SWMM Storage-Treatment for Analysis/ Design of Extended-Detention Ponds

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This chapter describes the application of the Storage-Treatment (S-T) Block of the EPA Storm Water Management Model (SWMM) to design and/or analyze extended-detention ponds (EDPs) for the reduction of pollutant loads from storm-water runoff. SWMM simulation results, supported with simple spreadsheet models, are presented to illustrate the influence of design features on expected pollutant-removal efficiency of this popular best-management practice (BMP). Important insights on the operational characteristics of EDPs are also provided, based on sensitivity analyses that were performed to evaluate certain alternative design features in actual case studies. The importance of this refined method for EDP design is emphasized with examples of how the use of common rules of thumb or guidelines from BMP manuals could result in unexpectedly poor EDP performance.

17.1 Introduction

The authors recently performed two projects that required quantitative assessments of the pollutant-removal efficiencies achieved with EDPs. SWMM (Version 4.31) was used to assess the effect of the proposed EDPs on long-term pollutant loadings from storm water. In one project, design features were based

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on generally accepted rules of thumb; in the other project, design features were based on an interpretation of recommendations provided in a State BMP guidance manual. In both projects, initial model projections produced surprisingly poor removal efficiencies. Subsequent analyses using SWMM and simple spreadsheet models provided insight into the operational aspects of EDPs and guidance for the selection of effective design features.

This chapter is organized as follows. Section 17.2 provides some general information describing EDPs and traditional design methods. Section 17.3 briefly reviews the capabilities, requirements, and output of the SWMM Storage-Treatment Block with regard to modeling EDPs. Section 17.4 presents the specific model-simulation procedures used in the analyses, provides some initial results, and introduces the need for additional analytical refinements. Section 17.5 describes the simple spreadsheet model developed for this purpose and highlights how this approach provides insights applicable to EDP design. Section 17.6 presents the results of the analysis, and Section 17.7 summarizes the conclusions of the chapter.

17.2 Extended-Detention Ponds (EDPs)

EDPs have become a popular BMP choice for storm-water control. A typical EDP (Figure 17.1) is constructed to retain storm-water runoff in a temporary pond that drains over a period of time, typically 24 to 48 h. Storm water is detained in an EDP because inflows can fill the pond much faster than the water is allowed to exit. EDPs eventually drain dry because the outlet is located at the bottom of

Figure 17.1 Typical extended-detention pond.

the pond. Variations on the design may include a small marsh area or permanent pond at the outlet structure to enhance biological pollutant removal and/or to enhance the wildlife habitat. EDPs can also be contoured and landscaped for a natural appearance.

17.2.1 Advantages of EDPs

Compared to other types of detention ponds, EDPs offer a variety of advantages. They are widely applicable for various drainage-area sizes and soil characteristics and are easily and inexpensively adapted from pre-existing dry or wet ponds. Due to their relatively brief detention times, EDPs do not generally release warm or anoxic water to downstream habitats and, because there is no permanent pool, EDPs can provide some recreational use (e.g. ballfields) and typically lack the safety and wetland-encroachment problems sometimes associated with wet ponds. Overall, EDPs are the least costly urban BMP available that can provide control of both hydraulic (flooding, erosion) and pollutant (water quality) problems associated with storm water.

17.2.2 Traditional Guidance for EDP Design

Previous guidance has typically expressed design of EDPs in terms of a volumetric capacity (*size*) as well as a holding time, often referred to as *residence* or *detention* time. As shown in Table 17.1, several rules of thumb for EDP design have been offered by various municipal authorities. Each method may provide a different level of performance with respect to hydraulic peak shaving, erosion control, and/or particulate removal over a given period of time.

In traditional guidance, the primary factor affecting EDP sizing is the expected amount of runoff generated from the drainage area for the design storm. The runoff generated is dependent upon the amount of precipitation and the size and permeability of the drainage area. As shown in Table 17.1, existing guidance typically defines the amount of precipitation based on a prescribed frequency-duration statistic for the region. For example, a 1-y, 24-h storm refers to the maximum amount of rainfall that is expected to fall over a 24-h period, an average of once annually. Some municipalities favor providing the size of the storm outright (e.g. a 25 mm storm), presumably to dispense with any confusion that might arise from expressing the frequency-duration statistic. Other municipalities, seeking to ensure that EDPs can capture the first flush of all storms, favor a method whereby the EDP capacity is expressed in terms of a certain runoff volume per unit drainage area.

