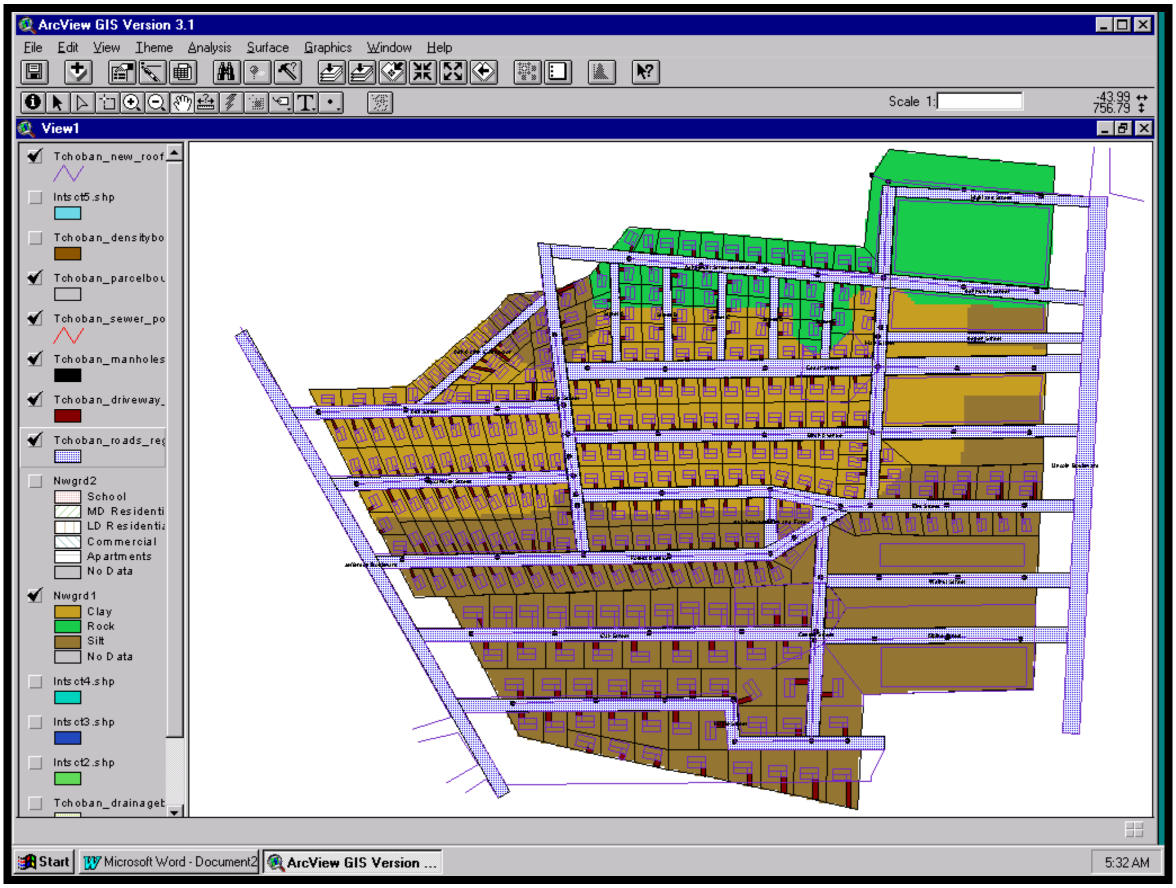


Figure 6-5. Study area soils.

Table 6-8. Right-of-Way Characteristics*

R/W (ft)	Length, (ft)	Curb (ft)	Parking (ft)	Landscaping strip (ft)	Sidewalk (ft)	Traffic Lanes (ft)
50	28680	4	8	10	8	20
60	1124	4	16	10	8	22
70	2741	4	16	18	8	24

*** Some of the parameters are summed from both sides of the street.**

Lot characteristics for the two single lot residential land use classifications are tabulated in Table 6-9. Lots were aggregated in this manner for the optimization, but not for the detailed cost analysis.

Table 6-9. Lot Characteristics for Residential Parcels

Land Use	# of Parcels	Roof Area (ft^2)	Patio (ft^2)	Driveway (ft^2)	Landscaping (ft^2)	Total Area (ft^2)
MD Residential (6–8 DU/AC)	255	1,600	200	600	3,600	6,000
LD Residential (2–5 DU/AC)	51	2,000	400	800	9,800	13,000

For the apartments, commercial, and school land uses, an aggregated analysis was used. This is because these land uses exhibited multi-parcel characteristics, such as for parking uses. A summary of these characteristics is found in Table 6-10.

Table 6-10. Aggregate Characteristics for Commercial, Apartments, and Schools

Land Use	Number of parcels	Stories	Parcel Area (ft^2)	Roof Area (ft^2)	Parking Area (ft^2)	Landscaping (ft^2)
Apartments	2	2	162,680	46,927	75,083	40,670
Commercial	6	1	481,070	152,839	304,678	23,553
School	3	1	149,407	69,080	51,807	28,521

6.4.2 Unit costs

Next, unit costs were developed for each development component. The results are presented below.

6.4.2.1 Landscaping costs

Landscaping costs depend upon several factors, including opportunity costs, the cost of soil preparation including topsoil, sod, and soil conditioners, and an irrigation system. In order to determine the opportunity cost, a land valuation analysis must be done for each land use. Land valuation analysis for a medium density residential lot is presented in Table 6-11. The area of each component of the medium density lot is listed in column 2 of Table 6-11. The percentage of each component is calculated in column 3.

Table 6-11. Land Valuation for Medium Density Lot

Component	Area (ft^2)	% of total	Cost (1/99 $/$ft^2$)	Construction Cost (1/99 $)	Total Land (1/99 $)	Unimproved Land (1/99 $)
Roof-house	1,200	20.0	56.25	67,500	8,790	5,860
Roof-garage	400	6.7	34.00	13,600	2,930	1,953
Driveway	600	10.0	4.00	2,400	4,395	2,930
Yard	3,600	60.0	1.00	3,600	26,370	17,580
Patio	200	3.3	4.00	800	1,465	977
Total	6,000	100.0		87,900	43,950	29,300

An estimate of the cost in $/$ft^2$ is found in column 4. Next, the construction cost is obtained by multiplying column 2 by column 4, and listing this in column 5. Next, the percentage in column 3 is multiplied by the total of column 5 to obtain an estimate of the land cost, in column 6. Column 7, the unimproved land cost, is obtained by multiplying the values in column 6 by 2/3. The value of the 3,600 ft^2 of land for the yard function is $26,370.

Next, opportunity costs must be calculated. This procedure is illustrated in Table 6-12. The value of $26,370 is annualized, using an interest rate of 6%, and an infinite term (as in equation 6.2), to obtain $1,582/yr. Then, this value is spread over 25 yrs at 6%, to obtain \$20,226. Dividing this value by 3,600 ft^2 gives \$5.62/ft^2. This value is used for all grass types because the underlying value of the land is assumed constant irrespective of the type of grass.

Landscaping costs were developed from RS Means (1996b), and updated to 1/99 \$, using the procedure shown in chapter 4 and are presented in Table 6-12 (for a medium density residential lot). The initial capital investment consists of the cost of soil preparation including sod, topsoil, and soil conditioners; and an irrigation system. For a good lawn, the present value of the initial landscaping investment is \$2.22/ft^2. Costs for lesser quality lawns drop to \$1.71/ft^2 and \$.95/ft^2 for fair and poor quality lawns. For the good lawn system, operation and maintenance costs add an additional \$2.45/ft^2 bringing the total to \$10.29/ft^2. An estimated 10% of this total cost is allocated to stormwater management. Similar estimates were made for fair and poor lawns. The resulting total costs per ft^2 vary from \$0.70 to \$1.03/ft^2. Better lawns have a lower CN and are thereby preferable from the viewpoint of being able to store more water. However, they also cost more. A linear programming model will be used to find the least costly mix.

Similar estimates were made for the land valuation of low density residential lots, commercial, apartments, and schools. A similar procedure was followed for these uses, except commercial, apartment, and school uses are aggregated as one lot. These valuations can be found in Table 6-13 for low density, Table 6-15, for commercial, Table 6-17 for apartments, and 6-19 for schools. Landscaping costs were determined the same way, and are found in Table 6-14 for low density residential, Table 6-16 for commercial, Table 6-18 for apartments, and Table 6-20 for schools.

Table 6-12. Cost Analysis of Landscaping for Medium Density Lot

Item	Input Data	Good 1/99 \$/ft²	Fair 1/99 \$/ft²	Poor 1/99 \$/ft²
A. Initial Capital Investment				
1. Soil preparation				
Initial cost of sod		0.43	0.34	0.26
Initial cost of topsoil, 6 in.		0.50	0.40	0.30
Spreading topsoil, 6 in.		0.64	0.51	0.38
Soil conditioners		0.03	0.02	0.01
Sprinkler system		0.62	0.44	0.00
		2.22	1.71	0.95
2. Opportunity Cost of Land				
Land Investment Cost, \$	26,370			
Opportunity cost investment rate, %	6			
Annual cost, \$/yr	1,582			
Interest rate/yr, %	6			
Present worth over 25 yr, \$	20,226			
Cost in \$/ft²		5.62	5.62	5.62
Total of initial capital investment		7.84	7.33	6.57
B. Operation & Maintenance Costs, \$				
Lawn watering				
in./yr	20			
% of permeable area that is irrigated	80			
Cost of water, \$/1,000 gal	1.50			
Present worth factor	12.78			
Present worth, \$/ft²		0.24	0.15	0.09
Lawn maintenance				
Weeks/yr	26			
\$/week	8.46			
Maintenance area, ft²	2880			
Present worth, \$/ft²		0.98	0.50	0.35
Sprinkler system maintenance		0.25	0.15	0.00
Total operation and maintenance costs, \$		1.46	0.80	0.44
C. Total Cost, \$/ft²		9.31	8.13	7.01
Portion attributable to stormwater				
Assumed %	10			
D. Cost for Stormwater		0.93	0.81	0.70

Table 6-13. Land Valuation for Low Density Lot

Component	Area (ft^2)	% of total	Cost (1/99 $/$ft^2$)	Construction Cost (1/99 $)	Total Land Cost (1/99 $)	Unimproved Land Cost (1/99 $)
Roof-house	1,600	12.3	56.25	90,000	7,274	4,849
Roof-garage	400	3.1	34.00	13,600	1,818	1,212
Driveway	800	6.2	4.00	3,200	3,637	2,425
Yard	9,800	75.4	1.00	9,800	44,552	29,702
Patio	400	3.1	4.00	1,600	1,818	1,212
Total	13,000	100.0		118,200	59,100	39,400

Table 6-14. Cost Analysis of Landscaping for Low Density Lot

Item	Input Data	Good $/$ft^2$	Fair $/$ft^2$	Poor $/$ft^2$
A. Initial Capital Investment				
1. Soil preparation				
Initial cost of sod		0.43	0.34	0.26
Initial cost of topsoil, 6 in.		0.50	0.40	0.30
Spreading topsoil, 6 in.		0.64	0.51	0.38
Soil conditioners		0.03	0.02	0.01
Sprinkler system		0.62	0.44	0.00
		2.22	1.71	0.95
2. Opportunity Cost of Land				
Land Investment Cost, $	44,552			
Opportunity cost investment rate, %	6			
Annual cost, $/yr	2,673			
Interest rate/yr, %	6			
Present worth over 25 yr, $	34,172			
Cost in $/$ft^2$		3.49	3.49	3.49
Total of initial capital investment		5.71	5.20	4.44
B. Operation & Maintenance Costs, $				
Lawn watering				
in./yr	20			
% of permeable area that is irrigated	80			
Cost of water, $/1,000 gal	1.50			
Present worth factor	12.78			
Present worth, $/$ft^2$		0.24	0.15	0.09
Lawn maintenance				
Weeks/yr	26			
$/week	17.00			
Maintenance area, ft^2	7840			
Present worth, $/$ft^2$		0.72	0.50	0.35
Sprinkler system maintenance		0.25	0.15	0.00
Total operation and maintenance costs, $		1.21	0.80	0.44
C. Total Cost, $/$ft^2$		6.92	6.00	4.88
Portion attributable to stormwater				
Assumed %	10			
D. Cost for Stormwater		0.69	0.60	0.49

