Chapter 15

Simulation of Stormwater Management Pond Configurations

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Treatment of stormwater in detention facilities is central to stormwater management practice. The performance of these facilities, however, is contingent on the mode of operation and a number of design variables. This chapter investigates the sensitivity of the performance of batch and continuous plug flow (PF) operation modes to variations in these design variables on a fractional removal and exceedance basis for fecal coliforms (FC) and suspended solids (SS).

15.1 Introduction

Detention of stormwater in ponds, possibly incorporating physical or chemical treatment, is the most commonly employed method for achieving effluent quality objectives for urban runoff. Spatial, financial and other engineering constraints, however, place an upper limit on the size of these facilities. Consequently, as water quality objectives become more stringent, the performance of

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these facilities, as measured by removal efficiency and number and duration of exceedances, has become a critical design constraint. Performance, however, is a function of mode of operation (batch or continuous), and pond configuration. The latter consist of a number of design parameters relating to flow dynamics within the facility and the temporal duration of treatment processes acting on the body of water contained within the facility as a whole.

Inefficiencies associated with short-circuiting, dead storage zones, and re-entrainment of settleable materials are typically observed in practice. A continuous hourly runoff quantity and quality simulator with treatment algorithms was used to evaluate the sensitivity of pond performance to variations in selected design parameters. The analyses were carried out for FC and SS for a long term precipitation series. The model was calibrated for quantity and quality to two typical urban catchments in the Ottawa area.

These analyses formed the basis of a systematic evaluation of the performance of a range of pond configurations in terms of removal efficiency and number and duration of exceedances. Parameters examined were: mode of operation (continuous and batch); pond volume; number of cells in the pond system; permanent pool (PP) size; discharge pipe diameter; batch mode detention time (TD); catchment runoff and quality characteristics; pollutant removal rate coefficient; and dry weather flow routing/by-passing. Four pond types considered representative of the likely range of pond configurations and modes of operation were evaluated. These were: continuous mode, PF (5 cells); continuous mode, completely mixed (CM) flow (1 cell); batch mode, 24 hour detention; and, batch mode, 72 hour detention. All ponds were simulated with and without a PP.

15.2 Simulation Methodology

The overall treatment performance of a pond will be influenced by the ratio of influent volume to active storage volume,

interevent time, shape of the hydrograph, baseflow rate, and quality of the influent. To account for the random variation of these input factors, a long term simulation approach was adopted. A historical 29 year rainfall time series (1960-1988), with actual variation of wet and dry periods for the area of interest was obtained for a gauge at Ottawa International airport.

The analysis of the large number of combinations of pond configurations, modes of operation, and other variables of interest would generate large, cumbersome data files. To facilitate the analysis, statistical methods were used on the generated flow quantity-quality time series to derive a minimum precipitation database required to produce representative simulations of the long term performance of any configuration (Droste et al., 1992; RMOC, 1992). This representative precipitation file which consisted of six key years ranging from wet-to-average-to-dry years, was then used in all subsequent analyses.

The continuous stormwater quantity-quality model QUAL-HYMO (Rowney and MacRae, 1992(a)), was selected as the simulator because of its versatility and ease of use. Excess precipitation is generated in the upland zone using a modified SCS-CN method for pervious areas and a volumetric runoff coefficient for impervious areas. Overland flow routing is performed using either the Williams' or Nash Unit Hydrograph methods. Baseflow was determined using a modified baseflow recession constant method. The simulations were performed over the swimming season, June through September of each year. Consequently, soil freeze-thaw and snowmelt processes, although accounted for in the model, were not utilized.

Pollutant loadings were determined using a buildup-washoff method for FC and a rating curve approach for SS in five separate size fractions (NURP distributions were assumed, EPA, 1986). Flow routing through a storage facility is achieved using the storage indication method. First order decay processes are applied to simulate bacterial dieoff and discrete particle settling is used to model sedimentation processes. A schematic of the POND routine in QUALHYMO is shown in Figure 15.1. The algorithms are described in detail by Rowney and MacRae

Figure 15.1: Control pond routing in QUALHYMO.