The second criteria typically used in EDP design is detention time. All else equal, longer detention times enhance pollutant-removal efficiencies and minimize hydraulic peaks downstream. *Detention time* is defined (Schueler, 1987) as

the average time parcels of water reside in an EDP for a particular storm. In practice, application of this definition is difficult, and traditional guidance has not made use of it. As shown in Table 17.1, traditional guidance on design detention time varies considerably, and the definition of detention time can be ambiguous. For example, rules 1 through 6 define a drain time over which it takes a full pond (that is, a pond at design capacity) to empty. This definition reflects the *longest* time for any parcel of water to be discharged, rather than the *average* time, as in the strict definition. But because the drain-time definition is a straightforward concept and is easy to calculate, it is more appealing than the strict definition. As suggested in the following discussions, an important accomplishment for storm-water control would be to identify a useful, unambiguous definition for pond residence time.

Table 17.1 Traditional sizing rules for EDPs.

Rule #	EDP Volume (ac-in)	EDP Release Time (h)	Reference
1	RO * A (RO = 0.5 in)	40 (minimum)	MC DEP, 1984a
2	P * Rv * A (P = 1-y, 24-h)	24 (minimum)	Md WRA, 1985b; PGC DER, 1984
3	P * Rv * A (P = 2-y, 24-h)	24	
4	P * Rv * A (P = 1.0 in)	24	
5	RO * A (RO = f(landuse))	40	FC DEM, 1980 NVPDC, 1980
6	RO * A (RO = 0.5 * PCI)	24	MD WRA, 1986b
7	1.2 * max of: or (P * Rv * A, P=1-y, 24-h)	24 (minimum) <i>average detention time</i> for design storm, subject to minimum necessary for erosion control, or 6 (minimum for 0.1 in storm)	Morton, 1992

A = contributory drainage area (ac)
Rv = runoff coefficient (unitless)
P = rainfall (in)
RO = runoff (in), based on landuse type from Chart A: NVPDC, 1980
PCI = percentage of drainage area that is impervious
Release Time = total period of time (h) during which the detained volume is released
Average Detention Time = average time (h) parcels of water reside in pond

17.3 SWMM Storage-Treatment Block

The SWMM Storage-Treatment (S-T) block provides a framework to simulate hydraulic storage and treatment of up to three different pollutants in as many as five interconnected storage/treatment units. S-T was originally conceived to simulate the routing of flows and pollutants through a dry- or wet-weather storage unit or treatment plant, but it has been enhanced and is now general enough for wide application. S-T may accept inputs for inflow and influent quality from any properly formatted source, including output from the SWMM RAIN and RUN-OFF blocks. Model output, which consists of either time series or summaries of discharged flows and pollutant concentrations, may be used as input for other SWMM blocks or may be post-processed for use with a host of other applications.

The analyses described herein applied the SWMM (Version 4.31; Huber et al., 1988) RAIN, RUNOFF, and S-T blocks to determine the average pollutant-removal efficiency for a given catchment area and EDP design for a long-term (2-y) period. Each of these model runs required approximately 60 minutes on a 200 MHz Pentium processor when runs included both RUNOFF and S-T blocks. Runtimes were 15 to 20 minutes when S-T used a RUNOFF interface file for input.

17.3.1 S-T Input Requirements

In addition to the inflow and concentration information provided in the RUNOFF interface files, the S-T block requires a number of other inputs to simulate EDP performance. These inputs include a description of the physical and operational characteristics of the EDP, options for either a completely mixed or a plug-flow regime, and information to describe the decay rates of the pollutants to be modeled.

Physical characteristics of the EDP are input with a matrix that provides, for each unit of depth in the EDP unit, the corresponding storage volume, surface area, and discharge rate. For the analyses described herein, this information was developed using design maps and drawings of the EDP and application of the conic method for reservoir volumes. The depth-versus-discharge values were computed using orifice and weir equations, as appropriate, and hence required information relating to the outlet structures, such as orifice diameter and weir dimensions.