Table 6-15. Land Valuation for Commercial Areas

Component	Area (ft^2)	% of total	Cost (1/99 $/$ft^2$)	Construction Cost (1/99 $)	Total Land Cost (1/99 $)	Unimproved Land Cost (1/99 $)
Roof	152,839	31.8	150.00	22,925,901	3,718,198	2,478,799
Parking	304,678	63.3	1.50	457,017	7,412,052	4,941,368
Driveway	0	0.0	1.50	0	0	0
Yard	23,553	4.9	1.00	23,553	572,985	381,990
Patio	0	0.0	4.00	0	0	0
Total	481,070	100.0		23,406,471	11,703,236	7,802,157

Table 6-16. Cost Analysis of Landscaping for Commercial Areas

Item	Input Data	Good 1/99 $/$ft^2$	Fair 1/99 $/$ft^2$	Poor 1/99 $/$ft^2$
A. Initial Capital Investment				
1. Soil preparation				
Initial cost of sod		0.43	0.34	0.26
Initial cost of topsoil, 6 in.		0.50	0.40	0.30
Spreading topsoil, 6 in.		0.64	0.51	0.38
Soil conditioners		0.03	0.02	0.01
Sprinkler system		0.62	0.44	0.00
		2.22	1.71	0.95
2. Opportunity Cost of Land				
Land Investment Cost, $	572,985			
Opportunity cost investment rate	6			
Annual cost, $/yr	34,379			
Interest rate/yr, %	6			
Present worth over 25 yr, $	439,481			
Cost in $/$ft^2$		18.66	18.66	18.66
Total of initial capital investment		20.88	20.37	19.61
B. Operation & Maintenance Costs, $				
Lawn watering				
In./yr	20			
% of permeable area that is irrigated	100			
Cost of water, $/1,000 gal	1.50			
Present worth factor	12.78			
Present worth, $/$ft^2$		0.24	0.15	0.09
Lawn maintenance				
Weeks/yr	26			
$/week	33.26			
Maintenance area, ft^2	23553			
Present worth, $/$ft^2$		0.47	0.50	0.35
Sprinkler system maintenance		0.25	0.15	0.00
Total operation and maintenance costs, $		0.96	0.80	0.44
C. Total Cost, $/$ft^2$		21.84	21.17	20.05
Portion attributable to stormwater				
Assumed %	10			
D. Cost for Stormwater		2.18	2.12	2.01

Table 6-17. Land Valuation for Apartments

Component	Area (ft^2)	% of total	Cost (1/99 $/$ft^2$)	Construction Cost (1/99 $)	Total Land Cost (1/99 $)	Unimproved Land Cost (1/99$)
Roof	46,927	28.8	84.38	3,959,466	593,187	395,458
Parking	75,083	46.2	1.50	112,625	949,100	632,733
Driveway	0	0.0	1.50	0	0	0
Yard	40,670	25.0	1.00	40,670	514,093	342,729
Patio	0	0.0	4.00	0	0	0
Total	162,680	100.0		4,112,760	2,056,380	1,370,920

Table 6-18. Cost Analysis of Landscaping for Apartments

Item	Input Data	Good 1/99 $/$ft^2$	Fair 1/99 $/$ft^2$	Poor 1/99 $/$ft^2$
A. Initial Capital Investment				
1. Soil preparation				
Initial cost of sod		0.43	0.34	0.26
Initial cost of topsoil, 6 in.		0.50	0.40	0.30
Spreading topsoil, 6 in.		0.64	0.51	0.38
Soil conditioners		0.03	0.02	0.01
Sprinkler system		0.62	0.44	0.00
		2.22	1	0.95
2. Opportunity Cost of Land				
Land Investment Cost	514,093			
Opportunity cost investment rate	6			
Annual cost, $/yr	30,846			
Interest rate/yr, %	6			
Present worth over 25 yr, $	394,310			
Cost in $/$ft^2$		9.70	9.70	9.70
Total of initial capital investment		11.92	11.41	10.65
B. Operation & Maintenance Costs, $				
Lawn watering				
In./yr	20			
% of permeable area that is irrigated	80			
Cost of water, $/1,000 gal	1.50			
Present worth factor	12.78			
Present worth, $/$ft^2$		0.24	0.15	0.09
Lawn maintenance				
Weeks/yr	26			
$/week	44.04			
Maintenance area, ft^2	32536			
Present worth, $/$ft^2$		0.45	0.50	0.35
Sprinkler system maintenance		0.25	0.15	0.00
Total operation and maintenance costs, $		0.94	0.80	0.44
C. Total Cost, $/$ft^2$		12.86	12.21	11.09
Portion attributable to stormwater				
Assumed %	10			
D. Cost for Stormwater		1.29	1.22	1.11

Table 6-19. Land Valuation for Schools

Component	Area (ft^2)	% of Total	Cost (1/99 $/$ft^2$)	Construction Cost (1/99 $)	Total Land Cost (1/99 $)	Unimproved Land Cost (1/99 $)
Roof	46,927	28.8	84.38	8,635,000	2,020,799	1,347,199
Parking	75,083	46.2	1.50	77,709	1,515,482	1,010,322
Driveway	0	0.0	1.50	0	0	0
Yard	40,670	25.0	1.00	28,521	834,334	556,222
Patio	0	0.0	4.00	0	0	0
Total	162,680	100.0		8,741,230	4,370,615	2,913,743

Table 6-20. Cost Analysis of Landscaping for Schools

Item	Input Data	Good 1/99 $/$ft^2$	Fair 1/99 $/$ft^2$	Poor 1/99 $/$ft^2$
A. Initial Capital Investment				
1. Soil preparation				
Initial cost of sod		0.43	0.34	0.26
Initial cost of topsoil, 6 in.		0.50	0.40	0.30
Spreading topsoil, 6 in.		0.64	0.51	0.38
Soil conditioners		0.03	0.02	0.01
Sprinkler system		0.62	0.44	0.00
		2.22	1.71	0.95
2. Opportunity Cost of Land				
Land Investment Cost, $	834,334			
Opportunity cost investment rate, %	6			
Annual cost, $/yr	50,060			
Interest rate/yr, %	6			
Present worth over 25 yr, $	639,935			
Cost in $/$ft^2$		22.44	22.44	22.44
Total of initial capital investment		24.66	24.15	23.39
B. Operation & Maintenance Costs, $				
Lawn watering				
In. per year	20			
% of permeable area that is irrigated	80			
Cost of water, $/1,000 gal	1.50			
Present worth factor	12.78			
Present worth, $/$ft^2$		0.24	0.15	0.09
Lawn maintenance				
Weeks/yr	26			
$/week	32.38			
Maintenance area, ft^2	22817			
Present worth, $/$ft^2$		0.47	0.50	0.35
Sprinkler system maintenance		0.25	0.15	0.00
Total operation and maintenance costs, $		0.96	0.80	0.44
C. Total Cost, $/$ft^2$		25.62	24.95	23.83
Portion attributable to stormwater				
Assumed %	10			
D. Cost for Stormwater		2.56	2.49	2.38

6.4.2.2 Right-of-way costs

Based upon the paving costs shown in Table 3-7 (explained in equations 3.4 to 3.8 and the profile selected from Table 6-8), costs were assigned to each right-of-way. These costs are presented as $/linear foot, assuming the widths from Table 6-8, and are presented in Table 6-21.

Table 6-21. Costs of Pavement, Curb and Gutter, and Sidewalks*

Right-of-Way	Curb (1/99 $)	Pavement (1/99 $)	Sidewalks (1/99 $)
50	13.89	33.63	2.40
60	13.89	45.64	2.40
70	13.89	48.04	2.40

*** Curbs are assumed to be both sides of the street with 2 ft in width**

Unit costs are $3.47/ft^2$ for curbs, $1.20/ft^2$ for pavement, and $.30/ft^2$ for sidewalks. Since the area of each paved surface is known, these ft^2 estimates can be multiplied by this area to obtain the total cost. Alternatively, the length (within each right-of-way type) may be multiplied by the unit factors found in Table 6-21.

The total right-of-way costs are not just a function of pavement costs. There is an opportunity cost to devoting land for right-of-way instead of for development. Several different methods can be used for determining the value of the right-of-way; the one selected here is that of using the lowest valued use, which is the opportunity cost for undeveloped land for low density residential use, or $3.49/ft^2$. This method is consistent with marginal cost analysis. Several street profiles were analyzed, and are shown in Table 6-22. Street 1 is a standard street with curb and gutter. Street 2 is a street with porous pavement and curb and gutter. Street 3 is a standard pavement street with swales. Street 4 is a street with porous pavement and swales. Because the right-of-way must remain constant, the travel lane was reduced in the case of streets using swales. These costs are added to the opportunity cost and apportioned to stormwater as shown in Table 6-22.

Table 6-22. Cost Analysis for 50 ft Right-of-Way

Item	Input Data	Street 1 (1/99 $/ft^2)	Street 2 (1/99 $/ft^2)	Street 3 (1/99 $/ft^2)	Street 4 (1/99 $/ft^2)
A. Initial Capital Investment					
Opportunity Cost: Low Density Residential		3.49	3.49	3.49	3.49
B. Pavement Costs					
width of street, ft	32				
width of swales, ft				12	12
width of pavement, ft		28	28	20	20
Swales, $/ft^2	3.00			36.00	36.00
curb and gutter, $/ft		13.89	13.89		
pavement, $/ft		33.63	42.04	24.02	30.03
total, $/ft		47.52	55.93	60.02	66.03
total of B, $/ft^2		1.49	1.75	1.88	2.06
C. Total, $/ft^2		4.97	5.23	5.36	5.55
Portion attributable to stormwater					
Assumed, %	5				
D. Cost for Stormwater		0.25	0.26	0.27	0.28

Similar analysis can be performed for 60 and 70 ft right-of-way streets. These results are presented in Tables 6.23 and 6.24.

Table 6-23. Cost Analysis for 60 ft Right-of-Way

Item	Input Data	Street 1 (1/99 $/ft^2)	Street 2 (1/99 $/ft^2)	Street 3 (1/99 $/ft^2)	Street 4 (1/99 $/ft^2)
A. Initial Capital Investment					
Opportunity Cost: Low Density Residential		3.49	3.49	3.49	3.49
B. Pavement Costs					
width of street, ft	42				
width of swales, ft				12	12
width of pavement, ft		38	38	38	38
swales, $/ft^2	3.00			36	36
curb and gutter, $/ft		13.89	13.89		
pavement, $/ft		45.64	57.05	45.64	57.05
total, $/ft		59.54	70.95	81.64	93.05
total, $/ft^2		1.42	1.69	1.94	2.22
C. Total, $/ft^2		4.90	5.18	5.43	5.70
Portion attributable to stormwater					
Assumed, %	5				
D. Cost for Stormwater		0.25	0.26	0.27	0.29

Proceeding from left to right in Tables 6.22 through 6.24, the streets have increasingly better infiltration characteristics. This is reflected in the curve numbers for the street, however, the street becomes more expensive. A linear program model can be used to determine the least costly mix.

Table 6-24. Cost Analysis for 70 ft Right-of-Way

Item	Input Data	Street 1 (1/99 $/ft^2)	Street 2 (1/99 $/ft^2)	Street 3 (1/99 $/ft^2)	Street 4 (1/99 $/ft^2)
A. Initial Capital Investment					
Opportunity Cost: Low Density Residential		3.49	3.49	3.49	3.49
B. Pavement Costs					
width of street, ft	44				
width of swales, ft				12	12
width of pavement, ft		40	40	40	40
swales, $/ft^2	3.00			36.00	36.00
curb and gutter, $/ft		13.89	13.89		
pavement, $/ft		48.04	60.05	48.04	60.05
Total, $/ft		61.94	73.95	84.04	96.05
Total, $/ft^2		1.41	1.68	1.91	2.18
C. Total, $/ft^2		4.89	5.17	5.40	5.67
Portion attributable to stormwater					
Assumed, %	5				
D. Cost for Stormwater		0.24	0.26	0.27	0.28

6.4.2.3 Costs for other land functions

The costs of parking, sidewalks and patios, and driveways were determined using a similar procedure. Parking lots were evaluated in the following forms: standard pavement, and three types of porous pavement of gradually increasing permeability. The cost analysis for parking is shown in Table 6-25. As the permeability of the parking area increases, it is given a lower curve number, but the cost rises as well. This can be investigated using a linear program model. A ratio of 5% was used to apportion the costs to stormwater.

