RUNQUAL
RUNOFF QUALITY
FROM DEVELOPMENT SITES

USERS MANUAL

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INTRODUCTION

This manual describes a continuous simulation model (RUNQUAL) which may be used to estimate runoff volumes and quality from development sites. The model also assesses the effectiveness of three best management practices (BMPs) for runoff controls: detention basins, infiltration retention and vegetated filter (buffer) strips.

The RUNQUAL model is written in Microsoft QuickBASIC 4.5 for personal computers using the MS-DOS operating system. The programs are provided in both executable (.EXE) and source code (.BAS) forms. They are currently limited to 10 land uses and 2 water quality parameters. Multiple model runs are required if analyses of more than 2 contaminants are needed at a site. Additional land uses can be accommodated by modification of source code dimension statements. However, this may cause scrolling of output screens.

Users are advised that RUNQUAL's estimates of contaminant loads and BMP effectiveness are approximate, only. The model should not be used for design purposes.

The main section of this manual describes the general features of RUNQUAL and illustrates the use of the program. Appendices contain mathematical descriptions, data sources and listing of data and output files for examples.

In the text of this manual, program and file names, menu options and input by the user are written in **bold**, <u>underline</u> and *italic*, respectively.

MODEL DESCRIPTION

The RUNQUAL model provides a continuous daily simulation of surface runoff and contaminant loads from the pervious and impervious surfaces of the various land uses on a development site. The resulting contaminated runoff is routed through BMPs which modify its characteristics before discharge from the site.

<u>Runoff Volume & Quality</u>

The runoff section of RUNQUAL is adapted from the urban runoff component of the Generalized Watershed Loading Functions (GWLF) model (Haith *et al.*, 1992). Runoff volumes are calculated from procedures given in the U.S. Soil Conservation Service's *Technical Release 55* (U.S. Soil Conservation Service, 1986). Contaminant loads are based on exponential accumulation and washoff functions similar to those used in SWMM (Huber & Dickinson, 1988) and STORM (Hydrologic Engineering Center, 1977). The pervious and impervious portions of each land uses are modeled separately and runoff and contaminant loads from the various surfaces are aggregated to provide daily totals. It is assumed that the site is small enough so that surface runoff travel times are much smaller than the model's 1-day time step.

The model user must specify the following for the pervious and impervious sections of each land use: areas, runoff curve numbers and accumulation rate and dissolved fraction for each contaminant. Data sources and default values for these parameters are provided in Appendix B.

Best Management Practices

Three basic types of BMPs are modeled - infiltration retention facilities, vegetated filter strips and detention basins. Detention basins may be dry or wet (sometimes referred to as extended dry basins and wet ponds, respectively). Infiltration facilities are trenches and basins which are designed to exfiltrate (leach to groundwater) specific volumes of runoff. Filter strips are grassed or forested areas through which runoff passes as sheet (unchannelized) flow. All site runoff is routed through the BMPs. If the practices are used in combination, runoff is routed through them in the following order: infiltration retention, filter strips and detention basins.

Infiltration/Retention. Infiltration facilities are designed to remove a specified constant flow volume from runoff. They require permeable soils and must be placed well above bedrock and seasonal high water tables. Grassed inlets or other filtering mechanisms are needed to prevent clogging with coarse sediment. The practice is modeled by assuming that contaminant removal is directly proportional to runoff retention. For example, if 40% of a day's runoff is retained by the facility, the contaminant load is also reduced 40%.

Vegetated Filter (Buffer) Strips. These practices are of marginal effectiveness in removing dissolved pollutants. However, provided sheet flow conditions are maintained, buffers of 100 ft (30 m) or less can remove all of the solid (adsorbed) material. Filter strips are modeled by assuming a linear removal efficiency for solids up to a width of 30 m (100% removal for buffer widths 30 m). This presumes that filter strip design is adequate to prevent flow channelization (small slopes and/or flow distribution). No removal of dissolved contaminant is considered.

Detention Basins. Both dry and wet basins are modeled by RUNQUAL. The latter requires specification of a "dead storage" volume equal to the basin volume below the discharge outlet. An orifice-type outlet is assumed and in addition to dead storage, the user must also specify the basin capacity, surface area, drainage (draw down) time and if applicable, the month during which annual cleaning takes place. Drainage time is the number of days required for the basin's active capacity (capacity - dead storage) to drain. Based on this parameter, the model iteratively calculates an outlet coefficient for the orifice discharge.

The basin model consists of daily balances for water and contaminant mass. All mass is conserved, and the only loss mechanisms are discharge through the basin outlet or overflow by the spillway and settling of solid material and subsequent removal by cleaning or dredging. Dissolved contaminants are assumed to be completely mixed in the basin at all times. Solid material is assumed completely mixed whenever inflow volume is sufficient to resuspend previously settled material.

RUNQUAL PROGRAM

Required Files

Simulations by RUNQUAL require the program (**RUNQUAL.EXE**) and two data files (**WEATHER.DAT** and **RUNQUAL.DAT**) on the default drive. **WEATHER.DAT** contains daily temperature (C) and precipitation (cm) data and **RUNQUAL.DAT** is a file of site characteristics (areas, curve numbers, contaminant accumulation rates, etc.). The program is initialed by typing *RUNQUAL*.

