Chapter 13

Quality Control Optimization of Extended Detention Dry Ponds

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The joint Ministry of the Environment/Ministry of Natural Resources (MOE/MNR) Interim Stormwater Quality Control Guidelines are intended to promote receiving water quality protection by requiring detention for stormwater discharges of specified volumes for specified detention times. The required detention times (t_d) are in turn specified by the class of receiving water (e.g. 12-24 hr t_d for discharge to cold water fishery areas and 72 hr t_d for discharge to body contact recreation areas). The more recent Stormwater Management Practices Planning and Design Manual (MOEE, 1994) recommends a uniform 24 hour detention time. The usual assumption implicit in specified detention times is that the longer detention time provides a higher level of water quality control. Furthermore, there is usually little quantitative justification for the specified detention times.

This chapter analyzes the implications of required detention times of extended detention dry ponds with respect to their actual pollution control performance. Longer detention times are compromised by two factors. First, the longer detention time of any runoff event increases the probability of a larger overflow for the subsequent event. The negative impact of pollution from the subsequent event overflow can outweigh the positive impact of greater pollution removal provided for the preceding event. Secondly, the marginal gain in removal efficiency of the pond is constantly diminishing with increasing detention times in accordance with sedimentation laws. It is clear by induction that for any given runoff characterization, pond design and settling velocity distribution, an optimal detention time will exist.

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An analysis methodology is presented for determining optimal detention times for extended detention dry ponds based on derived mathematical relationships among the water quality performance of ponds and the runoff, pond and settling velocity characteristics. The relationships are developed analytically with derived probability distribution theory. The water quality control performance is based on turbulent settling mechanisms for the removal of particulate pollutants. The numerical results from these models indicate that pollution control performance is maximized with typically short detention times and diminishes monotonically with increased detention time thereafter. Therefore, further increases in detention time can be counter-productive. It is concluded that currently available analysis technology for pond design based on quantitative water quality control measures is preferable to the specification of arbitrary detention times.

13.1 Introduction

Overland runoff from urbanized areas is greatly increased, compared to rural conditions, as a result of increased imperviousness and decreased availability of depression storage. Roofs and road pavements, for example, allow for the rapid transport of water into roadside ditches and/or storm sewers and eventually into natural watercourses. In addition to increased runoff, increased pollutant loading in the runoff also results from urbanization. To deal with augmented flows which may create erosion and flooding problems downstream, detention ponds or tanks have been employed effectively to attenuate the peak discharges from urban areas to receiving water bodies. These facilities, which utilize storage as their principal control mechanism, are often less effective in controlling pollutant loading to receiving water bodies.

Stormwater management practices (SWMPs) or best management practices (BMPs) have been developed in an attempt to control the pollution of receiving waters. Extended detention dry ponds are an example of these practices used to improve the quality of water discharging into natural watercourses. These facilities remove pollutants primarily through sedimentation. Since the concentrations of many pollutants in stormwater are proportional to the suspended solids concentration, the pollution control performance may be analyzed using suspended solids removal efficiencies.

Statistical models have been developed to analyze the performance of urban drainage systems for both quantity and quality control. These models are easy to implement and have minimal computation requirements when compared to more accurate but more complex continuous simulation models. Statistical models are, however, founded upon simplifying assumptions which may limit their applicability to screening level analyses. Adams and Bontje (1983)

developed analytical models based on derived probability distribution theory and incorporated them into a software package named the Statistical Urban Drainage Simulator (SUDS).

Studies conducted at the University of Toronto have compared the results of analytical probabilistic models with those of continuous simulation models and favourable comparisons have been obtained. Seto (1984) found that there was good agreement between STORM and the analytical models when it was assumed that the volume of a rainfall event, the event duration and the interevent time were statistically independent. Kauffman (1987) compared SUDS with STORM for a variety of Canadian climates and concluded that the models compared favourably under the following circumstances: the geographic location in question experienced an average of less than 120 rainfall events per year; the initial storage state of a downstream reservoir at the end of the last storm event was assumed to be full; and that for climates such as Toronto and Thunder Bay, the best interevent time definition (IETD) was 2 hours whereas for climates with frequent, low intensity rainfalls such as Vancouver and Victoria, the best IETD was 1 hour. Guo (1992) developed analytical models to analyze the performance of extended detention dry ponds, wet ponds without outlet control and wet ponds with outlet control based on the removal of suspended solids. The models for extended detention dry ponds were compared to the continuous simulation model SWMM with reasonably good agreement between the models in the middle range (between 40% and 70%) of long term suspended solids removal.