Table 6-25. Cost Analysis for Parking

Item	Input Data	Parking 1 (1/99 $/ft^2)	Parking 2 (1/99 $/ft^2)	Parking 3 (1/99 $/ft^2)	Parking 4 (1/99 $/ft^2)
A. Initial Capital Investment					
Opportunity Cost: Low Density Residential		3.49	3.49	3.49	3.49
B. Pavement Costs					
paving costs, $/ft^2	1.20	1.20	1.50	1.80	2.10
C. Total, $/ft^2		4.69	4.99	5.29	5.59
Portion attributable to stormwater					
Assumed %	5				
D. Cost for Stormwater		0.23	0.25	0.26	0.28

Two types of sidewalks were evaluated, standard and porous, and two types of patios, standard and porous. This analysis is shown in Table 6-26. Again, with the second sidewalk (or patio), the curve number decreases as the infiltration performance increases, however the cost also increases, albeit very slightly. A ratio of 5% was apportioned to stormwater costs.

Table 6-26. Cost Analysis for Sidewalks and Patios

Item	Input Data	Sidewalk1/ Patio1 (1/99 $/ft^2)	Sidewalk2/ Patio2 (1/99 $/ft^2)
A. Initial Capital Investment			
Opportunity Cost: Low Density Residential		3.49	3.49
B. Pavement Costs			
Sidewalk costs, $/ft^2	0.30	0.30	0.38
C. Total, $/ft^2		3.79	3.86
Portion attributable to stormwater			
Assumed, %	5		
D. Cost for Stormwater		0.19	0.19

Two types of driveways were evaluated, standard and porous, and this analysis is shown in Table 6-27. Again, with the second driveway, as the permeability increases, the curve number decreases, but the cost increases. A ratio of 5% was apportioned to stormwater costs.

Table 6-27. Cost Analysis for Driveways

Item	Input Data	Driveway 1 (1/99 $/ft^2)	Driveway 2 (1/99 $/ft^2)
A. Initial Capital Investment			
Opportunity Cost: Low Density Residential		3.49	3.49
B. Pavement Costs			
Paving costs, $/ft^2	1.20	1.20	1.50
C. Total, $/ft^2		4.69	4.99
Portion attributable to stormwater			
Assumed, %	5		
D. Cost for Stormwater		0.23	0.25

6.4.3 Summary of costs for each parcel

Based upon the landscaping costs shown in Tables 6-12, 6-14, 6-16, 6-18, and 6-20, the costs for parking in Table 6-25, the cost for sidewalks in Table 6-26, and the cost for driveways in Table 6-27, costs were assigned to each parcel. These costs are presented in Table 6-28. These costs are based upon the rooflines calculated directly from the figures or listed in Tables 6-9 (for single family residential lots) and the total parcel area. The total landscaping costs for the developed area is $14.5 million. The parking areas total $2 million, and the driveways total $969,000. These costs include opportunity costs.

Table 6-28. Parcel Development Costs

Add-ress	Street	Soil	Land Use	Area (ft^2)	Roof (ft^2)	Parking (ft^2)	Drive-ways (ft^2)	Patios (ft^2)	Impervious (ft^2)	Pervious (ft^2)	Landscaping (1/99 $)	Parking (1/99 $)	Driveway (1/99 $)	Total (1/99 $)
100	Alpine Street	Silt	Apartments	50320	0	37740	0	0	37740	12580	159,000	177,000	0	336,000
101	Alpine Street	Silt	Apartments	112360	46927	37343	0	0	84270	28090	354,000	176,000	0	530,000
200	Cedar Street	Clay	Commercial	25957	0	24659	0	0	24659	1298	29,000	116,000	0	145,000
200	Ashmount Street	Rock	Commercial	154915	57707	89462	0	0	147169	7746	168,000	420,000	0	588,000
201	Ashmount Street	Rock	Commercial	72968	0	69319	0	0	69319	3648	79,000	325,000	0	404,000
100	Highland Street	Rock	Commercial	80450	0	76427	0	0	76427	4022	87,000	359,000	0	446,000
200	Birch Avenue	Silt	Commercial	100139	95132	0	0	0	95132	5007	109,000	0	0	109,000
201	Birch Avenue	Silt	Commercial	46642	0	44810	0	0	44810	1832	40,000	211,000	0	251,000
105	Center Street	Silt	LD Residential	14235	2000		800	400	3200	11035	77,000	0	4,000	81,000
110	Center Street	Silt	LD Residential	18488	2000		800	400	3200	15288	106,000	0	4,000	110,000
120	Center Street	Silt	LD Residential	6844	2000		800	400	3200	3644	26,000	0	4,000	30,000
100	Maple Street	Silt	LD Residential	15082	2000		800	400	3200	11882	83,000	0	4,000	87,000
101	Maple Street	Silt	LD Residential	9927	2000		800	400	3200	6727	47,000	0	4,000	51,000
102	Maple Street	Silt	LD Residential	11751	2000		800	400	3200	8551	60,000	0	4,000	64,000
103	Maple Street	Silt	LD Residential	9742	2000		800	400	3200	6542	46,000	0	4,000	50,000
104	Maple Street	Silt	LD Residential	11025	2000		800	400	3200	7825	55,000	0	4,000	59,000
105	Maple Street	Silt	LD Residential	8744	2000		800	400	3200	5544	39,000	0	4,000	43,000
106	Maple Street	Silt	LD Residential	11441	2000		800	400	3200	8241	58,000	0	4,000	62,000
107	Maple Street	Silt	LD Residential	7667	2000		800	400	3200	4467	31,000	0	4,000	35,000
108	Maple Street	Silt	LD Residential	12942	2000		800	400	3200	9742	68,000	0	4,000	72,000
109	Maple Street	Silt	LD Residential	11518	2000		800	400	3200	8318	58,000	0	4,000	62,000
110	Maple Street	Silt	LD Residential	11728	2000		800	400	3200	8528	60,000	0	4,000	64,000
111	Maple Street	Silt	LD Residential	7707	2000		800	400	3200	4507	32,000	0	4,000	36,000
112	Maple Street	Silt	LD Residential	12053	2000		800	400	3200	8853	62,000	0	4,000	66,000
113	Maple Street	Silt	LD Residential	14291	2000		800	400	3200	11091	77,000	0	4,000	81,000
114	Maple Street	Silt	LD Residential	17653	2000		800	400	3200	14453	101,000	0	4,000	105,000
115	Maple Street	Silt	LD Residential	8015	2000		800	400	3200	4815	34,000	0	4,000	38,000
116	Maple Street	Silt	LD Residential	13857	2000		800	400	3200	10657	74,000	0	4,000	78,000
117	Maple Street	Silt	LD Residential	13778	2000		800	400	3200	10578	74,000	0	4,000	78,000
118	Maple Street	Silt	LD Residential	11207	2000		800	400	3200	8007	56,000	0	4,000	60,000
119	Maple Street	Silt	LD Residential	18674	2000		800	400	3200	15474	108,000	0	4,000	112,000
120	Maple Street	Silt	LD Residential	15565	2000		800	400	3200	12365	86,000	0	4,000	90,000
121	Maple Street	Silt	LD Residential	13029	2000		800	400	3200	9829	69,000	0	4,000	73,000
123	Maple Street	Silt	LD Residential	14017	2000		800	400	3200	10817	75,000	0	4,000	79,000
125	Maple Street	Silt	LD Residential	16758	2000		800	400	3200	13558	94,000	0	4,000	98,000
127	Maple Street	Silt	LD Residential	19500	2000		800	400	3200	16300	113,000	0	4,000	117,000
129	Maple Street	Silt	LD Residential	22449	2000		800	400	3200	19249	134,000	0	4,000	138,000
100	Oak Street	Silt	LD Residential	14049	2000		800	400	3200	10849	76,000	0	4,000	80,000
101	Oak Street	Silt	LD Residential	10172	2000		800	400	3200	6972	49,000	0	4,000	53,000
102	Oak Street	Silt	LD Residential	11049	2000		800	400	3200	7849	55,000	0	4,000	59,000
106	Oak Street	Silt	LD Residential	11131	2000		800	400	3200	7931	55,000	0	4,000	59,000
108	Oak Street	Silt	LD Residential	11239	2000		800	400	3200	8039	56,000	0	4,000	60,000
110	Oak Street	Silt	LD Residential	11681	2000		800	400	3200	8481	59,000	0	4,000	63,000
120	Oak Street	Silt	LD Residential	11993	2000		800	400	3200	8793	61,000	0	4,000	65,000
121	Oak Street	Silt	LD Residential	12611	2000		800	400	3200	9411	66,000	0	4,000	70,000