(1992b).

The model was calibrated to two Ottawa area watersheds, the Coventry and Merivale Trunk Storm Sewer (MTSS) catchments. Discrete events were sampled for FC and SS concentrations during 1981 (three events) and 1985 (three events) in the Coventry and MTSS catchments, respectively. The calibrated QUALHYMO runoff quantity-quality parameters for these catchments are described in RMOC (1992).

Land use in the Coventry catchment is predominantly single residential housing while in the MTSS woodland and industrial land uses predominate. The impervious fractions are approximately the same in each catchment (21% for Coventry and 19% for MTSS) but the Coventry catchment has much shorter times to peak. The major difference between the two catchments is the considerably lower quality of runoff from the Coventry catchment compared to the MTSS system. RMOC (1992) contains significantly more detail on calibrations and catchment characteristics.

15.3 Pond Design Variables

The number of pond parameters that could have a significant effect on treatment were categorized as follows:

- Mode of operation: batch and continuous flow (CF)
- Pond active storage volume
- Effluent pipe diameter
- TD in batch mode
- Number of cells in the pond system
- PP size
- Storm influent quantity and quality characteristics
- Pollutant removal rate coefficients
- Routing dry weather flow (DWF) into or around the pond

These parameters were systematically varied in over 7,000 simulations to develop performance and design curves.

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Performance was measured in terms of removal efficiency (fractional removal) and number and duration of exceedances (FC at 100 and 200 counts/dl and SS at 20 and 50 mg/L).

15.4 Simulation Results

It is not necessarily true that a configuration change will produce a consistent change in performance from dry to wet years because of all the variables affecting treatment, particularly event volume distributions and separation times. Therefore results from the six years were generally averaged.

15.4.1 Batch Treatment

The results of the simulations were somewhat unexpected for the batch mode of treatment. It was found that most of the variables except pond volume, DWF and the dieoff rate coefficient did not have any significant influence on the degree of treatment or the number of exceedances within the ranges of parameter values examined. Results for batch and CF modes of operation for percent removal, number and hours of exceedances are shown in Table 15.1. The effects of DWF and variations in the dieoff rate coefficient are discussed separately. The average results of all treatment parameters and the upper and lower lines that are one standard deviation away from the mean value are plotted as a function of pond volume in Figures 15.2 (fraction removed), 15.3 (number of exceedances), and 15.4 (duration of exceedances) for FC only.

Active Storage Volume

The active storage volume was varied from 3 to 20 mm (depth over the watershed). The standard deviations of the average treatment (whether percent removal, number or duration of exceedances) as shown in Figures 15.2 to 15.4 is primarily due to

variation in the meteorological input parameters between years.

For FC, pond performance increased 38% for removals, number of exceedances decreased by 68% to 80%, and duration of exceedances decreased by 82% to 88% over the 3 to 20 mm range in volumes. Efficiency with respect to SS increased by approximately 26% for fraction removed, from 90% to 96% for number of exceedances, and on the order of 95% for duration of exceedances. The treatment performance curves follow a classical diminishing returns pattern with the inflection point occurring between 6 and 9 mm for fraction removed, and at approximately 9 mm for number and duration of exceedances. The standard deviation as a percent of the average value ranges from approximately 16% to 2.6% (fraction removed), 28% to 3.2% (number of exceedances), and 53% to 109% (duration of exceedances) for 3 to 20 mm pond volumes respectively. With the exception of the influence of DWF and variation in the dieoff rate coefficient, the standard deviation at any volume exceeds the variation in performance attributed to all other design variables. The rationale for this observation is discussed in the following sections.

Effluent Pipe Diameter

The discharge pipe diameter did not have an influence on treatment in a batch pond because the large discharge pipe sizes used for the batch ponds drained the pond quickly. Pond drain times for pipe sizes used in the simulations are shown in Table 15.2 for the MTSS system.

