the filter cartridges: 360 ft^3 (10 m^3) for the large vault and 72 ft^3 (2.0 m^3) for the small vault.

The basic small vault (with filters) is estimated to cost \$10 000, and the basic large vault (with filters) is estimated to cost \$20 000. Each additional filter cartridge costs \$1 500. You can increase the treatment flow rate by adding additional filter vault units for the area, or using a larger vault able to contain more cartridges (which is not considered in these examples). Table 7.2 summarizes the basic options for different treatment flow rate objectives.

Table 7.2 Hypothetical costs for stormwater filters.

	\$ Cost for filters and basic vault	Total treatment flow rate (gpm)	Total storage in basic unit (ft^3)
Small vault with 3 filter cartridges	14 500	22.5	72
Small vault with 6 filter cartridges	19 000	45	72
Large vault with 9 filter cartridges	33 500	67.5	360
Large vault with 12 filter cartridges	38 000	90	360
Large vault with 15 filter cartridges	42 500	112.5	360

7.3.2 Storage Volumes and Costs

Additional storage can be added upgradient of the filters to reduce the needed treatment flow rates, based on the modeling shown in the first part of this chapter. The cost of this storage is estimated to be \$5 000 for 200 ft^3 (5.7 m^3), \$15 000 for 1 000 ft^3 (28 m^3), and \$40 000 for 6 000 ft^3 (85 m^3). Combinations of these storage units can be used for larger volumes. Table 7.3 summarizes these costs for the different storage volume options.

Table 7.3 Hypothetical costs for stormwater storage vaults.

Total storage volume (ft^3)	Number of each type of storage tank (200 ft^3–1 000 ft^3–6 000 ft^3)	Total cost for storage vaults (\$)
200	1–0–0	5 000
400	2–0–0	10 000
1 000	0–1–0	15 000
2 000	0–2–0	30 000
6 000	0–0–1	40 000
12 000	0–0–2	80 000

7.3.3 Treating 90% of the Annual Runoff

As shown in Table 7.4 and Figure 7.5, the most cost-effective solution is to use the basic filter only option with 15 filter cartridges at a total estimated cost of \$42 500/acre (\$105 000/ha) impervious area (design option 1), without any additional storage. The storage can significantly reduce the filter treatment flow rate and filter costs, but the added cost is not offset by the reduced filter cost.

Table 7.4 Treatment flow options to treat 90% annual runoff volume.

Design option	Storage (acre-inches)	Storage volume (ft^3/acre)	Treatment flow rate needed (gal/min/acre)	Cost for filters ($)	Cost for additional storage ($)	Total costs ($)
1	0	0	100	42 500	0*	42 500
2	0.063	228	100	42 500	0*	42 500
3	0.34	1 240	90	38 000	15 000	53 000
4	0.64	2 310	65	33 500	30 000	63 500
5	1.1	3 880	45	19 000	40 000	59 000

* There is no additional storage needed beyond the storage provided by the basic vault that contains the filter units.

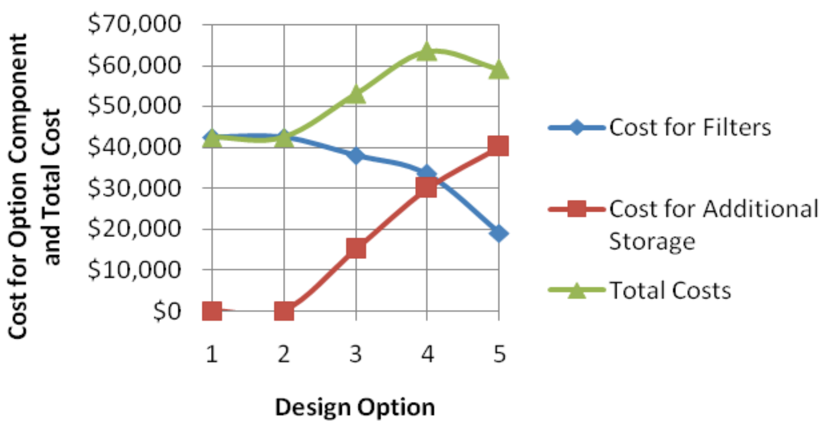

Figure 7.5 Costs for different storage-treatment options for 90% of annual flow control.