Add-ress	Street	Soil	Land Use	Area (ft^2)	Roof (ft^2)	Parking (ft^2)	Drive-ways (ft^2)	Patios (ft^2)	Impervious (ft^2)	Pervious (ft^2)	Landscaping (1/99 $)	Parking (1/99 $)	Driveway (1/99 $)	Total (1/99 $)
130	Oak Street	Silt	LD Residential	12127	2000		800	400	3200	8927	62,000	0	4,000	66,000
131	Oak Street	Silt	LD Residential	12680	2000		800	400	3200	9480	66,000	0	4,000	70,000
140	Oak Street	Silt	LD Residential	12646	2000		800	400	3200	9446	66,000	0	4,000	70,000
141	Oak Street	Silt	LD Residential	12749	2000		800	400	3200	9549	67,000	0	4,000	71,000
150	Oak Street	Silt	LD Residential	13048	2000		800	400	3200	9848	69,000	0	4,000	73,000
151	Oak Street	Silt	LD Residential	12818	2000		800	400	3200	9618	67,000	0	4,000	71,000
160	Oak Street	Silt	LD Residential	12950	2000		800	400	3200	9750	68,000	0	4,000	72,000
161	Oak Street	Silt	LD Residential	12886	2000		800	400	3200	9686	68,000	0	4,000	72,000
170	Oak Street	Silt	LD Residential	13016	2000		800	400	3200	9816	68,000	0	4,000	72,000
171	Oak Street	Silt	LD Residential	12955	2000		800	400	3200	9755	68,000	0	4,000	72,000
180	Oak Street	Silt	LD Residential	13412	2000		800	400	3200	10212	71,000	0	4,000	75,000
181	Oak Street	Silt	LD Residential	13618	2000		800	400	3200	10418	73,000	0	4,000	77,000
190	Oak Street	Silt	LD Residential	14363	2000		800	400	3200	11163	78,000	0	4,000	82,000
191	Oak Street	Silt	LD Residential	11552	2000		800	400	3200	8352	58,000	0	4,000	62,000
151	Acorn Street	Clay	MD Residential	6019	1600		600	200	2400	3619	38,000	0	3,000	41,000
160	Acorn Street	Clay	MD Residential	5286	1600		600	200	2400	2886	30,000	0	3,000	33,000
161	Acorn Street	Clay	MD Residential	3926	1600		600	200	2400	1526	16,000	0	3,000	19,000
165	Acorn Street	Clay	MD Residential	3853	1600		600	200	2400	1453	15,000	0	3,000	18,000
170	Acorn Street	Clay	MD Residential	5543	1600		600	200	2400	3143	33,000	0	3,000	36,000
171	Acorn Street	Clay	MD Residential	3926	1600		600	200	2400	1526	16,000	0	3,000	19,000
176	Acorn Street	Clay	MD Residential	5800	1600		600	200	2400	3400	35,000	0	3,000	38,000
179	Acorn Street	Clay	MD Residential	3926	1600		600	200	2400	1526	16,000	0	3,000	19,000
180	Acorn Street	Clay	MD Residential	4788	1600		600	200	2400	2388	25,000	0	3,000	28,000
181	Acorn Street	Clay	MD Residential	3926	1600		600	200	2400	1526	16,000	0	3,000	19,000
182	Acorn Street	Clay	MD Residential	4783	1600		600	200	2400	2383	25,000	0	3,000	28,000
100	Ash Street	Clay	MD Residential	5750	1600		600	200	2400	3350	35,000	0	3,000	38,000
101	Ash Street	Clay	MD Residential	6785	1600		600	200	2400	4385	46,000	0	3,000	49,000
110	Ash Street	Clay	MD Residential	6600	1600		600	200	2400	4200	44,000	0	3,000	47,000
111	Ash Street	Clay	MD Residential	6765	1600		600	200	2400	4365	45,000	0	3,000	48,000
120	Ash Street	Clay	MD Residential	6620	1600		600	200	2400	4220	44,000	0	3,000	47,000
121	Ash Street	Clay	MD Residential	6744	1600		600	200	2400	4344	45,000	0	3,000	48,000
131	Ash Street	Clay	MD Residential	6724	1600		600	200	2400	4324	45,000	0	3,000	48,000
135	Ash Street	Clay	MD Residential	6703	1600		600	200	2400	4303	45,000	0	3,000	48,000
139	Ash Street	Clay	MD Residential	6683	1600		600	200	2400	4283	45,000	0	3,000	48,000
141	Ash Street	Clay	MD Residential	6662	1600		600	200	2400	4262	44,000	0	3,000	47,000
150	Ash Street	Clay	MD Residential	3919	1600		600	200	2400	1519	16,000	0	3,000	19,000
151	Ash Street	Clay	MD Residential	6642	1600		600	200	2400	4242	44,000	0	3,000	47,000
160	Ash Street	Clay	MD Residential	4481	1600		600	200	2400	2081	22,000	0	3,000	25,000
161	Ash Street	Clay	MD Residential	6621	1600		600	200	2400	4221	44,000	0	3,000	47,000
170	Ash Street	Clay	MD Residential	4763	1600		600	200	2400	2363	25,000	0	3,000	28,000
171	Ash Street	Clay	MD Residential	6601	1600		600	200	2400	4201	44,000	0	3,000	47,000
180	Ash Street	Clay	MD Residential	4878	1600		600	200	2400	2478	26,000	0	3,000	29,000
181	Ash Street	Clay	MD Residential	6581	1600		600	200	2400	4181	44,000	0	3,000	47,000
190	Ash Street	Clay	MD Residential	4326	1600		600	200	2400	1926	20,000	0	3,000	23,000
191	Ash Street	Clay	MD Residential	6560	1600		600	200	2400	4160	43,000	0	3,000	46,000
100	Ash-Acorn Connec	Clay	MD Residential	3127	1600		600	200	2400	727	8,000	0	3,000	11,000

Add-ress	Street	Soil	Land Use	Area (ft^2)	Roof (ft^2)	Parking (ft^2)	Drive-ways (ft^2)	Patios (ft^2)	Impervious (ft^2)	Pervious (ft^2)	Landscaping (1/99 $)	Parking (1/99 $)	Driveway (1/99 $)	Total (1/99 $)
101	Ash-Acorn Connec	Clay	MD Residential	3180	1600		600	200	2400	780	9,000	0	3,000	12,000
111	Ash-Acorn Connec	Clay	MD Residential	3039	1600		600	200	2400	639	7,000	0	3,000	10,000
121	Ash-Acorn Connec	Clay	MD Residential	3157	1600		600	200	2400	757	8,000	0	3,000	11,000
131	Ash-Acorn Connec	Clay	MD Residential	2994	1600		600	200	2400	594	7,000	0	3,000	10,000
141	Ash-Acorn Connec	Clay	MD Residential	3086	1600		600	200	2400	686	8,000	0	3,000	11,000
150	Ash-Acorn Connec	Clay	MD Residential	4739	1600		600	200	2400	2339	25,000	0	3,000	28,000
151	Ash-Acorn Connec	Clay	MD Residential	3157	1600		600	200	2400	757	8,000	0	3,000	11,000
154	Ash-Acorn Connec	Clay	MD Residential	5648	1600		600	200	2400	3248	34,000	0	3,000	37,000
155	Ash-Acorn Connec	Clay	MD Residential	3109	1600		600	200	2400	709	8,000	0	3,000	11,000
161	Ash-Acorn Connec	Clay	MD Residential	3089	1600		600	200	2400	689	8,000	0	3,000	11,000
165	Ash-Acorn Connec	Clay	MD Residential	3149	1600		600	200	2400	749	8,000	0	3,000	11,000
166	Ash-Acorn Connec	Clay	MD Residential	5648	1600		600	200	2400	3248	34,000	0	3,000	37,000
170	Ash-Acorn Connec	Clay	MD Residential	4630	1600		600	200	2400	2230	23,000	0	3,000	26,000
171	Ash-Acorn Connec	Clay	MD Residential	3349	1600		600	200	2400	949	10,000	0	3,000	13,000
180	Ash-Acorn Connec	Clay	MD Residential	4818	1600		600	200	2400	2418	25,000	0	3,000	28,000
181	Ash-Acorn Connec	Clay	MD Residential	2948	1600		600	200	2400	548	6,000	0	3,000	9,000
190	Ash-Acorn Connec	Clay	MD Residential	4551	1600		600	200	2400	2151	23,000	0	3,000	26,000
191	Ash-Acorn Connec	Clay	MD Residential	2686	1600		600	200	2400	286	3,000	0	3,000	6,000
100	Birch Avenue	Clay	MD Residential	6469	1600		600	200	2400	4069	42,000	0	3,000	45,000
101	Birch Avenue	Clay	MD Residential	6554	1600		600	200	2400	4154	43,000	0	3,000	46,000
110	Birch Avenue	Clay	MD Residential	6477	1600		600	200	2400	4077	42,000	0	3,000	45,000
111	Birch Avenue	Clay	MD Residential	6522	1600		600	200	2400	4122	43,000	0	3,000	46,000
112	Birch Avenue	Clay	MD Residential	6484	1600		600	200	2400	4084	43,000	0	3,000	46,000
116	Birch Avenue	Clay	MD Residential	6492	1600		600	200	2400	4092	43,000	0	3,000	46,000
120	Birch Avenue	Clay	MD Residential	6499	1600		600	200	2400	4099	43,000	0	3,000	46,000
121	Birch Avenue	Clay	MD Residential	6490	1600		600	200	2400	4090	43,000	0	3,000	46,000
131	Birch Avenue	Clay	MD Residential	6457	1600		600	200	2400	4057	42,000	0	3,000	45,000
141	Birch Avenue	Clay	MD Residential	6425	1600		600	200	2400	4025	42,000	0	3,000	45,000
151	Birch Avenue	Clay	MD Residential	6360	1600		600	200	2400	3960	41,000	0	3,000	44,000
161	Birch Avenue	Clay	MD Residential	6328	1600		600	200	2400	3928	41,000	0	3,000	44,000
180	Birch Avenue	Clay	MD Residential	6560	1600		600	200	2400	4160	43,000	0	3,000	46,000
190	Birch Avenue	Clay	MD Residential	6568	1600		600	200	2400	4168	43,000	0	3,000	46,000
101	Cedar Street	Clay	MD Residential	6572	1600		600	200	2400	4172	43,000	0	3,000	46,000
111	Cedar Street	Clay	MD Residential	6580	1600		600	200	2400	4180	44,000	0	3,000	47,000
121	Cedar Street	Clay	MD Residential	6588	1600		600	200	2400	4188	44,000	0	3,000	47,000
131	Cedar Street	Clay	MD Residential	6595	1600		600	200	2400	4195	44,000	0	3,000	47,000
141	Cedar Street	Clay	MD Residential	6603	1600		600	200	2400	4203	44,000	0	3,000	47,000
181	Cedar Street	Clay	MD Residential	6663	1600		600	200	2400	4263	44,000	0	3,000	47,000
191	Cedar Street	Clay	MD Residential	6671	1600		600	200	2400	4271	44,000	0	3,000	47,000
100	Elm Street	Clay	MD Residential	6481	1600		600	200	2400	4081	43,000	0	3,000	46,000
110	Elm Street	Clay	MD Residential	6448	1600		600	200	2400	4048	42,000	0	3,000	45,000
120	Elm Street	Clay	MD Residential	6416	1600		600	200	2400	4016	42,000	0	3,000	45,000
130	Elm Street	Clay	MD Residential	6384	1600		600	200	2400	3984	42,000	0	3,000	45,000
140	Elm Street	Clay	MD Residential	6351	1600		600	200	2400	3951	41,000	0	3,000	44,000
150	Elm Street	Clay	MD Residential	6319	1600		600	200	2400	3919	41,000	0	3,000	44,000
160	Elm Street	Clay	MD Residential	6286	1600		600	200	2400	3886	41,000	0	3,000	44,000

Add-ress	Street	Soil	Land Use	Area (ft^2)	Roof (ft^2)	Parking (ft^2)	Drive-ways (ft^2)	Patios (ft^2)	Impervious (ft^2)	Pervious (ft^2)	Landscaping (1/99 $)	Parking (1/99 $)	Driveway (1/99 $)	Total (1/99 $)
170	Elm Street	Clay	MD Residential	6254	1600		600	200	2400	3854	40,000	0	3,000	43,000
106	Forest Avenue	Clay	MD Residential	6428	1600		600	200	2400	4028	42,000	0	3,000	45,000
101	Main Street	Clay	MD Residential	4993	1600		600	200	2400	2593	27,000	0	3,000	30,000
111	Main Street	Clay	MD Residential	5154	1600		600	200	2400	2754	29,000	0	3,000	32,000
120	Main Street	Clay	MD Residential	6770	1600		600	200	2400	4370	45,000	0	3,000	48,000
140	Main Street	Clay	MD Residential	6636	1600		600	200	2400	4236	44,000	0	3,000	47,000
141	Main Street	Clay	MD Residential	6323	1600		600	200	2400	3923	41,000	0	3,000	44,000
150	Main Street	Clay	MD Residential	4939	1600		600	200	2400	2539	27,000	0	3,000	30,000
151	Main Street	Clay	MD Residential	6323	1600		600	200	2400	3923	41,000	0	3,000	44,000
100	Street A	Clay	MD Residential	5072	1600		600	200	2400	2672	28,000	0	3,000	31,000
101	Street A	Clay	MD Residential	4644	1600		600	200	2400	2244	24,000	0	3,000	27,000
120	Street A	Clay	MD Residential	5072	1600		600	200	2400	2672	28,000	0	3,000	31,000
121	Street A	Clay	MD Residential	4789	1600		600	200	2400	2389	25,000	0	3,000	28,000
141	Street A	Clay	MD Residential	4934	1600		600	200	2400	2534	27,000	0	3,000	30,000
161	Street A	Clay	MD Residential	5079	1600		600	200	2400	2679	28,000	0	3,000	31,000
100	Street B	Clay	MD Residential	4787	1600		600	200	2400	2387	25,000	0	3,000	28,000
101	Street B	Clay	MD Residential	4953	1600		600	200	2400	2553	27,000	0	3,000	30,000
121	Street B	Clay	MD Residential	4953	1600		600	200	2400	2553	27,000	0	3,000	30,000
140	Street B	Clay	MD Residential	4787	1600		600	200	2400	2387	25,000	0	3,000	28,000
100	Street C	Clay	MD Residential	5609	1600		600	200	2400	3209	34,000	0	3,000	37,000
101	Street C	Clay	MD Residential	4737	1600		600	200	2400	2337	25,000	0	3,000	28,000
120	Street C	Clay	MD Residential	5609	1600		600	200	2400	3209	34,000	0	3,000	37,000
141	Street C	Clay	MD Residential	4888	1600		600	200	2400	2488	26,000	0	3,000	29,000
100	Street D	Clay	MD Residential	5254	1600		600	200	2400	2854	30,000	0	3,000	33,000
101	Street D	Clay	MD Residential	5461	1600		600	200	2400	3061	32,000	0	3,000	35,000
120	Street D	Clay	MD Residential	5254	1600		600	200	2400	2854	30,000	0	3,000	33,000
141	Street D	Clay	MD Residential	5461	1600		600	200	2400	3061	32,000	0	3,000	35,000
101	Street E	Clay	MD Residential	5192	1600		600	200	2400	2792	29,000	0	3,000	32,000
100	Sycamore Street	Clay	MD Residential	6480	1600		600	200	2400	4080	42,000	0	3,000	45,000
101	Sycamore Street	Clay	MD Residential	6511	1600		600	200	2400	4111	43,000	0	3,000	46,000
110	Sycamore Street	Clay	MD Residential	6460	1600		600	200	2400	4060	42,000	0	3,000	45,000
111	Sycamore Street	Clay	MD Residential	6712	1600		600	200	2400	4312	45,000	0	3,000	48,000
120	Sycamore Street	Clay	MD Residential	6439	1600		600	200	2400	4039	42,000	0	3,000	45,000
121	Sycamore Street	Clay	MD Residential	6470	1600		600	200	2400	4070	42,000	0	3,000	45,000
130	Sycamore Street	Clay	MD Residential	6419	1600		600	200	2400	4019	42,000	0	3,000	45,000
131	Sycamore Street	Clay	MD Residential	6492	1600		600	200	2400	4092	43,000	0	3,000	46,000
140	Sycamore Street	Clay	MD Residential	6399	1600		600	200	2400	3999	42,000	0	3,000	45,000
141	Sycamore Street	Clay	MD Residential	6514	1600		600	200	2400	4114	43,000	0	3,000	46,000
150	Sycamore Street	Clay	MD Residential	6378	1600		600	200	2400	3978	41,000	0	3,000	44,000
151	Sycamore Street	Clay	MD Residential	6536	1600		600	200	2400	4136	43,000	0	3,000	46,000
156	Sycamore Street	Clay	MD Residential	6358	1600		600	200	2400	3958	41,000	0	3,000	44,000
160	Sycamore Street	Clay	MD Residential	6337	1600		600	200	2400	3937	41,000	0	3,000	44,000
161	Sycamore Street	Clay	MD Residential	6558	1600		600	200	2400	4158	43,000	0	3,000	46,000
165	Sycamore Street	Clay	MD Residential	6580	1600		600	200	2400	4180	44,000	0	3,000	47,000
166	Sycamore Street	Clay	MD Residential	6317	1600		600	200	2400	3917	41,000	0	3,000	44,000
170	Sycamore Street	Clay	MD Residential	6296	1600		600	200	2400	3896	41,000	0	3,000	44,000