For 610 mm diameter pipes or larger the maximum draining time for ponds with a volume of 12 mm or less (for 90% of the volume) is 21 hours which is considerably less than the average interevent time. The time difference for draining lower fractions of the pond volume as a function of the minimum and maximum discharge pipe diameter is much less. Therefore a discharge pipe size of 610 mm or greater does not have a significant influence on the performance of a batch pond.

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Table 15.1: Removal statistics for MTSS ponds.

Operating Mode***	Det. Time (hr)	No. of Cells*	PP** (%)	Pond Volume (mm)					
				3	6	9	12	20	
<u>FC Fractional Removal</u>									
BATCH	24	1/5	0/20	0.724	0.876	0.935	0.960	0.981	
	72	1/5	0/20	0.717	0.865	0.925	0.952	0.980	
CONTINUOUS	-	1	100	0.612	0.749	0.817	0.857	0.915	
	-	5	100	0.732	0.878	0.933	0.959	0.983	
CONTINUOUS	-	1	50	0.565	0.728	0.811	0.859	0.921	
	-	5	50	0.673	0.848	0.918	0.951	0.981	
<u>SS Fractional Removal</u>									
BATCH	24	1/5	0/20	0.734	0.823	0.865	0.890	0.925	
	72	1/5	0/20	0.747	0.838	0.882	0.907	0.943	
CONTINUOUS	-	1	100	0.701	0.791	0.838	0.867	0.912	
	-	5	100	0.773	0.862	0.905	0.929	0.959	
CONTINUOUS	-	1	50	0.682	0.775	0.825	0.856	0.904	
	-	5	50	0.744	0.835	0.881	0.909	0.947	
<u>FC No. of Exceedances</u>									
BATCH	24	1/5	0/20	17.1	12.2	9.2	7.2	5.4	
	72	1/5	0/20	10.0	6.1	4.3	2.7	2.0	
CONTINUOUS	-	1	100	22.5	21.7	20.6	19.4	16.6	
	-	5	100	22.3	20.4	19.3	17.9	13.4	
CONTINUOUS	-	1	50	20.8	18.9	18.3	16.9	14.2	
	-	5	50	20.7	18.4	17.1	15.7	13.2	
<u>SS No. of Exceedances</u>									
BATCH	24	1/5	0/20	14.4	5.5	2.6	1.3	0.5	
	72	1/5	0/20	9.7	5.9	3.4	1.6	0.9	
CONTINUOUS	-	1	100	21.4	14.3	10.9	9.0	4.8	
	-	5	100	15.6	9.9	7.5	5.5	4.1	
CONTINUOUS	-	1	50	20.0	15.6	12.8	11.0	7.9	
	-	5	50	14.2	9.7	7.3	6.6	6.3	
<u>FC Duration of Exceedances</u>									
BATCH	24	1/5	0/20	273.9	194.9	125.2	83.5	47.9	
	72	1/5	0/20	278.5	201.8	130.0	83.3	34.2	
CONTINUOUS	-	1	100	428.5	462.8	471.6	435.7	352.9	
	-	5	100	325.0	254.0	186.4	140.8	79.3	
CONTINUOUS	-	1	50	583.8	616.7	600.8	558.3	471.3	
	-	5	50	476.3	346.8	259.6	195.9	103.8	
<u>SS Duration of Exceedances (hr)</u>									
BATCH	24	1/5	0/20	232.0	134.5	64.8	33.0	9.6	
	72	1/5	0/20	246.9	148.4	71.5	38.9	12.2	
CONTINUOUS	-	1	100	308.3	186.9	115.0	70.2	18.7	
	-	5	100	237.4	122.2	55.8	35.0	11.8	
CONTINUOUS	-	1	50	357.8	239.2	150.3	101.1	36.4	
	-	5	50	269.6	148.8	65.1	33.7	14.9	

* Batch run data with 1 and 5 cells were pooled together.

** Batch run data with PP's of 0 and 20% were pooled together.

*** Batch ponds had discharge pipe diameters of 610 and 1220 mm.
Continuous ponds had discharge pipe diameters of 304 and 610 mm.