The S-T block features several options for water-quality calculations that provide flexibility for modeling the operation of the storage unit and the behavior of various pollutants. Pollutants are routed through the detention unit by one of two modes: plug flow or complete mixing. The plug-flow option essentially assumes that inflowing parcels do not mix with one another while detained in the unit, and that the first parcel into the unit becomes the first parcel discharged from

the unit. Because most EDPs have irregular contours and, particularly during shallow-depth operation, lack uniform flow patterns, the completely mixed assumption is appropriate and was used for the analyses described herein.

The S-T block allows pollutants to be characterized based on concentration or, when the plug-flow option is used, based on concentration and particle characteristics. In the former case, pollutant treatment/decay rates are simulated using a first-order, exponential decay formulation. The latter case utilizes a removal mechanism that accounts for settling. The analyses described herein utilized the first-order, exponential decay rates for pollutant removal. The S-T block was set up as illustrated in the SWMM documentation (Huber, 1988; see page 322, equation 7-2) for the assignment of coefficients for Data Group G3 to analyze exponential decay in completely mixed systems. More information about how decay rates were selected is provided in Section 17.4.

17.3.2 S-T Output

Output from the S-T block is a time series of discharged flows and pollutant concentrations at specified intervals that are defined as multiples of the model time step. Output options include monthly, annual, and overall-period summaries of total inflows and loadings, and discharge flows and pollutant loadings. For the analyses described herein, a post-processing program was developed to reformat the output file to make it suitable for input into spreadsheets and in-house software analysis and graphics packages. The formatted output provided information about overflow incidents and EDP emptying time. Additional information about how the S-T output was used is presented later.

17.4 Model-Simulation Procedures

In two separate projects, the authors used the S-T block to analyze the potential long-term pollutant-removal efficiencies of EDP designs proposed by others. Similar approaches were followed in both projects. The following discussions summarize some of the procedures used to set up these model simulations.

17.4.1 EDP Designs

As discussed in Section 17.2, most traditional rules of thumb and guidance for EDP design are based on a single design storm. For the first case study, the EDP design was based on State guidance, which called for a capacity equal to the volume of runoff generated from a 1-y, 24-h-duration storm. Emptying time from a full-pond condition was stipulated to be not less than 24 h, and emptying time for a small (2.5 mm) runoff event was stipulated to be not less than six hours.

For the second case study, the design was based on a designers' rule of thumb stipulating that the EDP capacity be equal to the volume of runoff generated from a 1.5 in (38 mm) storm, and that the emptying time from a full-pond condition be not less than 48 h.

The physical dimensions of EDPs are often influenced by site constraints as well as regulatory guidance. This was the situation in both of the case studies investigated. In the first case above, for example, the EDP was to be located within a highway median. The study objective was to check that the performance of the already-designed EDP would meet the designers' expectations.

17.4.2 Simulation Period

Because EDP performance during a "design storm" will differ from the performance during other storms, the authors selected an approach to simulate performance over a long-term period so that the evaluation would be more representative of the expected performance. The authors examined the 30-y rainfall record for the US Weather Service rain gage at New York City's LaGuardia Airport, which is approximately 20 mi (32 km) from the study area. Balancing resource expenditures between longer simulation periods and additional alternative testing, the authors selected the rainfall record from two consecutive calendar years to provide representative conditions for the analyses. According to rainfall statistics developed using the SYNOP statistical rainfall analysis program (Driscoll et. al., 1989), the first of these two years was close to the average in annual rainfall, and the second had the third highest annual rainfall in the record (Driscoll et. al, 1989). As will be demonstrated below, the nominal difference in the EDP efficiencies calculated for these two years indicates that the simulation period is adequate for the project objectives and that a longer (e.g. 10-y) simulation period would produce essentially the same results.

17.4.3 Specification of Pollutants and Pollutant-Removal Rates

As mentioned above, the S-T block can accommodate up to three different pollutants in a single simulation. The following discussion summarizes the methodology used in this investigation to develop pollutant-removal rates as input for S-T. However, this method is shown only as an illustrative example; alternatively, these rates may be specified through direct measurement, model calibration, literature values, and best professional judgment.