Add-ress	Street	Soil	Land Use	Area (ft^2)	Roof (ft^2)	Parking (ft^2)	Drive-ways (ft^2)	Patios (ft^2)	Impervious (ft^2)	Pervious (ft^2)	Landscaping (1/99 $)	Parking (1/99 $)	Driveway (1/99 $)	Total (1/99 $)
171	Sycamore Street	Clay	MD Residential	5931	1600		600	200	2400	3531	37,000	0	3,000	40,000
180	Sycamore Street	Clay	MD Residential	6276	1600		600	200	2400	3876	40,000	0	3,000	43,000
181	Sycamore Street	Clay	MD Residential	5744	1600		600	200	2400	3344	35,000	0	3,000	38,000
190	Sycamore Street	Clay	MD Residential	6255	1600		600	200	2400	3855	40,000	0	3,000	43,000
191	Sycamore Street	Clay	MD Residential	6274	1600		600	200	2400	3874	40,000	0	3,000	43,000
193	Sycamore Street	Clay	MD Residential	5919	1600		600	200	2400	3519	37,000	0	3,000	40,000
101	Ashmount Street	Rock	MD Residential	6649	1600		600	200	2400	4249	44,000	0	3,000	47,000
110	Ashmount Street	Rock	MD Residential	5611	1600		600	200	2400	3211	34,000	0	3,000	37,000
120	Ashmount Street	Rock	MD Residential	5524	1600		600	200	2400	3124	33,000	0	3,000	36,000
130	Ashmount Street	Rock	MD Residential	6461	1600		600	200	2400	4061	42,000	0	3,000	45,000
140	Ashmount Street	Rock	MD Residential	6805	1600		600	200	2400	4405	46,000	0	3,000	49,000
150	Ashmount Street	Rock	MD Residential	6624	1600		600	200	2400	4224	44,000	0	3,000	47,000
156	Ashmount Street	Rock	MD Residential	6875	1600		600	200	2400	4475	47,000	0	3,000	50,000
158	Ashmount Street	Rock	MD Residential	6554	1600		600	200	2400	4154	43,000	0	3,000	46,000
160	Ashmount Street	Rock	MD Residential	6693	1600		600	200	2400	4293	45,000	0	3,000	48,000
170	Ashmount Street	Rock	MD Residential	6533	1600		600	200	2400	4133	43,000	0	3,000	46,000
180	Ashmount Street	Rock	MD Residential	6461	1600		600	200	2400	4061	42,000	0	3,000	45,000
190	Ashmount Street	Rock	MD Residential	5691	1600		600	200	2400	3291	34,000	0	3,000	37,000
161	Main Street	Rock	MD Residential	6323	1600		600	200	2400	3923	41,000	0	3,000	44,000
130	Street A	Rock	MD Residential	5072	1600		600	200	2400	2672	28,000	0	3,000	31,000
170	Street A	Rock	MD Residential	5072	1600		600	200	2400	2672	28,000	0	3,000	31,000
190	Street A	Rock	MD Residential	5072	1600		600	200	2400	2672	28,000	0	3,000	31,000
141	Street B	Rock	MD Residential	4953	1600		600	200	2400	2553	27,000	0	3,000	30,000
160	Street B	Rock	MD Residential	4787	1600		600	200	2400	2387	25,000	0	3,000	28,000
180	Street B	Rock	MD Residential	4787	1600		600	200	2400	2387	25,000	0	3,000	28,000
181	Street B	Rock	MD Residential	4953	1600		600	200	2400	2553	27,000	0	3,000	30,000
190	Street B	Rock	MD Residential	4787	1600		600	200	2400	2387	25,000	0	3,000	28,000
191	Street B	Rock	MD Residential	4953	1600		600	200	2400	2553	27,000	0	3,000	30,000
160	Street C	Rock	MD Residential	5609	1600		600	200	2400	3209	34,000	0	3,000	37,000
161	Street C	Rock	MD Residential	5039	1600		600	200	2400	2639	28,000	0	3,000	31,000
171	Street C	Rock	MD Residential	5189	1600		600	200	2400	2789	29,000	0	3,000	32,000
190	Street C	Rock	MD Residential	5609	1600		600	200	2400	3209	34,000	0	3,000	37,000
191	Street C	Rock	MD Residential	5340	1600		600	200	2400	2940	31,000	0	3,000	34,000
180	Street D	Rock	MD Residential	5254	1600		600	200	2400	2854	30,000	0	3,000	33,000
181	Street D	Rock	MD Residential	5461	1600		600	200	2400	3061	32,000	0	3,000	35,000
190	Street D	Rock	MD Residential	5254	1600		600	200	2400	2854	30,000	0	3,000	33,000
191	Street D	Rock	MD Residential	5461	1600		600	200	2400	3061	32,000	0	3,000	35,000
100	Street E	Rock	MD Residential	6520	1600		600	200	2400	4120	43,000	0	3,000	46,000
120	Street E	Rock	MD Residential	6520	1600		600	200	2400	4120	43,000	0	3,000	46,000
151	Street E	Rock	MD Residential	5363	1600		600	200	2400	2963	31,000	0	3,000	34,000
171	Street E	Rock	MD Residential	5533	1600		600	200	2400	3133	33,000	0	3,000	36,000
190	Street E	Rock	MD Residential	6520	1600		600	200	2400	4120	43,000	0	3,000	46,000
191	Street E	Rock	MD Residential	5704	1600		600	200	2400	3304	35,000	0	3,000	38,000
126	Birch Avenue	Silt	MD Residential	6507	1600		600	200	2400	4107	43,000	0	3,000	46,000
130	Birch Avenue	Silt	MD Residential	6515	1600		600	200	2400	4115	43,000	0	3,000	46,000
136	Birch Avenue	Silt	MD Residential	6522	1600		600	200	2400	4122	43,000	0	3,000	46,000

Add-ress	Street	Soil	Land Use	Area (ft^2)	Roof (ft^2)	Parking (ft^2)	Drive-ways (ft^2)	Patios (ft^2)	Impervious (ft^2)	Pervious (ft^2)	Landscaping (1/99 $)	Parking (1/99 $)	Driveway (1/99 $)	Total (1/99 $)
140	Birch Avenue	Silt	MD Residential	6530	1600		600	200	2400	4130	43,000	0	3,000	46,000
150	Birch Avenue	Silt	MD Residential	6537	1600		600	200	2400	4137	43,000	0	3,000	46,000
160	Birch Avenue	Silt	MD Residential	6545	1600		600	200	2400	4145	43,000	0	3,000	46,000
170	Birch Avenue	Silt	MD Residential	6552	1600		600	200	2400	4152	43,000	0	3,000	46,000
171	Birch Avenue	Silt	MD Residential	6345	1600		600	200	2400	3945	41,000	0	3,000	44,000
181	Birch Avenue	Silt	MD Residential	6939	1600		600	200	2400	4539	47,000	0	3,000	50,000
191	Birch Avenue	Silt	MD Residential	7911	1600		600	200	2400	5511	57,000	0	3,000	60,000
193	Birch Avenue	Silt	MD Residential	5095	1600		600	200	2400	2695	28,000	0	3,000	31,000
151	Cedar Street	Silt	MD Residential	6610	1600		600	200	2400	4210	44,000	0	3,000	47,000
155	Cedar Street	Silt	MD Residential	6618	1600		600	200	2400	4218	44,000	0	3,000	47,000
161	Cedar Street	Silt	MD Residential	6625	1600		600	200	2400	4225	44,000	0	3,000	47,000
165	Cedar Street	Silt	MD Residential	6633	1600		600	200	2400	4233	44,000	0	3,000	47,000
171	Cedar Street	Silt	MD Residential	6641	1600		600	200	2400	4241	44,000	0	3,000	47,000
175	Cedar Street	Silt	MD Residential	6648	1600		600	200	2400	4248	44,000	0	3,000	47,000
179	Cedar Street	Silt	MD Residential	6656	1600		600	200	2400	4256	44,000	0	3,000	47,000
101	Elm Street	Silt	MD Residential	6663	1600		600	200	2400	4263	44,000	0	3,000	47,000
111	Elm Street	Silt	MD Residential	6667	1600		600	200	2400	4267	44,000	0	3,000	47,000
121	Elm Street	Silt	MD Residential	6671	1600		600	200	2400	4271	44,000	0	3,000	47,000
131	Elm Street	Silt	MD Residential	6676	1600		600	200	2400	4276	45,000	0	3,000	48,000
141	Elm Street	Silt	MD Residential	6680	1600		600	200	2400	4280	45,000	0	3,000	48,000
151	Elm Street	Silt	MD Residential	6684	1600		600	200	2400	4284	45,000	0	3,000	48,000
176	Elm Street	Silt	MD Residential	6070	1600		600	200	2400	3670	38,000	0	3,000	41,000
180	Elm Street	Silt	MD Residential	6675	1600		600	200	2400	4275	45,000	0	3,000	48,000
181	Elm Street	Silt	MD Residential	6688	1600		600	200	2400	4288	45,000	0	3,000	48,000
190	Elm Street	Silt	MD Residential	6941	1600		600	200	2400	4541	47,000	0	3,000	50,000
191	Elm Street	Silt	MD Residential	6693	1600		600	200	2400	4293	45,000	0	3,000	48,000
193	Elm Street	Silt	MD Residential	4843	1600		600	200	2400	2443	26,000	0	3,000	29,000
195	Elm Street	Silt	MD Residential	4131	1600		600	200	2400	1731	18,000	0	3,000	21,000
201	Elm Street	Silt	MD Residential	6416	1600		600	200	2400	4016	42,000	0	3,000	45,000
221	Elm Street	Silt	MD Residential	6106	1600		600	200	2400	3706	39,000	0	3,000	42,000
231	Elm Street	Silt	MD Residential	6452	1600		600	200	2400	4052	42,000	0	3,000	45,000
241	Elm Street	Silt	MD Residential	6627	1600		600	200	2400	4227	44,000	0	3,000	47,000
244	Elm Street	Silt	MD Residential	6706	1600		600	200	2400	4306	45,000	0	3,000	48,000
250	Elm Street	Silt	MD Residential	6894	1600		600	200	2400	4494	47,000	0	3,000	50,000
251	Elm Street	Silt	MD Residential	6665	1600		600	200	2400	4265	44,000	0	3,000	47,000
254	Elm Street	Silt	MD Residential	6256	1600		600	200	2400	3856	40,000	0	3,000	43,000
260	Elm Street	Silt	MD Residential	6865	1600		600	200	2400	4465	46,000	0	3,000	49,000
261	Elm Street	Silt	MD Residential	6682	1600		600	200	2400	4282	45,000	0	3,000	48,000
270	Elm Street	Silt	MD Residential	6463	1600		600	200	2400	4063	42,000	0	3,000	45,000
274	Elm Street	Silt	MD Residential	6886	1600		600	200	2400	4486	47,000	0	3,000	50,000
280	Elm Street	Silt	MD Residential	6909	1600		600	200	2400	4509	47,000	0	3,000	50,000
281	Elm Street	Silt	MD Residential	6699	1600		600	200	2400	4299	45,000	0	3,000	48,000
290	Elm Street	Silt	MD Residential	6765	1600		600	200	2400	4365	45,000	0	3,000	48,000
291	Elm Street	Silt	MD Residential	6716	1600		600	200	2400	4316	45,000	0	3,000	48,000
100	Forest Avenue	Silt	MD Residential	6312	1600		600	200	2400	3912	41,000	0	3,000	44,000
101	Forest Avenue	Silt	MD Residential	7572	1600		600	200	2400	5172	54,000	0	3,000	57,000