7.3.4 Treating 100% of the Annual Runoff

As shown in Table 7.5 and Figure 7.6, the most cost-effective solution when needing to treat 100% of the total annual flow is to use the largest amount of storage (design option 5), for a total estimated cost of $82500/acre (0.4 ha) impervious area. Because of the large treatment flow rates, a more cost-effective solution for this filter may be to use a larger vault that can contain the total number of filter cartridges in a single vault unit, as 70 cartridges are needed to treat the 500 gal/min (32 L/s) peak flow rate. The single much larger vault may cost less than the multiple units assumed in this example.

The increased cost to treat 100% of the peak expected flows is about twice the cost of treating 90% of the total runoff volume. It is likely that it would be much more cost effective to treat additional areas at a reduced cost than to treat smaller areas at a higher level of treatment.

2

Table 7. 5 Treatment flow options to treat 100% annual runoff volume.

Design option	Storage (acre-in.)	Storage volume (ft^3/acre)	Treatment flow rate needed (gal/min/acre)	Cost for filters ($)	Cost for additional storage ($)	Total Cost ($)
1	0	0	500	212 500	0	212 500
2	0.062 7	228	500	212 500	0	212 500
3	0.341	1 240	300	127 500	5 000	132 500
4	0.636	2 310	200	85 000	30 000	115 000
5	1.067	3 880	100	42 500	40 000	82 500

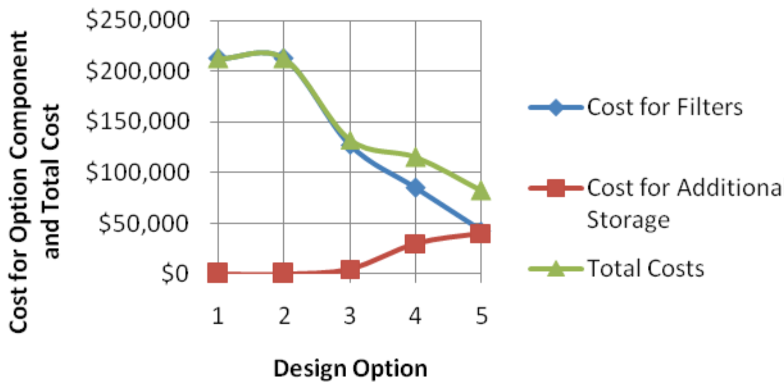

Figure 7.6 Costs for different storage-treatment options for 100% of annual flow control.

7.3.5 Treating the Annual Runoff to Meet TMDL Requirements

In this example, it is assumed that the filter unit can reduce the SSC at the 85% level under all flow conditions considered. This is a simplistic assumption used for these calculations. The treatment flow options vary for each level of control desired, as shown in Tables 7.6 and 7.7.

Table 7.6 Fraction of annual flows to be treated to meet load reduction goals.

Design option (% SSC load reductions)	Fraction of total annual flow that must be treated
40	48%
60	71%
80	95%

As shown in Table 7.7 and Figure 7.7, only the smallest vault with two cartridges is needed to provide 40% reductions in SSC for any of these filter treatment rates. No additional storage is needed. The expected total cost is \$13 000/acre (\$33 500/ha) of impervious area to meet this TMDL discharge goal.

Table 7.7 40% SSC load reductions (48% annual flow treated at 85% reductions).

Design option	Storage (acre-in.)	Storage volume (ft^3/acre)	Treatment flow rate needed (gal/min/acre)	Cost for filters ($)	Cost for additional storage ($)	Total costs ($)
1	0	0	14	13 000	0	13 000
2	0.063	228	14	13 000	0	13 000
3	0.34	1 240	14	13 000	5 000	18 000
4	0.64	2 310	13	13 000	30 000	43 000
5	1.1	3 880	11	13 000	40 000	53 000