Modeled pollutants simulated in these case studies included total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), and fecal coliform (FC). In the RUNOFF block, a rating-curve quality option was selected to relate runoff concentrations to runoff flow. Where possible, pollutant-removal rates for use in S-T were developed using overall removal efficiencies attributed to EDPs in

guidance documents (Schueler, 1987), as follows. The S-T block defines the pollutant-removal efficiency on the basis of a decay rate, k , according to the following equation:

$$E = E_{\max} (1 - e^{-kt}) \quad (17.1)$$

where:

- E = the overall pollutant-removal efficiency (fraction)
- $E_{\max}$ = the maximum removal (fraction) typically attainable with EDPs
- k = the pollutant-removal (or decay) rate (per time step)
- t = the time elapsed (time step), and
- e = the base of the natural logarithm.

To determine k , values for E and $E_{\max}$ were selected from the lower and upper range of the efficiencies listed in the State guidance, and t was assigned as one day (the design detention time for an EDP in State guidance). For example, for TSS removal, the State guidance reported a removal-efficiency range of 80 to 95%. Assigning E as 0.8 and $E_{\max}$ as 0.95, and t as 1.0 d, k was back-calculated as about 1.84/d. This rate was then assigned in the S-T input for this pollutant, after conversion to the model time step. The k rates for other simulated pollutants were computed in the same manner.

No information was available in the State guidance for EDP performance with FC removal. Based upon a search of the literature, a die-off rate of 1.0/d was selected as the k rate in the S-T model. The resulting FC removal efficiencies were consistent with those generally associated with EDPs (Schueler, 1991, CWP, 1997).

17.4.4 Initial S-T Results

Once the inputs for the SWMM analyses were prepared as described above, the model simulations were performed. The S-T summary files provided the information necessary to calculate the overall pollutant-removal efficiency on either a monthly, annual or total-simulation basis. Pollutant-removal efficiency was calculated as the ratio of total pollutant mass removed by the EDP to the total pollutant mass influent to the EDP over the simulation period.

In both cases, the SWMM-calculated pollutant-removal efficiencies were much lower than had been expected, based on the ranges published in the guidance. Selected initial results for the first case study are shown as an example in Table 17.2.

Even after the input files had been double-checked for typographical errors, the calculated pollutant removals were suspiciously low relative to those generally expected for EDPs. However, because the S-T output was not amenable to easy interpretation, the possible factors contributing to the lower-than-expected results could not be ascertained easily.

Table 17.2 SWMM-calculated performance for EDP (designed using traditional guidance).

Pollutant	Pollutant-Removal Efficiency	
	Calculated	Expected Range *
Total Suspended Solids (TSS)	17%	80 – 95%
Total Nitrogen (TN)	7%	40 – 60%
Total Phosphorus (TP)	9%	50 – 75%

*Note: Expected Range taken from Scheuler, 1987

17.4.5 Post-Processing Programs

The S-T block output files for the two-year simulations were large and unwieldy, and neither they nor the summary output files provided information that could be interpreted easily to ascertain the reasons for the lower-than-expected pollutant-removal results. In fact, the output was so unmanageable, initial erroneous results due to a simple mistake in the input files went unnoticed until late in the design. To facilitate interpretation of the model output and to help screen for erroneous results, two simple programs were developed. The first program is a simple post-processor to summarize and reformat the S-T output, and the second program is a simple spreadsheet model designed to provide a screening-level check of the S-T output and to provide insight into EDP design issues.

A simple FORTRAN program was developed to read and reformat the large and unwieldy S-T output files and to create workable summaries of the output in terms of pollutant loadings and removal efficiencies. In addition, the program keeps track of how many times the EDP fills to capacity and how long the EDP is dry versus how long it is wet. These results indicated that, with the original outlet orifice, the EDP never would have filled to capacity during the 2-y simulation, even during the largest storm simulated. Furthermore, the EDP would have been essentially dry about 95% of the time when there was no runoff. For most storms, virtually all flow passes through the orifice with minimal detention. Without detention time, the EDP has minimal potential for treatment of pollutants.

Even with the additional information supplied with the post-processor, interpretation of the results was not easy and suspicions could be checked only with trial-and-error iterations of SWMM simulations. There was no way to be sure that a typographical error was not lurking in the input or even that SWMM was calculating correctly. A screening-level spreadsheet model was then developed to provide a check against the S-T output. Although it provides only approximate results, the spreadsheet model has easily understood inputs and outputs that make it easy to trace factors such as residence time and pollutant-removal rates. As described in the next section, this spreadsheet model provided a way to check the S-T model output, and it also provided a means to generate insight into operational features and the relative importance of the design factors.