Add-ress	Street	Soil	Land Use	Area (ft^2)	Roof (ft^2)	Parking (ft^2)	Drive-ways (ft^2)	Patios (ft^2)	Impervious (ft^2)	Pervious (ft^2)	Landscaping (1/99 $)	Parking (1/99 $)	Driveway (1/99 $)	Total (1/99 $)
110	Forest Avenue	Silt	MD Residential	6424	1600		600	200	2400	4024	42,000	0	3,000	45,000
111	Forest Avenue	Silt	MD Residential	6971	1600		600	200	2400	4571	48,000	0	3,000	51,000
120	Forest Avenue	Silt	MD Residential	6294	1600		600	200	2400	3894	41,000	0	3,000	44,000
130	Forest Avenue	Silt	MD Residential	6313	1600		600	200	2400	3913	41,000	0	3,000	44,000
140	Forest Avenue	Silt	MD Residential	6353	1600		600	200	2400	3953	41,000	0	3,000	44,000
141	Forest Avenue	Silt	MD Residential	6998	1600		600	200	2400	4598	48,000	0	3,000	51,000
150	Forest Avenue	Silt	MD Residential	6333	1600		600	200	2400	3933	41,000	0	3,000	44,000
151	Forest Avenue	Silt	MD Residential	6875	1600		600	200	2400	4475	47,000	0	3,000	50,000
160	Forest Avenue	Silt	MD Residential	6372	1600		600	200	2400	3972	41,000	0	3,000	44,000
161	Forest Avenue	Silt	MD Residential	6694	1600		600	200	2400	4294	45,000	0	3,000	48,000
170	Forest Avenue	Silt	MD Residential	6392	1600		600	200	2400	3992	42,000	0	3,000	45,000
171	Forest Avenue	Silt	MD Residential	6619	1600		600	200	2400	4219	44,000	0	3,000	47,000
180	Forest Avenue	Silt	MD Residential	8120	1600		600	200	2400	5720	59,000	0	3,000	62,000
181	Forest Avenue	Silt	MD Residential	6724	1600		600	200	2400	4324	45,000	0	3,000	48,000
186	Forest Avenue	Silt	MD Residential	6312	1600		600	200	2400	3912	41,000	0	3,000	44,000
190	Forest Avenue	Silt	MD Residential	6079	1600		600	200	2400	3679	38,000	0	3,000	41,000
191	Forest Avenue	Silt	MD Residential	6599	1600		600	200	2400	4199	44,000	0	3,000	47,000
200	Forest Avenue	Silt	MD Residential	6558	1600		600	200	2400	4158	43,000	0	3,000	46,000
201	Forest Avenue	Silt	MD Residential	6500	1600		600	200	2400	4100	43,000	0	3,000	46,000
205	Forest Avenue	Silt	MD Residential	6389	1600		600	200	2400	3989	42,000	0	3,000	45,000
210	Forest Avenue	Silt	MD Residential	6562	1600		600	200	2400	4162	43,000	0	3,000	46,000
211	Forest Avenue	Silt	MD Residential	6266	1600		600	200	2400	3866	40,000	0	3,000	43,000
220	Forest Avenue	Silt	MD Residential	6566	1600		600	200	2400	4166	43,000	0	3,000	46,000
221	Forest Avenue	Silt	MD Residential	6326	1600		600	200	2400	3926	41,000	0	3,000	44,000
230	Forest Avenue	Silt	MD Residential	6570	1600		600	200	2400	4170	43,000	0	3,000	46,000
231	Forest Avenue	Silt	MD Residential	6133	1600		600	200	2400	3733	39,000	0	3,000	42,000
240	Forest Avenue	Silt	MD Residential	6575	1600		600	200	2400	4175	43,000	0	3,000	46,000
241	Forest Avenue	Silt	MD Residential	6025	1600		600	200	2400	3625	38,000	0	3,000	41,000
250	Forest Avenue	Silt	MD Residential	6579	1600		600	200	2400	4179	44,000	0	3,000	47,000
251	Forest Avenue	Silt	MD Residential	6193	1600		600	200	2400	3793	40,000	0	3,000	43,000
261	Forest Avenue	Silt	MD Residential	6379	1600		600	200	2400	3979	41,000	0	3,000	44,000
270	Forest Avenue	Silt	MD Residential	6583	1600		600	200	2400	4183	44,000	0	3,000	47,000
271	Forest Avenue	Silt	MD Residential	6169	1600		600	200	2400	3769	39,000	0	3,000	42,000
280	Forest Avenue	Silt	MD Residential	6587	1600		600	200	2400	4187	44,000	0	3,000	47,000
281	Forest Avenue	Silt	MD Residential	5411	1600		600	200	2400	3011	31,000	0	3,000	34,000
290	Forest Avenue	Silt	MD Residential	3196	1600		600	200	2400	796	9,000	0	3,000	12,000
291	Forest Avenue	Silt	MD Residential	5894	1600		600	200	2400	3494	36,000	0	3,000	39,000
293	Forest Avenue	Silt	MD Residential	3230	1600		600	200	2400	830	9,000	0	3,000	12,000
121	Main Street	Silt	MD Residential	5200	1600		600	200	2400	2800	29,000	0	3,000	32,000
125	Center Street	Silt	School	8600	0	8600	0	0	8600	0	0	41,000	0	41,000
100	Walnut Street	Silt	School	97601	69080	0	0	0	69080	28521	725,000	0	0	25,000
101	Walnut Street	Silt	School	43206	0	43206	0	0	43206	0	0	203,000	0	203,000
											14,498,000	2,028,000	969,000	17,495,000

6.4.4 Summary of costs for each right-of-way

A preliminary estimate of the right-of-way costs of development is obtained by:

1) Extracting the length and area attributes for each object using the "streets" theme from the ArcView database;
2) Multiplying the unit costs found in Table 6-22 for 50 ft rights-of-way; Table 6-23 for 60 ft rights-of-way, and Table 6-24 for 70 ft rights-of-way by the area of each right-of-way parcel.

The right-of-way cost data are presented in Table 6-29. Total paving costs for the development are $2.3 million. Total opportunity costs for the area within the right-of-way are $5.9 million. The total landscaping costs for the rights of way are $884,000.

Table 6-29. Right-of-Way Costs

Street Name	RW width, (ft)	RW length, (ft)	Area (ft^2)	Paving Cost (1/99 $)	Opportunity Cost (1/99 $)	Landscaping Cost (1/99 $)	Total Cost (1/99 $)
Acorn Street	50	1640	81990	114,000	286,000	42,000.00	442,000
Alpine Street	50	1125	56272	78,000	197,000	29,000.00	304,000
Ash Street	50	1205	60251	84,000	211,000	31,000.00	326,000
Ash-Acorn Connector	50	844	42214	59,000	148,000	22,000.00	229,000
Ashmount Street	50	870	43492	61,000	152,000	22,000.00	235,000
Ashmount Street ext.	50	1620	80981	112,000	283,000	41,000.00	436,000
Aspen Street	50	851	42537	59,000	149,000	22,000.00	230,000
Birch Avenue	50	2574	128701	178,000	449,000	65,000.00	692,000
Cedar Street	50	2899	144940	201,000	506,000	73,000.00	780,000
Center Street	60	1124	67445	92,000	236,000	29,000.00	357,000
Elm Street	50	2639	131944	183,000	461,000	67,000.00	711,000
Forest Avenue	50	2622	131119	182,000	458,000	66,000.00	706,000
Highland Street	50	831	41568	58,000	145,000	21,000.00	224,000
Main Street	70	2741	191895	230,000	670,000	124,000.00	1,024,000
Maple Street	50	2153	107667	149,000	376,000	55,000.00	580,000
Oak Street	50	1751	87540	122,000	306,000	44,000.00	472,000
Street A	50	490	24491	34,000	86,000	13,000.00	133,000
Street B	50	465	23267	33,000	82,000	12,000.00	127,000
Street C	50	517	25829	36,000	91,000	13,000.00	140,000
Street D	50	415	20756	29,000	73,000	11,000.00	113,000
Street E	50	397	19875	28,000	70,000	10,000.00	108,000
stub between Elm and Forest	50	519	25951	36,000	91,000	14,000.00	141,000
Sycamore Street	50	1086	54281	76,000	190,000	28,000.00	294,000
Walnut Street	50	1167	58349	81,000	204,000	30,000.00	315,000
Total			1693357	2,315,000	5,920,000	884,000	9,119,000

6.5 Estimated cost of BMP controls

The following sections describe the methodology used to determine runoff volumes, evaluate the calculated difference in volume between the predevelopment and post development scenarios, and lay out the procedure for estimating unit costs/gal of selected controls for the optimization process.

6.5.1 Determination of runoff volumes using SCS method

Each developed land use is assigned a curve number (CN) based upon work done by the Soil Conservation Service (1986). The initial abstraction, or available storage is estimated by the following equation:

$$I_a = \frac{200}{CN} - 2 \tag{6-3}$$

The final list of 10 permeable and 16 impermeable candidate land uses, with their expected effectiveness as measured by their curve number (CN), and the associated initial abstraction in inches, calculated using equation 6.3 are shown in Table 6-30. The CNs range from 25 – 98. The initial abstraction associated with a CN of 25 is 6.00 in of precipitation. Making this land impervious increases the CN to 98 with an associated initial abstraction of only 0.04 in, a major loss of infiltration capacity. Using unit costs in $\$/ft^2$, and having determined the appropriate abstraction, it is possible to convert the control option costs to $/gal., which is done in the last four columns of Table 6-30. These values are unique to the soil type heading the column. Unit costs expressed as $/gal are useful for comparative purposes, as will be seen later.