Figure 15.2: FC removal in 24 and 72 hr batch ponds for MTSS.

Detention Time

TD in a batch pond was expected to have a significant influence. Although the overall percent removal did not change significantly when the TD was changed from 24 to 72 hours, the number of exceedances dropped significantly as shown in Table 15.1.

Benefits gained in terms of fractional removal by increasing the detention of pond contents are somewhat offset by an increase in the number of events that do not receive full treatment. At longer TDs the pond volume is full for greater periods of time and the likelihood of an event occurring and overflowing the pond increases. Mixing of fresh influent with pond contents that have been treated for some time will deteriorate the overflow

Figure 15.3: Number of FC exceedances for MTSS batch ponds.

quality and probably result in an exceedance. This is the primary explanation why overall removals did not change to a significant extent as TD was increased from 24 to 72 hours as shown in Table 15.1.

The reasons for the relatively large decrease in the number of exceedances with an increase from 24 to 72 hours TD (Table 15.1), is due to complex interactions of many factors. The main reason is that the 24 hour detention period is not sufficient for dieoff to reduce FC levels below 100/dl. Consequently, normal operation of the pond will often result in an exceedance. Effluent that is discharged from the 72 hour batch pond frequently approaches 100% removal. Overflow from a pond operated at either TD results in an exceedance. Since the most common

Figure 15.4: Duration of FC exceedances for MTSS batch ponds.

output from a pond is effluent that has resided in the pond for the specified TD, the number of exceedances decreases for the 72 hour batch pond.

Permanent Pool

Increasing the PP by up to 20% of the total pond volume did not cause a significant change in treatment indices. Although the number of overflows will increase to some extent, the water in the PP zone has resided in the pond for a long time and will have experienced higher degrees of treatment. This will cause some dilution of fresh influent during an event. For events that cause an overflow, the quality of the overflow will be slightly improved

Table 15.2: Drain times of MTSS test ponds.

Pond Volume (mm)	3	6	9	12	20
Volume Removed	Time to Drain Indicated Volume (hr)				
Diameter 304 mm					
100	45	90	235	280	300
90	22	44	66	88	147
75	17	32	49	65	108
Diameter 610 mm					
100	16	32	48	64	107
90	6	11	16	21	35
75	4	7	11	15	24
Diameter 914 mm					
100	9	18	27	36	60
90	3	6	8	11	18
75	2	4	6	7	12
Diameter 1220 mm					
100	4	12	18	24	41
90	2	4	7	9	15
75	1	2	4	5	8

due to dilution. For events that do not overflow the available volume, quality will again be improved while the contents reside in the pond and when the effluent is finally discharged.

In this analysis total design volume was divided into active and PP storage. As PP size increased, active storage volume was decreased in order to maintain a constant total pond volume. Consequently, there will be a breakpoint as PP size increases

where the overall performance of the pond significantly decreases because of the increased volume of overflows.

Influent Quantity-Quality

The lower quality runoff generated in the Coventry catchment was responsible for a deterioration in pond performance for 24 hour detention for both FC and SS. The removal mechanics in QUALHYMO will not result in large differences in overall percent removal but the number and duration of exceedances will significantly increase as influent concentrations of pollutant rise. Influent concentration was not a significant factor influencing performance for a 72 hour detention batch pond for either FC or SS.

15.4.2 Continuous Flow Treatment

In this case the data were separately grouped according to the configuration parameters of PF, CM and PP of 50 and 100% (four different combinations) to determine average removals and exceedances over the six years. Each of these configuration changes resulted in a significant change in one or more of the treatment indices. The data for CF configurations are given in Table 15.1 for ease of comparison with batch treatment results.

The data are plotted in Figures 15.5 (fraction removed), 15.6 (number of exceedances), and 15.7 (duration of exceedances) for FC data only. The plots for the CF data do not show lines of one standard deviation above and below the average because of the amount of information displayed.