In this chapter, the models developed by Adams and Bontje (1983) are used to evaluate extended detention dry pond quality control performance as a function of detention time.

13.2 Statistical Analysis of Rainfall

Hydrologic processes, such as rainfall, are stochastic in nature and, as such, can be analyzed statistically by fitting observed data to probability density functions (PDFs). This is accomplished by separating the rainfall record into discrete rainfall events based on a minimum interevent time definition (IETD). The IETD is the minimum temporal spacing required between rainfall events to consider the events as separate.

Once the rainfall record is divided into discrete events, histograms of various rainfall characteristics may be produced and PDFs fitted to the histograms. Adams et al. (1986) show that for meteorological characteristics such as event rainfall volume, event duration and interevent time, exponential PDFs may be fitted to the histograms. The following are the exponential distributions for the above mentioned rainfall characteristics:

Event Duration, t (hr):

$$f_T(t) = \lambda e^{-\lambda t}; \quad \lambda = 1/\bar{t} \quad (\text{hr}^{-1}) \quad (13.1)$$

Interevent Time, b (hr):

$$f_B(b) = \psi e^{-\psi b}; \quad \psi = 1/\bar{b} \quad (\text{hr}^{-1}) \quad (13.2)$$

Event Rainfall Volume, v (mm):

$$f_V(v) = \zeta e^{-\zeta v}; \quad \zeta = 1/\bar{v} \quad (\text{mm}^{-1}) \quad (13.3)$$

where $\bar{v}$, $\bar{t}$ and $\bar{b}$ are the mean rainfall event volume, duration and interevent time, respectively. Values for the meteorological parameters λ , ψ and ζ have been determined for various locations across Canada using various IETDs.

13.3 Model of Urban Drainage System

Adams and Bontje (1983) developed analytical models using derived probability distribution theory using the following relationship to model the transformation of rainfall to runoff:

$$v_r = \begin{cases} 0 & \text{if } v \leq S_d \\ \phi(v - S_d) & \text{if } v > S_d \end{cases} \quad (13.4)$$

where v is the rainfall volume (mm), S_d is the depression storage (mm), ϕ is the runoff coefficient and v_r is the runoff volume as shown in Figure 13.1.

Other pertinent relationships derived by Adams and Bontje (1983) are as follows:

- Average Annual Volume of Runoff, R (mm):

$$R = \frac{\theta \phi}{\zeta} e^{-\zeta S_d} \quad (13.5)$$

where θ is the average annual number of rainfall events which is determined by the statistical analysis of rainfall data based on a specified IETD as discussed above.

Figure 13.1 Schematic of urban drainage system (Adams and Bontje, 1983).

- Probability per Rainfall Event of Any Magnitude Spill, $G_P(0)$:

$$G_P(0) = \left[\frac{\frac{\lambda}{\Omega}}{\frac{\lambda}{\Omega} + \frac{\zeta}{\phi}} \right] \left[\frac{\frac{\psi}{\Omega} + \frac{\zeta}{\phi} e^{-\left(\frac{\psi}{\Omega} + \frac{\zeta}{\phi}\right)S}}{\frac{\psi}{\Omega} + \frac{\zeta}{\phi}} \right] e^{-\zeta S_d} \quad (13.6)$$

where S is the capacity of the detention pond in mm and Ω is the constant controlled outflow rate from the detention pond in mm/hr, both of which are normalized with respect to catchment area.