17.5 Spreadsheet Model

A simple spreadsheet model was originally developed to provide an independent check of the S-T calculations for a particular storm. To keep the spreadsheet simple, the entire storm runoff volume is assumed to enter the EDP instantaneously. Based on the same depth/volume/outflow relationships specified in the S-T input, the model then calculates the time that it takes each of several depth layers to empty. These emptying times are then used, in conjunction with the same first-order pollutant-decay/removal rates specified in the S-T input, to estimate the pollutant mass removed from each depth layer. The model then computes the total mass of pollutants removed from all layers and the overall EDP pollutant-removal efficiency. In sum, given a particular storm, the spreadsheet model estimates the fill level, the overall emptying time, the total influent mass, the total mass removed, and the overall pollutant-removal efficiency.

To check the results of the S-T block, a large but brief (e.g. 70-mm-in-1-h) storm is simulated with SWMM. The calculated runoff volume is then input into the spreadsheet model. Because the runoff enters the pond almost instantaneously, the S-T-calculated fill volume will closely match the spreadsheet fill volume. The spreadsheet calculations for removal efficiency, which are based on a coarse vertical segmentation of layers, are approximate but not unreasonable and roughly match the S-T results.

Although first conceived as a means to check the S-T output, the spreadsheet model provides a simple method to view and interpret the effects of changing the outlet orifice diameter and/or the pollutant-removal (or decay) rate. The spreadsheet shows the time that it takes each layer to empty and the resulting pollutant removals achieved in each layer and overall. Therefore, the spreadsheet model was used not only to verify that the S-T block was calculating correctly, but also to provide insight into the relative importance of key design features.

As an illustration, Table 17.3 shows the spreadsheet model set up for the original EDP design and TSS as the pollutant. The first four columns show the relationship between rainfall statistics (total volume, number of expected occurrences per year, return period) and the corresponding pond depth, assuming that the entire rainfall volume reaches the pond in one hour. Each row, therefore, represents a vertical layer in the pond. Column 5 contains the corresponding pond storage volume with each depth, or, equivalently, the runoff volume from the corresponding rainfall in column 1. Column 6 shows the incremental storage volume of the layer in the pond. Columns 7 and 8 show the orifice-and total-outflow rates (based upon the orifice and weir equations used to develop the depth-outflow equations for S-T input) for each depth (note the weir-crest elevation is 0.97 m above the pond bottom). Column 9 shows the average flow rate applicable for each layer, and column 10 shows the corresponding total time each layer takes to drain. Column 11 provides the total pollutant mass in the layer,

Table 17.3 Simple spreadsheet model.