Active Pond Storage

The CF mode of operation was also evaluated over a 3 to 20 mm range of active storage volumes. Pond performance increased on the order of 34% to 63% in fraction removed, 26% to 40% in number of exceedances, and 17% to 78% in the duration of

Figure 15.5: FC removal for CF ponds for MTSS.

exceedances for FC over this volume range. Performance for SS increased from 27% to 32% for fraction removed, 55% to 77% in number of exceedances, and 90% to 95% in duration of exceedances.

Similar to the batch ponds, the performance curves follow a classical diminishing returns form. The variation in performance over the range of volumes simulated is attributed to the influence of other design parameters such as number of cells, and the size of the PP.

Effluent Pipe Diameter

Under CF operation, pond contents begin to discharge at the beginning of an event and continue to discharge at a rate

Figure 15.6: Number of exceedances for CF ponds for MTSS.

proportional to the depth of water in the pond. Maximum treatment will be obtained by limiting the discharge rate to maximize the detention of the influent. In this analysis pipe diameters of 304 and 610 mm were evaluated. Pipes smaller than 304 mm in diameter are subject to clogging.

Number of Cells

Not surprisingly, a PF (five cell) pond improves treatment performance over a CM reactor by 15% to 17% for fraction of pollutant removed, and approximately 14% and 58% in number and duration of exceedances, respectively for FC over the range of volume examined. Pond effectiveness for SS removal

Figure 15.7: Duration of FC exceedances in CF ponds for MTSS catchment.

increased by 6% to 11% in fraction removed, 4% to 5% in number of exceedances, and 2% to 6% in duration of exceedances. However, a PF reactor is only marginally superior in performance in terms of fraction removed to a batch pond. But the number of exceedances is on the order of 50% higher for the PF CF pond compared to the batch configurations.

The explanation of why removals are higher in a PF CF pond but the number of exceedances is also higher compared to batch configurations, is that although the five cell pond is a close approximation of an ideal PF reactor, there is still some dispersion. A portion of the influent does disperse through the five cell CF pond and escapes in the effluent with very little

treatment. In contrast, batch mode operation ensures that no effluent is released before the specified retention time provided there are no overflows. These occurrences are enough to raise the number of exceedances significantly for the five cell CF pond relative to the batch configurations. The fractional removal rate of the five cell CF pond remains at a slightly higher value because its volume utilization is higher than an equivalent batch pond.

Permanent Pool

Increasing the PP of a CF pond from 50% to 100% increased the performance due to an increase in volume utilization. Fractional removal increased on the order of 1% to 8%, number of exceedances actually increased by 1% to 17%, while duration of exceedances decreased by 25% to 32% for FC over the range of volumes simulated. Performance for SS increased from 1% to 4% in fraction removed; there was a 7% to 39% decrease in the number of exceedances, and 11% to 49% decrease in duration of exceedances. The effect of the increase in PP size generally increased with increasing active storage capacity and the number of cells.

Influent Quantity-Quality

Fractional removals increase by 7.6% to 14.6% for FC between MTSS and Coventry for a 3 mm pond implying that poorer water quality degrades pond performance. This effect diminishes with increasing volume (-0.1% to 1.7% increase in FC removal for a 20 mm pond). The same trend was observed for SS which showed a 3.2% to 5.7% increase for a 3 mm pond and no effective change for a 20 mm pond. Number of exceedances also declined for FC by 3% to 9% for a 3 mm pond and 5% to 10% for a 20 mm pond. However, performance with regard to SS deteriorated, with number of exceedances increasing from 1.5 to 38.7% for a 3 mm pond and -1% (decrease) to 720% increase for a 20 mm pond. The behaviour of duration of exceedances was

also complex. The higher quality influent recorded an increase in duration of exceedances of between 33% and 71% for a 3 mm pond and a 4.6% to 21% decrease for a 20 mm pond for FC over the lower quality influent. The same trend was observed for SS where an increase in duration of exceedances between 23% to 85% was recorded for the higher quality influent for a 3 mm pond and a range of -43% (decrease) to a 20% increase was noted over the lower quality influent in a 20 mm pond. The differences were somewhat due to the different hydrographs and pollutographs generated in each catchment.