- Average Annual Uncontrolled Spill Volume, P_u (mm):

$$P_u = \frac{\theta \phi}{\zeta} G_P(0) \quad (13.7)$$

- Average Annual Fraction of Pollutant Mass Controlled, C_p :

$$C_p = \eta \left(1 - \frac{P_u}{R} \right) \quad (13.8)$$

where η is the pollutant removal efficiency of the detention pond which will be discussed later. It is important to note that this is a simplified version of the

equation given in Adams and Bontje (1983) which incorporated a downstream treatment plant as well as the treatment of spills in storage, neither of which is applicable to the analysis of pollution control performance of the extended detention dry pond presented herein.

Substituting Equation 13.5 and Equation 13.7 into Equation 13.8 and simplifying yields the following expression for fraction of pollutant mass controlled:

$$C_P = \eta \left[1 - \frac{GP(0)}{e^{-\zeta S_d}} \right] \quad (13.9)$$

13.4 Detention Storage Requirements and Outflow Rate

It is valuable to develop expressions for detention storage (S) and outflow (Ω) in terms of the average detention time (t_d) in order to model the pollution control as a function of t_d . The average excess rainfall intensity (i_e) is given by:

$$i_e = \frac{\phi(v - S_d)}{t} \quad (13.10)$$

where v is the volume of rainfall in mm, t is the duration of the rainfall event in hr and i_e is in mm/hr. The inflow hydrograph to the detention pond is assumed to be that of a square wave with amplitude equal to i_e as shown in Figure 13.2.

The required storage volume can be estimated by integrating the square wave inflow hydrograph over the region from Ω to i_e (Figure 13.2) and is given by:

$$S = t(i_e - \Omega) \quad (13.11)$$

Figure 13.2 Required pond storage.

Substituting Equation 13.10 into Equation 13.11 and simplifying yields:

$$S = \phi(v - S_d) - \Omega t \quad (13.12)$$

and the average detention time can be estimated as:

$$t_d = \frac{1}{2} \frac{S}{\Omega} \quad (13.13)$$

Isolating Equation 13.13 for Ω and substituting into Equation 13.12 gives:

$$S = \frac{2\phi(v - S_d)t_d}{2t_d + t} \quad (13.14)$$

while substituting Equation 13.14 into Equation 13.13 and isolating for Ω gives:

$$\Omega = \frac{\phi(v - S_d)}{2t_d + t} \quad (13.15)$$

Therefore, knowing the catchment parameters ϕ , S_d and incorporating a design storm with known v and t , the required storage volume and outflow rate for the pond can be determined for any average detention time using Equation 13.14 and Equation 13.15, respectively. Furthermore, substituting these expressions into Equation 13.6, the probability of spill per rainfall event can be calculated for any detention time.

13.5 Suspended Solids (SS) Removal Efficiency

Extended detention dry ponds exhibit continuous flow through conditions, therefore it is assumed that the mechanism for SS removal is turbulent settling. The SS removal efficiency (η) under turbulent conditions is given by (Fair and Geyer, 1954):

$$\eta = 1 - \left[1 + \frac{1}{n} \frac{V_s A}{Q} \right]^{-n} \quad (13.16)$$

where V_s is the settling velocity of a specific particle in m/hr, A is the surface area of the detention pond in m^2 , Q is the pond outflow rate in m^3/hr and n is a turbulence or short-circuiting constant. Values of n as suggested by Fair and Geyer (1954) range from $n=\infty$ for ideal performance and $n=1$ for very poor performance.

It is convenient to express Q in mm/hr ($\Omega=Q/A_c$) as opposed to m^3/hr as in Equation 13.16. Performing the necessary conversions, the above equation can be expressed in the following form:

$$\eta = 1 - \left[1 + \frac{1000V_s A}{n\Omega A_c} \right]^{-n} \quad (13.17)$$

where A_c is the area of the catchment in m^2 and Ω is in mm/hr. Equation 13.17 is useful in the analysis of existing or proposed catchments with stormwater quality control facilities. For the purposes of this chapter, and in order to provide more generalized results, it is convenient to express the efficiency in terms of detention pond depth. This is achieved by relating the catchment area (A_c) to the surface area of the pond (A) based on the required storage volume:

$$SA_c = hA \quad (13.18)$$

where h is the pond depth in mm, S is in mm, A and A_c are in m^2 . Isolating the term A/A_c and substituting into Equation 13.17 gives:

$$\eta = 1 - \left[1 + \frac{1000V_s S}{n\Omega h} \right]^{-n} \quad (13.19)$$

Substituting Equation 13.13 (cancelling Ω) into Equation 13.19 yields:

$$\eta = 1 - \left[1 + \frac{2000V_s t_d}{n h} \right]^{-n} \quad (13.20)$$

This equation presents an expression for suspended solids removal efficiency from an extended detention dry pond as a function of average settling velocity of particulate pollutants, detention time and depth of pond.