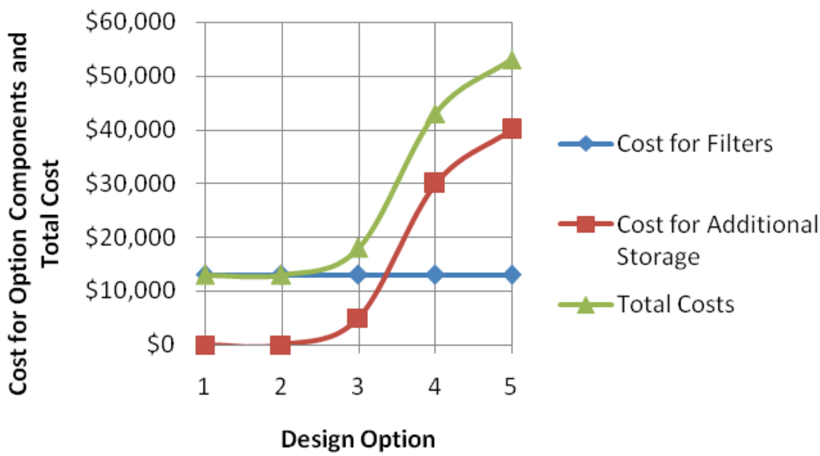

Figure 7.7 Costs for different storage-treatment options for 40% SSC load reductions.

Only the smallest vault with five filter cartridges is needed to provide the least cost option (shown in Table 7.8 and Figure 7.8) for an annual 60% SSC yield reduction. The expected total cost is $19 000/acre ($47 000/ha) of impervious area to meet this TMDL discharge goal.

Table 7.8 60% SSC load reductions (71% annual flow treated at 85% reductions).

Design option	Storage (acre-in.)	Storage volume (ft^3/acre)	Treatment flow rate needed (gal/min/acre)	Cost for filters ($)	Cost for additional storage ($)	Total costs ($)
1	0	0	39	19 000	0	19 000
2	0.062 7	228	39	19 000	0	19 000
3	0.341	1 240	35	17 500	5 000	22 500
4	0.636	2 310	32	17 500	30 000	47 500
5	1.067	3 880	22	14 500	40 000	54 500

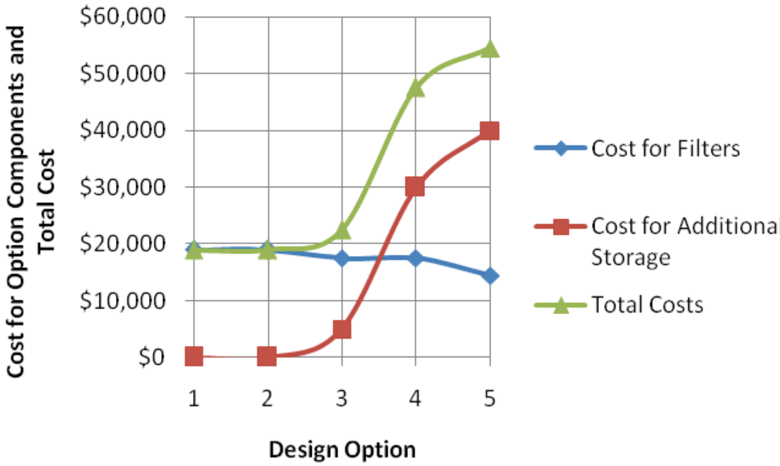

Figure 7.8 Costs for different storage-treatment options for 60% SSC load reductions.

In the third case to meet an 80% SSC reduction goal, an intermediate design option is slightly more cost effective than the others, as shown in Table 7.9 and Figure 7.9. This option uses the large vault with 15 filter cartridges, plus the small vault with three more cartridges, in addition to 1 240 ft^3 ($35m^3$) storage. The expected total cost is $62 000/acre ($153 000/ha) of impervious area to meet this TMDL discharge goal. It is possible that a larger vault that can contain all of the 18 filter cartridges would be less costly.

Table 7.9 80% SSC load reductions (95% annual flow treated at 85% reductions).