The rank of configurations with respect to each other in terms of any performance index was consistent regardless of the influent quality.

15.4.3 Sensitivity Analysis of FC Dieoff Rate

Gietz,(1983) measured FC dieoff rates that ranged from 0.9 to 2.4 d^{-1} (base e). All previous runs were made at a FC dieoff rate of 2.5 d^{-1} ($t_{90} = 22$ hr) to determine the best performance of the ponds. The influence of FC dieoff rate on treatment was examined by using FC dieoff rates at the lower ($k_d = 0.9 \text{ d}^{-1}$; $t_{90} = 62$ hr) and average ($k_d = 1.8 \text{ d}^{-1}$; $t_{90} = 30$ hr) values reported by Gietz (1983).

The analysis was performed by examining a batch pond receiving MTSS simulated runoff and a continuous mode pond receiving Coventry simulated runoff. The pond characteristics were as follows:

Batch (1): 24 hr TD; 0% PP; 1 cell; pipe diameter- 610 mm

Batch (2): 72 hr TD; 0% PP; 1 cell; pipe diameter- 610 mm

PF: 100% PP; 5 cells; pipe diameter- 304 mm

CM: 50% PP; 1 cell; pipe diameter- 304 mm

These pond configurations bracket the range of performance.

All pond volumes and all six key years were included in the analysis. The plots of fraction removed and number of exceedances for FC are shown in Figures 15.8 to 15.11 for the PF and 72 hour batch mode operating conditions.

Figure 15.8: FC removal in a PF CF (MTSS) pond as a function of dieoff rate coefficient.

From Figures 15.8 and 15.9 it is observed that the influence of the variation in dieoff rate coefficient in FC removal decreases as pond volume increases. Referring to Figure 15.8 for example, the difference between FC removal using a dieoff rate coefficient of 0.9 (minimum) and 2.5 (maximum) was 15% at a pond volume of 3 mm and only 8% at a volume of 20 mm. The same trend was observed for 72 hour batch mode operation as shown in Figure 15.9.

Figure 15.9: FC removal in a 72 hr batch (MTSS) pond as a function of dieoff rate coefficient.

In terms of number of exceedances the variation in dieoff rate coefficient increases in significance with increasing storage volume. Referring to Figure 15.10 for a PF CF pond the variation in performance was <1% at 3 mm volume to approximately 10% for 20 mm volume for a range of 0.9 (minimum) to 2.5 (maximum) in the dieoff rate coefficient. For 72 hour batch operation an increase from 0.9 to 2.5 d^{-1} in the dieoff rate coefficient produced decreases of 47% and 75% in number of exceedances at 3 and 20 mm volumes respectively. In the CM CF pond the number of exceedances did not exhibit any sensitivity to dieoff rate changes.

The 72 hour batch pond is the best treatment option in terms of removal and number of exceedances regardless of the dieoff

Figure 15.10: Number of FC exceedances in a PF CF (MTSS) pond as a function of dieoff rate coefficient.

rate. It is also interesting to note that for either 6 or 12 mm ponds, there is a very large increase in the number of exceedances when the FC dieoff rate drops to its minimum value but that there is no difference in the number of exceedances at average or maximum dieoff rates. The exceedances were primarily due to excess volume of runoff over the pond volume. Removal rates for the lower dieoff rate were not as satisfactory for the 72 hour batch pond. Consequently, the variability in dieoff rate may not produce effluent that reliably achieves the target goals of 100 FC/dl at 4 or less times per swimming season unless a pond approaching 20 mm of runoff volume is designed.

Figure 15.11: Number of FC exceedances in a 72 hr batch (MTSS) pond as a function of dieoff rate coefficient.

15.4.4 The Effect of Dry Weather Flow on Treatment

DWF will cause pond contents to be released sooner than desired, decreasing the time for treatment. Although pond contents will be diluted to a degree by DWF, the lower detention period will result in deterioration of treatment as DWF rate increases. An exercise was performed to determine the critical DWF rate where the rate of deterioration of treatment begins to accelerate. The DWF rate was specified in terms of the time required for the DWF to fill the pond volume.