Due to the variability of pollutants and their associated settling velocities in urban runoff, a settling velocity distribution can be used to determine the overall removal efficiency according to the following expression:

$$\eta_{\text{tot}} = \sum_{i=1}^k F_i \left\{ 1 - \left[1 + \frac{2000 V_{si} t_d}{n h} \right]^{-n} \right\} \quad (13.21)$$

where η_{tot} is the overall removal efficiency, V_{si} and F_i are the average settling velocity and the fraction of total mass contained in the i^{th} size fraction, respectively.

The expression for pollution control (Equation 13.9) can be solved knowing the settling velocity distribution of particulate pollutants in stormwater, the catchment parameters and the rainfall characteristics for the geographic location of the drainage system. It is important to note that this expression does not account for effects of scour which result in the resuspension of settled pollutants in the pond. Since it is very difficult to account for such effects theoretically, it is problematic to incorporate them into the model presented herein. If, however, reliable field data were available, it could be possible to incorporate these effects into the short-circuiting constant (n) as part of the calibration process.

13.6 Input Parameters Used in Analysis

To employ the model for pollution control developed herein, a variety of input parameters are required, some with assumptions underlying their usage. This section provides the values used in the analysis and explanations of their usage. The examination of the impact of changing the input parameters on the overall results of this work is conducted later.

13.6.1 Catchment Parameters

The depression storage and runoff coefficient for a catchment are difficult to determine and must be estimated. In the analysis of the performance of detention ponds for pollution control, values of 0.5 for the runoff coefficient (ϕ) and 1 mm for the depression storage (S_d) were used. These values are typical of many urban catchments.

13.6.2 Meteorological Parameters

The parameters characterizing the rainfall volume (ζ), duration (λ) and interevent time (ψ) are dependent upon geographic location. The analysis used an IETD of 2 hours for Toronto International Airport rainfall statistics. The IETD of 2 hours was determined by previous research (Kauffman, 1987) to be

appropriate for conditions in Ontario, namely Toronto and Thunder Bay. The resulting parameter values are $\zeta=0.200/\text{mm}$, $\lambda=0.282/\text{hr}$, and $\psi=0.0174/\text{hr}$.

13.6.3 Settling Velocity Distribution

The Ontario Ministry of the Environment and Energy (1994) give a settling velocity distribution based on the Nationwide Urban Runoff Program conducted by the U.S. Environmental Protection Agency. This distribution is assumed herein to be indicative of conditions in Ontario and is presented in Table 13.1 in units of m/hr.

Table 13.1 Settling velocity distribution in stormwater (MOEE, 1994).

Size Fraction	% of Particle Mass	Avg. V_s (m/hr)
$\leq 20\mu\text{m}$	0-20	0.0091
$20\mu\text{m} < x \leq 40\mu\text{m}$	20-30	0.0468
$40\mu\text{m} < x \leq 60\mu\text{m}$	30-40	0.0914
$60\mu\text{m} < x \leq 0.13\text{mm}$	40-60	0.457
$0.13\text{mm} < x \leq 0.40\text{mm}$	60-80	2.13
$0.40\text{mm} < x \leq 4.00\text{mm}$	80-100	19.8

13.6.4 Depth of Detention Pond

The Stormwater Management Practices Planning and Design Manual (MOEE, 1994) indicates that the depth of an extended detention dry pond be limited to 2 m to 3 m. A pond depth of 2 m was used in the analysis.

13.6.5 Turbulence Constant

The determination of the SS removal efficiency requires a value for the turbulence constant, n . In this analysis, a turbulence constant of 3, describing good performance, was used. This value results in relatively conservative estimates of removal efficiency.