SIMPLE SPREADSHEET MODEL FOR EDP PERFORMANCE						orifice coefficient = 0.60 orifice area = 0.136 sf orifice diameter = 0.417 ft orifice diameter = 5.00 inches				Flow = 80 % ** Rmax = 96 % suggested k = 1.84583 per day k = 1.84 per day			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
STORM			POND GEOMETRY			POND FLOW RATES			TIME		POLLUTANT		
Total Rain+ (inch)	No. Per Year	++ Return Period	Depth ft (ft)	Total Volume (cf)	Layer Volume (cf)	Orifice (cfs)	Total (cfs)	Layer (cf/hr)	To Drain Layer (hr)	Average Contact (day)	Mass Initial* (unit)	Mass Removed (unit)	Mass Removed (%)
2.89	0.8	15 mo	3.28	91,786	5,843	1.189	142.43	258,483	0.02	0.00	5,843	5	0.1
2.71	1.0	12 mo	3.16	65,943	12,894	1.171	1.171	4,137	3.12	0.07	12,894	1,398	11
2.30	1.6	7.5 mo	2.95	73,049	16,688	1.128	1.128	3,943	4.23	0.22	16,688	5,258	32
1.78	3.2	4.0 mo	2.62	56,361	14,753	1.063	1.063	3,705	3.98	0.39	14,753	7,178	49
1.31	6.5	2.0 mo	2.30	41,608	12,947	0.996	0.996	3,451	3.75	0.55	12,947	7,639	61
0.90	13	1.0 mo	1.97	28,661	11,254	0.921	0.921	3,172	3.55	0.70	11,254	7,760	69
0.55	27	0.5 mo	1.64	17,407	8,493	0.841	0.841	2,866	2.96	0.84	8,493	6,345	75
0.28	48	1 wk	1.31	8,914	5,152	0.751	0.751	2,522	2.04	0.94	5,152	4,032	78
0.12	64	6 days	0.98	3,762	2,647	0.650	0.650	2,150	1.24	1.01	2,647	2,124	80
0.04			0.66	1,115	977	0.533	0.533	1,639	0.60	1.05	977	794	81
0.004			0.33	138	138	0.377	0.377	679	0.20	2.19	138	129	93
			0.00	0		0.000	0.000						
OVERALL: 91,786									25.70	0.45	91,786	42,661	47
									or 1.07 da	***	OVERALL REMOVAL EFFICIENCY		
NOTES:													
* storm size producing runoff equivalent to corresponding storage volume													
++ approximate frequency at which indicated storms occur													
+++ total flow rate includes orifice flow and over-weir flow													
* initial mass calculated assuming 1 mass unit per cf													
*** Rflow, Rmax expected performance from EDPs from Schueler, 1987; suggested k assumes Rflow associated with 24-hour detention time													
**** Weighted (by layer volume) Average Contact Time													

assuming a completely mixed unit concentration. Column 12 shows the cumulative period of time water resides in each layer for the largest storm shown in column 1. Column 13 then shows the total mass removed from each layer. Column 14 shows the percentage of the initial mass that is removed from each layer, and the overall EDP pollutant-removal efficiency is calculated using the totals for initial pollutant mass and pollutant mass removed.

The spreadsheet model inputs are easily modified. The pollutant decay/removal rate may be changed simply by changing the value in the cell at the top of column 13, and the orifice diameter may be changed by altering the value in the cell at the bottom of column 7. Smaller storms may be analyzed simply by zeroing out the larger storms. Through the process of altering these parameters, the designer can check the SWMM results and can also gain insight into the operation and performance of the EDP. Some insights gained during the case studies are discussed in the next section.

In this example, for a storm that fills the EDP, the spreadsheet calculates a TSS-removal efficiency of 47% with a 127-mm orifice. This compares to an SWMM-calculated efficiency of 49% when, for purposes of comparison, SWMM input was altered so that the same storm runoff entered the pond in one hour. Of course, the assumption that the entire runoff volume enters the pond at once is a simplification that, as discussed in the last section, may inflate performance projections. Nevertheless, the simplicity of the spreadsheet model makes it a useful screening tool when used in conjunction with SWMM.

It should be noted that the spreadsheet model is set up so that all runoff is routed through the EDP. When a storm is large enough to fill the pond to a depth greater than the weir height of the outlet structure, then a portion of the flow receives a reduced level of treatment—due to the high discharge rate provided by the weir and the corresponding reduced residence time for the excess runoff volume. This is evident in the example, where the runoff volume (91,786 cf) exceeds the EDP capacity (85,943 cf), sending excess volume (5,843 cf) over the weir in a short period of time (0.02 h), thereby providing little mass removal (0.1%) for that portion of the total volume. Because the overall mass-removal rate accounts for the total mass out and the total mass in, the spreadsheet model accounts for the effect of the “spillover.” Thus, larger storms (with more excess runoff) will further reduce the overall performance of the EDP. However, in the cases investigated and as shown in the example, the EDP was sized for a rather large storm (1-y return period) so that during the 2-y simulation period only a couple of storms caused the EDP to fill beyond capacity. The effect of these large storms on long-term EDP performance is diminished since only a small percentage of the total runoff volume “spills over” the weir. In fact, as demonstrated below, smaller orifice sizes enhance the long-term pollutant removals because the increased residence time they provide for all storms more than offsets the increased “spillover” volumes.

17.6 SWMM Simulation Results

The SWMM simulation results indicated that the original EDP designs, which were based upon traditional rules of thumb and guidance documents, would have achieved poor performance results in both case studies investigated. To gain an understanding of why performance was below expectations, several sensitivity analyses of various design factors were conducted using the simple spreadsheet model in conjunction with SWMM. The results of these analyses were provided to the clients, who will use them as a basis for considering design modifications. The following discussion presents selected results from one of the case studies to illustrate the results of the modeling and sensitivity analyses.