6.5.2 Breakdown of calculated volumes per function

A functional analysis within each land use and soil classification is performed by adding the total amounts of area for the functions of roof, lawns, driveways, and parking (for non-right-of-way uses), and streets, curbs, parking, sidewalks, and lawns for rights-of-way areas. Volumes of developed runoff can then be calculated by multiplying the initial abstraction by the appropriate area. Predevelopment runoff can be calculated using the composite curve number 63.07 for the area prior to development, determining an initial abstraction for each soil group, and multiplying this again by the area as done for the developed volumes. The result of this analysis is found in Table 6-31.

The functions are then compared across land uses by computing the difference between the sum of the function's pre-development and post-development storage volumes. This is plotted as a bar chart in Figure 6-6. The greatest impact by far is from streets and roofs, with roughly equal values of storage volume reduction. Patios are insignificant in this analysis. Lawns actually add a great deal of storage, somewhat offsetting the drastic reductions from roofs and streets. Driveways and parking lots result in smaller reductions in volume; however, because it is concentrated over smaller areas, the local impact may be great.

Table 6-30. SCS Hydrologic Classifications, and Calculation of Unit Storage Values (SCS, 1986)

		Cover Description		Curve Number				Initial Abstraction (in.)				Unit cost (1/99 $/ft^2)	Unit Cost (1/99 $/gal)			
No.	Type	Cover type and hydrologic condition	ID	A	B	C	D	A	B	C	D		A	B	C	D
1	Permeable	Aspen-mountain brush mixture: Fair:30%–70% ground cover	Aspen F	28	48	57	63	5.14	2.17	1.51	1.17	2.00	0.62	1.48	2.13	2.73
2	Permeable	Aspen-mountain brush mixture: Good: >70% ground cover	Aspen G	25	30	41	48	6.00	4.67	2.88	2.17	3.00	0.80	1.03	1.67	2.22
1	Impervious	Driveway	Driveway 1	98	98	98	98	0.04	0.04	0.04	0.04	0.23	9.21	9.21	9.21	9.21
2	Impervious	Driveway-porous pavement	Driveway 2	70	80	85	87	0.86	0.50	0.35	0.30	0.25	0.47	0.80	1.13	1.34
3	Permeable	Lawns, pasture, grassland: Fair condition (grass cover 50%–75%)	Grass F	49	69	79	84	2.08	0.90	0.53	0.38	0.81	0.63	1.45	2.45	3.42
4	Permeable	Lawns, pasture, grassland: Good condition (grass cover >75%)	Grass G	39	61	74	80	3.13	1.28	0.70	0.50	1.03	0.53	1.29	2.35	3.30
5	Permeable	Lawns, pasture, grassland: Poor condition (grass cover < 50%)	Grass P	68	79	86	89	0.94	0.53	0.33	0.25	0.70	1.19	2.12	3.45	4.55
6	Impervious	Parking	Parking 1	98	98	98	98	0.04	0.04	0.04	0.04	0.23	9.21	9.21	9.21	9.21
4	Impervious	Porous parking 1	Parking 2	61	75	83	87	1.28	0.67	0.41	0.30	0.25	0.31	0.60	0.98	1.34
5	Impervious	Porous parking 2	Parking 3	46	65	77	82	2.35	1.08	0.60	0.44	0.26	0.18	0.39	0.71	0.97
6	Impervious	Porous parking 3	Parking 4	36	55	67	72	3.56	1.64	0.99	0.78	0.28	0.13	0.27	0.46	0.58
7	Impervious	Patio	Patio 1	95	95	95	95	0.11	0.11	0.11	0.11	0.19	2.89	2.89	2.89	2.89
8	Impervious	Porous patio	Patio 2	76	85	89	91	0.63	0.35	0.25	0.20	0.19	0.49	0.88	1.25	1.57
9	Impervious	Roof	Roof 1	95	95	95	95	0.11	0.11	0.11	0.11	0.00	0.00	0.00	0.00	0.00
10	Impervious	Roof with detention	Roof 2	85	85	85	85	0.35	0.35	0.35	0.35	1.50	6.82	6.82	6.82	6.82
11	Impervious	Sidewalks	Sidewalk 1	98	98	98	98	0.04	0.04	0.04	0.04	0.19	7.44	7.44	7.44	7.44
12	Impervious	Sidewalks with porous materials	Sidewalk 2	70	80	85	87	0.86	0.50	0.35	0.30	0.19	0.36	0.62	0.88	1.04
13	Permeable	Storage-offsite in infiltration/detention basins	Storage	15	20	35	40	11.33	8.00	3.71	3.00	5.00	0.71	1.00	2.16	2.67
14	Impervious	Street with curb and gutter	Street 1	98	98	98	98	0.04	0.04	0.04	0.04	0.25	9.77	9.77	9.77	9.77
15	Impervious	Street with curb and gutter and porous pavement	Street 2	70	80	85	87	0.86	0.50	0.35	0.30	0.26	0.49	0.84	1.19	1.41
16	Impervious	Street with swales	Street 3	76	85	89	91	0.63	0.35	0.25	0.20	0.27	0.68	1.22	1.74	2.17
17	Impervious	Street with swales and porous pavement	Street 4	61	75	83	87	1.28	0.67	0.41	0.30	0.28	0.35	0.67	1.09	1.49
18	Permeable	Swales 1	Swales 1	46	65	77	82	2.35	1.08	0.60	0.44	3.00	2.05	4.47	8.06	10.96
19	Permeable	Swales 2	Swales 2	29	50	62	67	4.90	2.00	1.23	0.99	6.00	1.97	4.81	7.85	9.77
20	Permeable	Woods:Fair: Woods are grazed but not burned, and some forest litter	Woods F	36	60	73	79	3.56	1.33	0.74	0.53	0.80	0.36	0.96	1.73	2.41
21	Permeable	Woods:Good: Woods without grazing, and adequate litter and brush	Woods G	25	55	70	77	6.00	1.64	0.86	0.60	1.40	0.37	1.37	2.62	3.76

Table 6-31. Calculation of Developed and Predevelopment Stormwater Volumes

					Developed		Total Dev.	Undev.		Total Undev.
Land Use	**Function**	**B**	**D, Total**	**Area, Total**	**Volume, B**	**Volume, D**	**Volume**	**B**	**D**	**Volume**
		(ft^2)	**(ft^2)**	**(ft^2)**	**(ft^3)**	**(ft^3)**	**(ft^3)**	**(ft^3)**	**(ft^3)**	**(ft^3)**
Apartments	Roof	46,927	0	46,927	412	0	412	4,580	0	4,580
	Parking	75,083	0	75,083	255	0	255	7,327	0	7,327
	Driveway	0	0	0	0	0	0	0	0	0
	Lawns	40,670	0	40,670	4,334	0	4,334	3,969	0	3,969
Commercial	Roof	95,132	57,707	152,839	834	506	1,341	9,284	49	9,333
	Parking	44,810	259,868	304,678	152	884	1,036	4,373	86	4,459
	Driveway	0	0	0	0	0	0	0	0	0
	Lawns	6,839	16,714	23,553	729	696	1,425	667	68	735
MD Residential	Roof	140,800	267,200	408,000	1,235	2,344	3,579	13,741	229	13,969
	Parking	0	0	0	0	0	0	0	0	0
	Driveway	52,800	100,200	153,000	180	341	520	5,153	33	5,186
	Lawns	353,666	538,755	892,420	37,686	22,448	60,134	34,514	2,191	36,705
	Patio	17,600	33,400	51,000	154	293	447			0
LD Residential	Roof	102,000	0	102,000	895	0	895	9,954	0	9,954
	Parking	0	0	0	0	0	0	0	0	0
	Driveway	40,800	0	40,800	139	0	139	3,982	0	3,982
	Lawns	491,233	0	491,233	52,344	0	52,344	47,939	0	47,939
	Patio	20,400	0	20,400	179	0	179			0
School	Roof	69,080	0	69,080	606	0	606	6,742	0	6,742
	Parking	51,806	0	51,806	176	0	176	5,056	0	5,056
	Driveway	0	0	0	0	0	0	0	0	0
	Lawns	28,521	0	28,521	3,039	0	3,039	2,783	0	2,783
Streets										
50	ROW	659,728	774,288	1,434,016						
	Street with curb and gutter	105,556	123,886	229,443	359	421	780	10,301	41	10,342
	Parking	105,556	123,886	229,443	359	421	780	10,301	41	10,342
	Sidewalks	105,556	123,886	229,443	359	421	780	10,301	41	10,342
	curb	52,778	61,943	114,721	180	211	390	5,151	21	5,171
	Lawns	52,778	61,943	114,721	3,952	1,966	5,918	5,151	192	5,343
60	ROW	87,540	0	87,540						
	Street with curb and gutter	11,672	0	11,672	40	0	40	1,139	0	1,139
	Parking	23,344	0	23,344	79	0	79	2,278	0	2,278
	Sidewalks	11,672	0	11,672	40	0	40	1,139	0	1,139
	Curb	5,836	0	5,836	20	0	20	570	0	570
	Lawns	5,836	0	5,836	437	0	437	570	0	570
70	ROW	13,195	189,531	202,726						
	Street with curb and gutter	1,508	21,661	23,169	5	74	79	147	7	154
	Parking	3,016	43,321	46,337	10	147	158	294	14	309
	Sidewalks	1,508	21,661	23,169	5	74	79	147	7	154
	Curb	754	10,830	11,584	3	37	39	74	4	77
	Lawns	754	10,830	11,584	56	344	400	74	34	107
	Total			1,724,282			140,882			21,0758

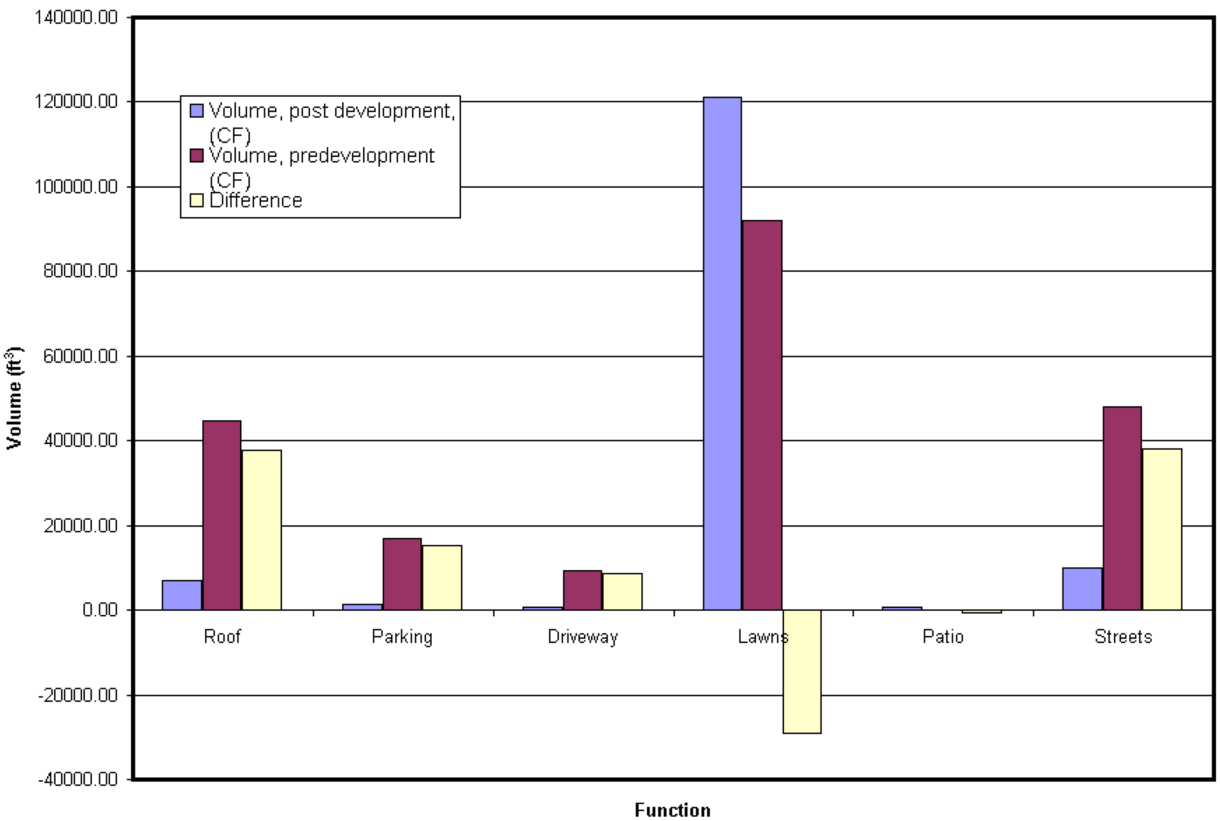


Figure 6-6. Allocation of available storage for initial abstraction and land use.