13.6.6 Design Rainfall

This chapter uses the design rainfall as described by the Interim Stormwater Quality Control Guidelines for New Development (MOE/MNR, 1991); that is, a 25 mm, 2 hr rainfall to determine the storage requirements of the quality control facility.

13.7 Results of Analysis

The governing expression for pollution control (Equation 13. 9) is dependent upon two main driving forces. These are the removal efficiency (η) as discussed in the previous section, and the term $\frac{G_P(0)}{e^{-\zeta S_d}}$ describing the probability of volume of spill and which is dependent upon the meteorological and catchment parameters. It is useful to show the relationship of these components to understand how the model for pollution control operates. Figure 13.3 shows how these components vary with detention time using Toronto International Airport rainfall statistics.

Figure 13.3 Behaviour of driving forces behind pollution control model.

It is evident that as detention time increases, the removal efficiency increases in a decreasing manner while the $\frac{G_P(0)}{e^{-\zeta S_d}}$ term, which is directly related to the probability of spillage per rainfall event, increases monotonically beyond very small detention times. The combination of these two factors, according to Equation 13.9, will produce a curve for pollution control with respect to detention time, which contains a maximum value attainable for pollution control. This is a result of the fact that the marginal increases in removal efficiency do not outweigh the marginal increases in the probability of spillage as detention time increases. This result is shown in Figure 13.4 which is generated using the values of input parameters described above.

Figure 13.4 Pollution control performance of extended detention dry pond.

Figure 13.4 shows that there exists an optimal detention time for pollution control from an extended detention dry pond, with a steady decline in performance thereafter. These results indicate that for the optimal detention time of 22 hours, the maximum pollution control is 68.7%. That is, on average a maximum of almost 70% of suspended solids can be removed from urban runoff discharging into natural watercourses. By detaining the runoff for an average of 72 hours, the performance is significantly reduced to 60.4%.

13.8 Sensitivity Analysis

To observe the effect of varying the input parameters, sensitivity analyses have been conducted. A brief summary of the results is presented below. (For details of the sensitivity analyses, see Papa (1995))

13.8.1 Varying Catchment Parameters

By algebraic manipulation, it can be shown that the pollution control performance of the detention pond is independent of the runoff coefficient, ϕ . It is important to note that this independence applies to the particular pollution control performance measure used in this model and may not be the case for other measures and therefore care should be exercised in selecting the runoff coefficient for measures sensitive to it. Also, Papa (1995) shows that the pollution control performance is insensitive to variations in the depression storage of a catchment.

13.8.2 Varying Settling Velocity Distribution

Due to the uncertainty of settling velocity distributions, it is difficult to perform a comprehensive sensitivity analysis. For the present analysis, the average settling velocities of the distribution given in Table 13.1 were augmented and reduced by 20% to observe the impact on the overall pond performance. Figure 13.5 shows the results of the analysis.

Figure 13.5 Sensitivity analysis for varying settling velocity distribution.

Figure 13.5 shows that even for changes of up to 20% in the average settling velocities for each size fraction as given in Table 13.1, the effect on the removal efficiency is almost negligible. It should be noted that this result is no substitute for actual site data; however, in the lack thereof, the distribution given in Table 13.1 is commonly used.

13.8.3 Varying Detention Pond Depth

It can be seen in Equation 13.16 that the SS removal efficiency is dependent upon the depth of the pond. Figure 13.6 shows the impact of varying the pond depth on the overall pollution control performance of the detention pond.

It is evident from Figure 13.6 that the depth of the pond has a rather large influence on the performance of the pond. From the analysis, it was determined

Figure 13.6 Sensitivity analysis for varying pond depth.

that as pond depth decreases, the maximum level of pollution control increases and the optimal detention time decreases. Figure 13.7 presents the relationship between optimal detention time, maximum pollution control and pond depth in a convenient manner.