17.6.1 Poor Pollutant-Removal Efficiencies from EDPs

The initial EDP designs were based upon traditional rules of thumb and guidance documents that do not necessarily guard against selection of orifice sizes that could allow most storm volumes to pass, undetained, through the ponds. Although the potential of these EDP designs to perform poorly was revealed before they were built, there is evidence that such poor performance may not be uncommon in existing EDPs that may also have been designed using similar traditional rules of thumb and guidance. At least one survey (Galli, 1992) has found that most EDPs—particularly those designed for larger storms—were not achieving their target detention times, and that smaller storms pass through with little or no control. Other information (CWP, 1995, 1997) confirms that, with adequate detention time, EDPs can achieve good removal efficiencies. The recommendation is to design systems that provide detention for a range of storm sizes, perhaps using orifices as small as 50 mm (which are reported to work for long periods of time without clogging).

17.6.2 Orifice Sizing

Sensitivity analyses were conducted to determine the effect of using orifice sizes from 127 mm (the orifice size specified in the original design) down to 50 mm (the minimum recommended to guard against clogging). The number of times during the 2-y simulation period that the pond volume reaches full capacity increases from 0 with the 127-mm orifice to 5 with the 50-mm orifice, but the real difference is in the increased detention of runoff from *all* storms. Figure 17.2 illustrates how the smaller, 50-mm orifice increases utilization of pond capacity beyond that achieved with the 127-mm orifice. With the 127 mm orifice, the EDP has standing water only about 5% of the time that there is no runoff. This percentage increases to roughly 20% with a 50-mm orifice. This increased

Figure 17.2 Utilization of EDP capacity.

detention of runoff in the pond directly affects the pollutant-removals achieved. Figure 17.3 depicts the pollutant-removal efficiencies for TSS, TN and TP over the range of orifice diameters simulated. As shown, the pollutant-removal efficiency is several times greater with the smaller orifice size.

Figure 17.3 Longterm EDP performance, removal efficiency vs. orifice diameter.

17.6.3 EDP Capacity

A second set of sensitivity runs was performed to evaluate whether a smaller EDP could achieve similar pollutant-removal efficiencies. Because the original EDP design was long and of constant depth, a smaller-capacity pond was simulated simply by reducing the length of the original, thereby maintaining the same side slopes and weir height. The volume was adjusted so that runoff from the 3-month, 24-h storm (rather than the 1-y, 24-h storm) would be detained. The resulting capacity was approximately 45% of the original. Model simulations were performed for orifice sizes of 127, 75, and 50 mm.

Figure 17.4 presents a comparison of the TSS-removal efficiency for various orifice sizes with both EDP sizes. This figure indicates that equivalent TSS-removal efficiencies can be achieved with the smaller-sized EDP simply by using orifice diameters of about 125 mm less than specified for the larger EDP. For removal efficiencies above about 55%, however, the smaller EDP would require an orifice diameter of less than 50 mm, which may cause premature clogging. Figures 17.5 and 17.6 present similar representations for TN and TP.

Figure 17.4 Longterm EDP performance, effect of EDP capacity on TSS removal.

Figure 17.5 Longterm EDP performance effect of EDP capacity on TN removal.

Figure 17.6 Longterm EDP performance effect of EDP capacity on TP removal.

17.6.4 Suggested Alternative Approach for Detention Time and EDP Design

Clearly, designing EDPs to maximize detention time over a wide range of storms is the key to achieving good pollutant-removal efficiencies. Unfortunately, traditional guidance does not provide a useful quantification of detention time that relates to long-term performance, and the strict hydraulic definition is not so easily understood or determined. An important accomplishment for storm-water control would be to identify a useful, unambiguous definition for pond residence time for a long-term condition. The following discussion presents one possible alternative for this definition.