For this analysis only two pond volumes were examined: 6

and 12 mm and the average year (1971) runoff input series was used. Imposing a uniform DWF input to the ponds will not add any significant variability to the results. The following configurations were analyzed:

Batch:	TD- 24 hr; 5 cells; 0% PP; pipe diam.- 610 mm
PF:	5 cells; 100% PP; pipe diameter- 610 mm

Both MTSS and the Coventry catchments were included in the analysis. Typical results for MTSS catchment are shown in Figures 15.12 and 15.13 (fraction removed), and Figures 15.14 and 15.15 (number of exceedances) for FC and SS respectively. The results for the Coventry runoff simulations were similar.

Figure 15.12 for FC removal indicates that pond performance will deteriorate rapidly for a DWF rate that fills the pond in less than 5 days. A similar inflection point occurs on Fig. 15.13 for SS removal. To avoid undue deterioration of pond performance by DWF bypass, measures may be required when the DWF rate fills the pond in five days or less and a bypass may be recommended when the DWF rate will fill the pond in ten days or less. The same general trend is observed in Figures 15.14 and 15.15 for the effect of DWF on FC and SS number of exceedances, respectively.

Selecting a base value for the DWF is difficult given seasonal variation of DWF. If the value selected is too high then significant amounts of runoff will be bypassed to the receiving water without treatment. This is a particular concern for events of long duration. Although careful evaluation of DWF variation is required to select the optimum value, fortunately there is some leeway in the allowance for DWF inflow into a pond since the simulations have shown that a DWF that fills the pond in five days or more will not significantly deteriorate pond performance. Therefore this amount of DWF can be allowed to enter the pond at all times. When DWF fluctuations will rise above this value the challenge is to design a DWF bypass that will not violate the five day pond fill up rule and to assess if the bypassed flow will not result in a significant amount of untreated runoff.

Figure 15.12: DWF effect on FC removal in MTSS ponds.

If the amount of untreated runoff is high when maintaining the five day rule, there are two solutions: pond volume can be increased which increases the DWF inflow allowance or a more sophisticated control structure can be designed that directs all flow into the pond during a runoff event and bypasses DWF at other times.

15.5 Summary of Simulation Results

The results of the simulations have shown that a PF CF pond under ideal conditions with no short-circuiting or dead volume provides the highest degree of treatment on an overall removal

Figure 15.13: DWF effect on SS removal in MTSS ponds.

basis for the parameters of concern. The size of the active storage volume, the number of cells, and the size of the PP were found to be significant design parameters. Although small outlet pipe diameters are preferred, there was no significant treatment variation when the pipe diameter of CF ponds was less than 610 mm.

The batch mode of operation is only marginally inferior in performance to a PF reactor in terms of removal (within 2%) while providing a 50% decrease in the number of exceedances. This observation holds over a likely range of dieoff rate coefficients. For the batch mode of operation, discharge pipe sizes between 610 and 1220 mm and a PP of 0 or 20% did not cause any significant change in treatment parameters. The

Figure 15.14: DWF effect on the number of FC exceedances for MTSS ponds.

number of cells (between one and five) in the batch reactor did have a tendency to increase removals by up to 5% but the number of exceedances did not change significantly with respect to this configuration change.

DWF rates which will fill a pond in less than five days will rapidly accelerate the degradation of pond performance. Consequently, it may be mandatory to bypass DWF in those situations where DWF rates exceed the five day criterion. DWF rates that fill a pond in ten days or longer will not deteriorate the treatment in any pond.

Pond volumes between 9 and 12 mm of runoff for the entire catchment provide optimal performance based on the treatment

Figure 15.15: DWF effect on the number of SS exceedances for MTSS ponds.

indices. However, variability in the FC dieoff rate will not allow the target value of four exceedances per summer to be consistently achieved even in the most efficient pond configuration (72 hour batch mode) without disinfection.

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