It can be seen from Figure 13.7 that for small pond depths, the required detention time is relatively small and the percent pollution control is relatively large. Unfortunately however, there is a practical lower limit to the depth of the pond since it is rarely feasible to construct detention ponds of very low depths due to the large land requirements. Figure 13.7, however can prove to be an extremely powerful and cost-efficient planning tool since it summarizes many results of this chapter in a single graph. The mathematics involved in the analytical model presented herein need not be used, provided a graph similar to that of Figure 13.7 is available. The stormwater management planner need only know the depth of pond desired (which is derived from the required storage volume and desired land area) to determine the optimal detention time and hence the maximum attainable pollution control. Although Figure 13.7 is specifically for urban catchments for which Toronto International Airport rainfall statistics are applicable, a series of these plots may be derived for any rainfall monitoring station. Another way of expressing the results shown in Figure 13.7 is to relate the maximum pollution control and the optimal detention time in terms of a ratio of the surface area of the pond to the catchment area (A/A_c). The expression for removal efficiency in terms of this ratio is given by Equation 13.17 and illustrated in Figure 13.8.

Figure 13.7 Relationship between pollution control, optimal detention time and pond depth.

Figure 13.8 Relationship between pollution control, optimal detention time and the ratio of pond area to catchment area (A/A_c).

13.8.4 Varying Turbulence Constant

The performance characteristics of extended detention dry ponds are not well known, and therefore, in the modeling of such facilities, assumptions must be made regarding the pollutant removal mechanisms. This work employed turbulent settling as given by Fair and Geyer (1954) with a turbulence constant (n) of 3. This value is conservative when compared to the case of ideal performance ($n=\infty$) and is assumed herein to give reasonable results. The turbulence constant attempts to account for the reduction in sedimentation efficiency caused by: eddy currents which result from the inertia of the incoming fluid; currents which result from wind action on the water surface; thermal convection currents and; density-driven currents.

Figure 13.9 Sensitivity analysis for varying turbulence constant.

The results shown in Figure 13.9 indicate that there is relatively little difference between the pollution control curves for the cases of good performance ($n=3$) and ideal performance ($n=\infty$). There is a greater difference, however, between these curves and the curve representing very poor performance ($n=1$). Although the curves display different levels of pollution control, their optimal detention times are almost identical. Therefore the model developed herein is able to determine the optimal detention times regardless of the chosen turbulence constant. Field data will be required to calibrate the model to determine the maximum level of pollution control.

13.8.5 Meteorological Parameters

The parameters characterizing the rainfall volume, duration and interevent time are dependent upon geographic location. For this reason, the mean, standard deviation and 95% confidence intervals were determined for each of the parameters using data from monitoring stations across the province of Ontario. The following discussions show the effects of the varying parameters on the pollution control performance of an extended detention dry pond. Table 13.2 shows the results of the statistical analysis.

For the following analyses, the mean values for the meteorological parameters are used as one of the parameters is varied.

Table 13.2 Statistical analysis of meteorological parameters.

Parameter	μ	σ	95% Confidence Interval
λ (hr ⁻¹)	0.286	0.0125	0.264-0.308
ψ (hr ⁻¹)	0.0173	0.0023	0.0132-0.0213
ζ (mm ⁻¹)	0.201	0.0109	0.182-0.220

Varying Rainfall Duration

Figure 13.10 shows the effect of varying the rainfall duration parameter, λ , on the pollution control performance of the extended detention dry pond. The results indicate that the performance of the pond is rather independent of location.

Figure 13.10 Effect of varying average rainfall duration.

Varying Rainfall Interevent Time

The pollution control performance is expected to be sensitive to the interevent time since the interevent time dictates the time within which the detention pond is free to drain. Therefore, for shorter average interevent times, the drainage time is reduced. This results in the increased possibility of the pond not having completely drained, resulting in the increased probability of spillage during the next rainfall event, and hence, poorer performance. Conversely, longer interevent times on average will result in increased pond performance. Figure 13.11 shows the results of the analysis.

Figure 13.11 Effect of varying average rainfall interevent time.

Varying Rainfall Volume

The performance of the detention pond is also dependent upon the average rainfall volume (ζ). Since this parameter dictates the volume of runoff entering the pond, the larger the volume, the greater the likelihood of spillage and hence poorer overall performance. Figure 13.12 shows the results of the analysis. In general, the results indicate that the pollution control performance is relatively insensitive to the variability of average rainfall volume across Ontario.