6.5.3 Estimated unit costs of various functional land use options

BMP control costs are estimated in $\$/ft^2$. These costs are assumed incremental costs over and above the costs of conventional systems. These unit cost estimates are preliminary in that the proper definition of cost depends upon alternatives that provide "equivalent" levels of service. For example, consider the following three options for a 6,000 ft^2 lawn:

- Conventional lawn with a sprinkling system
- 3,000 ft^2 of conventional lawn and 3,000 ft^2 of forest
- 2,000 ft^2 of conventional lawn; 2,000 ft^2 of forest; and 2,000 ft^2 of swales

While it is possible to estimate the cost of each of these three options, the customer must view these options as providing the same level of service for them to be considered equivalent. If the customer strongly prefers the conventional lawn, then it is inaccurate to select other options based on lower cost if they are not perceived to be equivalent. Further work is needed to provide a more accurate assessment of equivalent landscapes. For this example customers are assumed to simply select the least costly combination of BMP controls.

Using the procedures developed in section 6.4, unit costs for controls determined by Table 6-30 were used for eight different land-use model: low and medium density residential; commercial; school; apartment; and 50, 60, and 70 ft rights-of-way. The unit costs, which include opportunity costs, are listed in Table 6-32. An alternative analysis was performed which excluded the effect of opportunity costs. These unit costs are presented in Table 6-33.

Table 6-32. Calculation of Unit Costs for Controls, Including Land Opportunity Costs

ID	LD Res. (1/99 $/ft^2)	MD Res. (1/99 $/ft^2)	Commer. (1/99 $/ft^2)	School (1/99 $/ft^2)	Apartm't (1/99 $/ft^2)	RW50 (1/99 $/ft^2)	RW60 (1/99 $/ft^2)	RW70 (1/99 $/ft^2)
Aspen F	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Aspen G	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Driveway 1	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Driveway 2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Grass F	0.60	0.60	2.12	2.49	1.22	0.60	0.60	0.60
Grass G	0.69	0.69	2.18	2.56	1.29	0.69	0.69	0.69
Grass P	0.49	0.49	2.01	2.38	1.11	0.49	0.49	0.49
Parking 1	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Parking 2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Parking 3	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Parking 4	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Patio 1	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Patio 2	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Roof 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Roof 2	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Sidewalk 1	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Sidewalk 2	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Storage	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Street 1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.24
Street 2	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Street 3	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Street 4	0.28	0.29	0.28	0.28	0.28	0.28	0.29	0.28
Swales 1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Swales 2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Woods F	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Woods G	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40

Table 6-33. Calculation of Unit Costs for Controls, Excluding Land Opportunity Costs

ID	LD Res. (1/99 $/ft^2)	MD Res. (1/99 $/ft^2)	Commer. (1/99 $/ft^2)	School (1/99 $/ft^2)	Apartm't (1/99 $/ft^2)	RW50 (1/99 $/ft^2)	RW60 (1/99 $/ft^2)	RW70 (1/99 $/ft^2)
Aspen F	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Aspen G	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Driveway 1	0.06	0.23	0.23	0.23	0.23	0.06	0.06	0.06
Driveway 2	0.08	0.25	0.25	0.25	0.25	0.08	0.08	0.08
Grass F	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Grass G	0.34	0.37	0.32	0.32	0.32	0.34	0.34	0.34
Grass P	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Parking 1	0.06	0.23	0.23	0.23	0.23	0.06	0.06	0.06
Parking 2	0.08	0.25	0.25	0.25	0.25	0.08	0.08	0.08
Parking 3	0.09	0.26	0.26	0.26	0.26	0.09	0.09	0.09
Parking 4	0.11	0.28	0.28	0.28	0.28	0.11	0.11	0.11
Patio 1	0.02	0.19	0.19	0.19	0.19	0.02	0.02	0.02
Patio 2	0.02	0.19	0.19	0.19	0.19	0.02	0.02	0.02
Roof 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Roof 2	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Sidewalk 1	0.02	0.19	0.19	0.19	0.19	0.02	0.02	0.02
Sidewalk 2	0.02	0.19	0.19	0.19	0.19	0.02	0.02	0.02
Storage	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Street 1	0.07	0.25	0.25	0.25	0.25	0.07	0.07	0.07
Street 2	0.09	0.26	0.26	0.26	0.26	0.09	0.08	0.08
Street 3	0.09	0.27	0.27	0.27	0.27	0.09	0.10	0.10
Street 4	0.10	0.28	0.28	0.28	0.28	0.10	0.11	0.11
Swales 1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Swales 2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Woods F	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Woods G	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40

The reasonableness of these estimates can be judged by comparing them to the unit cost of storage systems reported in the literature; first converting them to unit costs in terms of $/gal for a given soil type, as done in Table 6-30. Storage costs described in chapter 5 of this report range from about $0.03 to $15.12/ gal (Table 6-34, is calculated using the equations from Chapter 5, obtaining a cost, then dividing the cost by the volume in gal.). Using $5.00/ ft^2 in Table 6-32 and 6-33, the results range from $0.71–$2.67/gal, well within an acceptable range. Costs for swales were estimated based upon the range of equation 4.13. Costs for aspen and woods are estimated based upon typical landscaping costs, and comparing the computed $/gal unit costs with others for reasonableness. The incremental cost for roofed area is based on the added cost of directing this runoff toward an appropriate permeable area, and again was checked for reasonableness.

Table 6-34. Range of Costs for Storage

Volume (1,000 gal.)	EPA CSO storage (1/99 $/gal)	Detention Basin (1/99 $/gal)	Retention Basin (1/99 $/gal)	Infiltration Basin (1/99 $/gal)
1	15.12	0.47	0.34	0.45
10	10.13	0.23	0.19	0.22
100	6.79	0.11	0.11	0.11
1,000	4.55	0.06	0.06	0.05
10,000	3.05	0.03	0.03	0.03

6.6 Results of BMP Optimization for Happy Acres

The detailed results of the optimization can be found in the companion report Heaney et al. (1998c). The optimal total system cost, including land opportunity costs for Happy Acres is $4.2 million (calibrated to the Denver/Boulder, CO area). The total system cost, neglecting opportunity costs is $3.9 million. This represents approximately 15%–19 % of the total $26.6 million investment overall (not including buildings).

Direct comparison to the values obtained here for the micro-storm analysis with those for the major storm analysis cannot be done, as it is normally expected that the total costs for micro-storm drainage control would be less than that for minor and major storms ($915,000 and $1.21 million, respectively). A key issue here is that the allocation of a fixed percentage of costs to stormwater control needs to be evaluated further. This percentage is essentially unknown at present.

Chapter 7

Summary and Conclusions

Cost estimation procedures for urban stormwater systems were primarily developed prior to 1980. Simple equations using one or two explanatory variables were, and still are being used to estimate costs. Modern hardware and software enable a move to data driven approaches and a focus on developing good databases for developing cost estimates. Equations are a very restrictive way to present information and should only be used for simple summaries. The availability of computerized cost databases from companies such as R.S. Means provide a very good source of information about current unit costs. In order to significantly advance the state of the art in cost effectiveness modeling, unit cost data need to be directly linked to process-simulators as demonstrated in chapter 5. This spreadsheet model can be adapted to a wide variety of physical settings and used to do a comprehensive evaluation of the nature of system costs and their relative importance. Five scenarios were evaluated to illustrate the use of this model. However, the variety of what-if analyses is virtually limitless. There are well over 1,000 variables for this 106 acre storm drainage design, thus, the number of combinations is very large. While this process-oriented approach is a major improvement over existing practices, it is still severely limited in that it only does what-if analysis and cannot systematically do what's-best optimization analysis. Currently, such an approach using intelligent search techniques is in development and this method has successfully been applied to optimization of water distribution systems (Lippai et al., 1999).

The application of GIS technology allows for a more thorough, parcel based approach to the analysis of water quality impacts during micro-storms from land use changes and development. Although the hydrologic model used here is limited (as with the rational model used in the sewer design model for the major and minor storms), it is apparent that many impacts could then be traced directly to their origin

This initial exploration into storm drainage design cost estimation suggests the following gaps in knowledge to be addressed by additional research:

1. A process-oriented approach to cost-effectiveness evaluations is essential. Curve fitting approaches to cost estimation based on as-built systems are too aggregate and the databases too inconsistent to provide the reliable estimates needed to enhance our understanding of the underlying cause-effect relationships.
2. The unit cost data provided by companies such as R.S. Means are a valuable source of the necessary cost data and should be an integral part of the overall cost-effectiveness evaluations.
3. The spreadsheet model presented in this report should be expanded to implement intelligent search techniques to determine optimal design.
4. An accurate representation of the system hydraulics is essential to meaningful system optimization. While the spreadsheet can be used for simple hydraulic analysis, it is essential to link the spreadsheet with hydraulic analyzers such as SWMM so that the

hydraulics can be done more accurately. We have already done such linkages in looking at water distribution systems by linking the optimizer with EPANET (Lippai et al., 1999).

5. The Rational Method to estimate peak inflows to pipes is archaic and should be replaced by data centered approaches. For example, the cost of this sewer system design depends heavily on the assumed travel time to the sewer inlet. Yet, this value is difficult to estimate accurately.
6. Conventional storm sewer design should also check how the system performs during small storms when lower velocities might prevail and cause sediment accumulations in the sewers.
7. The analysis needs to be expanded to include the effect of storage on the system design. However, before evaluating storage, it is imperative to use more realistic storm hydrographs and not continue to compound our ignorance by using simple extensions of the Rational Method.
8. The method needs to be expanded to include onsite controls such as infiltration. Such an analysis is not simple since storage routing is required at the parcel level in addition to evaluating larger storage systems.
9. A database of flow and quality monitoring for small (100 acres or less) catchments is needed to evaluate actual system response for small drainage areas. These catchments can be used for overall cost-effectiveness evaluations.
10. The benefits of urban stormwater systems need to be quantified. Flood damages are relatively easy to estimate. However, stormwater quality control benefits are more elusive.
11. The overall system evaluation should include structural and non-structural BMPs as well as conventional storm drainage systems.
12. The incidence of benefits and costs of alternative drainage systems needs to be quantified. Residents who control their problems on site should receive fair credit for reducing system cost.
13. Downstream receiving water impacts should be included in the evaluations.
14. A combined sewer design should be evaluated and its cost apportioned among wastewater and stormwater. The effect of providing additional storage in the combined sewer should be evaluated.
15. The cost optimization should be refined to take into account both the broader land use optimization, and to allocate the costs down to each land use, and to each parcel. Combined with GIS, this analysis should be done for several different scenarios (micro-storms, minor storms, and major storms).
16. The impact of streets and parking as integral parts of the urban stormwater system needs to be evaluated. Streets and parking comprise the majority of the directly connected impervious areas for stormwater systems. Hence, they are a major source of the problem. However, they also comprise an essential element of the stormwater management system, especially during periods of very high runoff when the sewers are overloaded. A significant part of the cost of streets and parking is for drainage. This cost needs to be included in the overall cost of stormwater management systems. A preliminary attempt has been made here to quantify these impacts in micro-storms. More work at identifying these impacts, and assessing an allocated, true cost of alleviating these impacts to these sources is essential for containment.

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