Design option	Storage (acre-in.)	Storage volume (ft^3/acre)	Treatment flow rate needed (gal/min/acre)	Cost for filters	Cost for additional storage	Total costs
1	0	0	160	$63 000	$0	$63 000
2	0.062 7	228	160	$63 000	$0	$63 000
3	0.341	1 240	130	$57 000	$5 000	$62 000
4	0.636	2 310	100	$41 000	$30 000	$71 000
5	1.067	3 880	53	$33 500	$40 000	$73 500

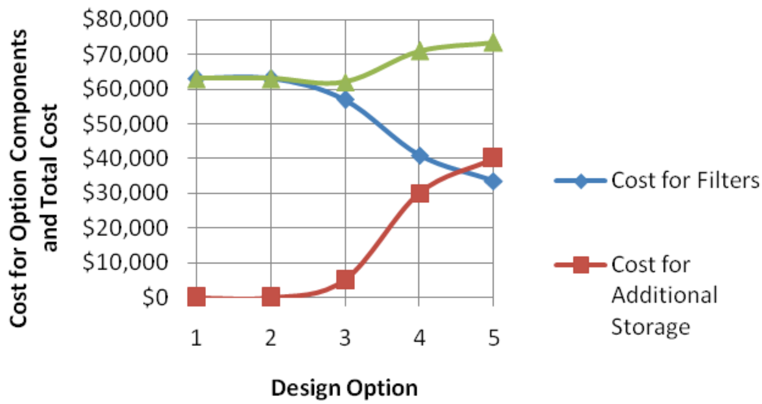

Figure 7.9 Costs for different storage-treatment options for 80% SSC load reductions.

The hypothetical filter options used in these examples may provide varying levels of treatment for different flow conditions and influent concentrations. This was not considered in these simple examples. WinSLAMM is currently being modified to incorporate stormwater media filters that will consider these additional performance attributes. Direct analyses will then be possible to evaluate different filter treatment options, with different treatment objectives (effluent quality, volume treated. or mass discharges), and to calculate life cycle costs that consider the initial construction costs (the only costs considered in the above examples), land costs, maintenance costs, and financing costs. The use of a decision analysis framework that considers other attributes is recommended for the final decisions. A detailed example of decision analysis to assist in the selection of stormwater controls is provided by Pitt and Voorhees (2007) and Alfaqih and Pitt (2009).

7.4 Conclusions

This chapter presents an example for conducting long term simulations of stormwater treatment filters. The results can be used to predict performance, and to prepare design curves that can assist in sizing stormwater filters for specific areas and objectives. There is a need for continuous long term simulations to evaluate and design water quality stormwater controls. The proper evaluation of urban hydrologic processes is critical, especially when calculating flows associated with small and intermediate sized rains. These processes, in conjunction with long term simulations, enable realistic calculations to be made. Probability distributions of modeling outcomes that relate to many receiving water objectives in urban areas can also be prepared from the results of long term water quality simulations. The use of single design storms and hydrological calculations that focus on larger events do not provide accurate or sufficient information for the rains affecting receiving water resources, and distort information pertaining to the sources of flows and pollutants.

This chapter illustrates a basic approach to the design and sizing of stormwater filters, based on treatment flow rate information. The continuous simulations produce treatment flow rate plots that can be used in evaluating different annual total flow treatment objectives. Some stormwater quality models can calculate these factors directly, while with others, it is possible to post-process high resolution flow calculation results in a spreadsheet. It is possible to determine the treatment flow rates needed to treat different fractions of the total long term flows. Combinations of storage and filtration can also be evaluated to identify the most cost effective solutions for a site.

Examples for several different treatment objectives are presented for Madison using a 5 y rainfall record that was selected as being representative of long term conditions. These examples, using WinSLAMM, show how the treatment flow rate is dependent on treatment objectives and how, in many cases, storage can be used to reduce the overall expected costs of the treatment systems.

The methods presented in this chapter can be used by regulators to assist in the development of regulations covering treatment goals for local conditions, by manufacturers of stormwater filters in the preparation of design curves to assist in the sizing of filter units to meet these objectives, and by stormwater designers to help select alternative stormwater treatment systems. Obviously, the specific results presented in this chapter are not intended to be applied to other areas having other rain, or cost, conditions.

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