Combining the Effects of Variable Meteorology

By cumulating the effects of varying the meteorological parameters a *worst case* scenario can be obtained. Figure 13.13 shows the cumulative impact on the performance of the quality control facility. The results for Ontario rainfall data indicate that the optimal detention time will, under the above *worst case* scenario,

Figure 13.12 Effect of varying average rainfall volume.

Figure 13.13 Cumulative impact of varying meteorological parameters.

exist between 17 hours and 29 hours, and the maximum pollution control will exist between 62.2% and 71.6%. The mean values are 22 hours and 68.8% for optimal detention time and maximum pollution, respectively. Note that Figure 13.13 was obtained using a pond depth of 2 m.

Investigation of Other Locations in Canada

This discussion provides a comparison between model performance for average Ontario locations and locations in Canada with significantly different climates, namely Vancouver (U.B.C. monitoring station) which experiences relatively short interevent times, and Lethbridge Airport (Alberta) whose rainfall interevent times are rather long. For Vancouver rainfall data, an IETD of 1 hour was used since this value was found to represent Vancouver's climate (Kauffman, 1987). An IETD of 2 hours was assumed to represent Lethbridge. The purpose of this analysis is to exhibit the behaviour of pollution control with respect to detention time for climates with rather extreme conditions.

Figure 13.14 shows the drastic effect the average interevent time can have on the performance characteristics of an extended detention dry pond. In locations such as Vancouver, subjected to frequent rainfalls, the performance decreases more rapidly after a relatively early peak is reached. Drier climates, such as that of Lethbridge, can achieve higher levels of pollution control by employing longer detention times.

Figure 13.14 Comparison of performances for various locations in Canada.

13.9 Conclusions

There are two main driving forces affecting the average pollution control performance of an extended detention dry pond. These are: pollutant removal efficiency which increases at a decreasing rate with respect to time of detention; and the probability of a spill occurring which increases as the detention time increases. The combination of these two effects produces a curve containing a maximum value for pollution control, after which the performance steadily decreases with increasing detention time. The optimal detention time is frequently in the range of 24 hours and detention times as long as 72 hours decrease the quality control performance attainable by the pond. The mathematical relationships developed in this chapter provide a simple method of estimating optimal detention times. These relationships can be used to develop graphs which relate the maximum level of pollution control and the optimal detention time to the ratio of pond area to catchment area. These graphs can be effectively used at the preliminary planning and design stages to estimate detention times, pollution control levels and pond configuration. Further developments to incorporate other pollutant removal mechanisms (e.g. biological uptake and decay) and testing the models with continuous simulation models are recommended for future work.

Notation

A	Surface Area of Pond, m ²
A _c	Catchment Area, m ²
b	Interevent Time, hr
F _i	Fraction of Total Mass Contained in i th Size Fraction
f _x (x)	Probability Density Function of Random Variable X
G _p (0)	Probability per Rainfall Event of Any Magnitude Spill
h	Depth of Detention Pond, mm
n	Turbulence or Short-Circuiting Constant
P _u	Average Annual Uncontrolled Spill Volume, mm
Q	Controlled Release Rate from Pond, m ³ /hr
R	Average Annual Volume of Runoff, mm
S	Capacity of Storage Facility/Detention Pond, mm
S _d	Depression Storage, mm
SS	Suspended Solids
t	Rainfall Duration, hr
t _d	Average Detention Time, hr
v	Rainfall Volume, mm
v _r	Runoff Volume, mm
V _s	Settling Velocity, m/hr

V_{si}	Average Settling Velocity of the i^{th} Size Fraction
ϕ	Runoff Coefficient
λ	Parameter for Exponential PDF of Rainfall Duration, hr^{-1}
η	Suspended Solids Removal Efficiency
η_{tot}	Overall Suspended Solids Removal Efficiency
θ	Average Annual Number of Rainfall Events
Ω	Controlled Release Rate from Storage Facility/Detention Pond, mm/hr
ψ	Parameter for Exponential PDF of Rainfall Intervent Time, hr^{-1}
ζ	Parameter for Exponential PDF of Rainfall Volume, mm^{-1}

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