The SWMM output provides information regarding the total mass influent to the EDP during the simulation as well as the total mass discharging from the EDP. The difference is the total mass treated. Because the pollutant-removal/decay rate, (k , as input to S-T), is known, it is possible to solve the first-order decay equation for the effective, overall detention time:

$$M_{out} = M_{in} e^{-kt_e} \quad (17.2)$$

where:

- M_{out} = the mass of pollutant removed by EDP during simulation period
- M_{in} = the mass of pollutant influent to the EDP during simulation period
- e = the base of the natural logarithm
- k = the pollutant-removal (or decay) rate (per time step, e.g. 1/d), and
- t_e = the effective, overall detention time (time step, e.g. days) during simulation period.

Substituting for the pollutant-removal efficiency,

$$E = (M_{in} - M_{out})/M_{in} \quad (17.3)$$

and solving for t_e :

$$t_e = -\ln(1-E)/k \quad (17.4)$$

For a given pollutant, the target pollutant-removal efficiency (E) and the estimated pollutant decay rate (k) can be entered into the equation above to solve for the required effective detention time (t_e). (Note that the target pollutant-removal efficiency is subject to the maximum removal rate possible with EDPs, and that the decay rate should be calculated as discussed in Section 17.4.2.)

This effective detention time may provide a useful parameter with which to guide EDP design. For example, for a given EDP design, the spreadsheet model shows the approximate storm size for which the effective detention time (calculated in equation 4 above) matches the average detention time (calculated in the spreadsheet model). The target removal efficiency would be met for any storm of this size or greater.

Based on the results of the analyses performed for the case studies, the simple-spreadsheet-calculated EDP performance for the average storm (approximately 125 mm) approximates the SWMM/S-T-calculated performance for the long-term simulation. Therefore, one possible design approach might be to attempt to achieve a drain time that matches the effective detention time for the average storm, or for a 125-mm storm. (Drain time is suggested because it is a design parameter with which designers are already familiar.) Refinements to the design could then be made using the SWMM/S-T approach outlined above. Although this approach is still being developed, it does represent a starting point for refining current guidance and rules of thumb. In the meantime, existing guidance and rules of thumb should be applied with caution when designing EDPs.

17.7 Conclusions and Recommendations

Analyses performed herein using SWMM/S-T indicate that two EDP designs developed using traditional rules of thumb and existing State guidance not only provided poor pollutant-removal efficiencies, but also left designers with the erroneous impression that bigger is better. Surveys of existing EDPs confirm that most do not achieve their target detention times for larger storms, and typically offer little or no detention for small storms. These facts highlight the need to improve design methodology beyond traditional rules of thumb and guidance.

The first recommendation is that performance should be judged over a long-term period, rather than for a single design storm. Optimizing designs using long-term simulations more realistically reflects the actual performance of the EDP, rather than the performance for a single and often rare storm condition.

A second recommendation is to evaluate pollutant-removal efficiency during the design process to ensure that performance will be acceptable. The SWMM S-T framework provides an analytical framework that is suitable for analysis of EDP designs for single storms or for long-term simulations. However, to perform screening analyses for preliminary design, SWMM S-T can be cumbersome, and its results can be difficult to interpret. A simple spreadsheet model can serve as a screening tool and can provide a means to interpret the SWMM results.

A third recommendation is to use a simple screening tool to help interpret SWMM results during the design process. In the investigations described herein, EDP designs were optimized using SWMM/S-T and the simple spreadsheet model. Compared to the original designs, these optimized designs provide superior pollutant removals and/or smaller ponds that are less expensive, less obtrusive, and less disruptive to the environment. The optimized designs employ smaller outlet orifices to maximize detention times. Because orifice diameters less than 50 mm may be prone to clogging, this size imposed a limit on the EDP performance. Improved EDP performance is possible if alternate outlet designs are developed that can provide detention of smaller storms without being prone to clogging.

Finally, an important accomplishment for storm-water control would be to develop a useful, unambiguous definition of detention time that could be applied in EDP design. Traditional guidance associates EDP design with infrequent, large storms. However, because pollutant-removal efficiency is a function of detention for all storms, using a more frequently occurring storm, such as the average storm or perhaps a 125-mm storm, would be more appropriate. One possible definition for detention time is suggested herein, as is a design approach to use that definition in conjunction with a more frequently occurring storm. Although this approach is still being developed, it does represent a starting point for refining current guidance and rules of thumb. In the meantime, existing guidance and rules of thumb should be applied with caution when designing EDPs.

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