A 10-yr daily weather record (1/1/70 - 12/31/79) for Batavia, NY is included on the disk as **BAT17012.79**. Two other files on the disk (**RESULTS.DAT** and **SUMMARY.DAT**) are output files from the detention basin run of the Example. The source code listing **RUNQUAL.BAS** is provided on the disk for users wishing to modify the model.

Program Menus

After the program is initiated, the user provides input by responding to a series of menus, the first one of which is given in Display 1.

```
Select one of the following :
      1      Create, modify or print RUNQUAL.DAT
      2      Run simulation
      3      Obtain output
      4      Stop (End)
?
```

Display 1.   Program Main Menu

Selection of the first option (Create, modify or print RUNQUAL.DAT) permits us to manipulate the input data file, following the menu given in Display 2. Option 1 (Create new RUNQUAL.DAT file) will query the user regarding the necessary site data and create the data file. Alternatively, the user could create a **RUNQUAL.DAT** file with a text editor. In either case, the new file will write over the previous version, so the user should copy the old version to a new file name if it is to be preserved. Option 2 (Modify existing RUNQUAL.DAT file) allows the user to change selected values of a previously saved **RUNQUAL.DAT** file.

```
Select :
      1       Create new RUNQUAL.DAT file
      2       Modify existing RUNQUAL.DAT file
      3       Print RUNQUAL data
  otherwise   Return
?
```

Display 2. Options for Manipulating Input Data File.

```
 Select :  (For printing RUNQUAL data)
      1       Print to screen
      2       Print a hard copy (turn on printer first)
      3       Print to a file named  RUNQUAL.TXT
  otherwise   Return
?
```

Display 3. Options for Printing Out Input Data.

Option 3 activates a print menu (Display 3) which, as with all of the program's printing menus, permits printing to screen, printer or text file.

```
Select :
      1       Print summary
      2       Print annual results
      3       Print monthly results
  otherwise   Return
?
```

Display 4. Output Options.

Selection of the Obtain output option from the main menu in Display 1 allows the user to specify summary, annual or monthly results. The summary values are mean values over the duration of the simulation period.

Options from the Run simulation menu are illustrated in the following example.

EXAMPLE

Use of the RUNQUAL program is illustrated for a 70 ha development site near Batavia, NY. Physical characteristics of the site are given in Table 1. The pollutants of concern are nitrogen and phosphorus, and their accumulation rates and dissolved fractions are given in Table 2. These values were selected from the Tables given in Appendix B. Ten years of daily weather data for the period January 1, 1970 - December 31, 1979 were used in the simulations.

			Curve Numbers[a/]	
Land Use	Area (ha)	Impervious Fraction	Impervious	Pervious
Residential	35	0.40	92	74
Industrial	10	0.70	98	79
Shopping Center	25	0.90	98	79

[a/] Average antecedent moisture conditions

Table 1. Physical Characteristics of Example Site.

	Nitrogen			Phosphorus		
Land Use	Impervious	Pervious	Dissolved fraction	Impervious	Pervious	Dissolved fraction
	(kg/ha-day)			(kg/ha-day)		
Residential	0.090	0.022	0.28	0.0112	0.0039	0.37
Industrial	0.101	0.012	0.30	0.0112	0.0019	0.21
Shopping Center	0.056	0.012	0.33	0.0067	0.0019	0.40

Table 2. Contaminant Accumulation Rates and Dissolved Fractions.

Base Run - No Controls

An initial simulation run was made to evaluate the nitrogen and phosphorus loads without any BMPs. Mean values over the 10-year period, as produced by the Print summary option (Display 4) are shown in Table 3.

Effects of Retention and Filter Strip

Next the combined effects of infiltration/retention of 1.0 cm of site runoff and a 10 m buffer were evaluated. After selection of the Run simulation option from the main menu, inputs are specified for the simulation as indicated in Display 5. Summary results are shown in Table 4.

These BMPs drastically reduce runoff volumes and nutrient loads from the site. The major impact is due to infiltration. When site conditions are suitable, this can be an extremely effective means of controlling runoff. However, the percolation requirements and necessary depths to bed rock and seasonal high water table will preclude this BMP at many sites.

```
Select one of the following :
      1       Create, modify or print RUNQUAL.DAT
      2       Run simulation
      3       Obtain output
      4       Stop (End)
? 2


Title of simulation? 70 ha Example – Retention & Filter Strip
Length of run in years? 10
Infiltration retention (Y/N) ? y
Retention runoff (cm over site) =  ? 1
Vegetated filter (buffer) strip (Y/N) ? y
Filter strip width (m) = ? 10
Detention basin (Y/N)? n
```

Display 5. Specifying Run Options for Retention & Filter Strip BMPs.

Effects of a Large Wet Detention Basin

A third simulation run evaluated a large (2-ha) wet pond with a 50,000 m^3 capacity, 30,000 m^3 dead storage (permanent pool) and 10 day drainage time (draw down period). July cleaning of the pond was also specified. The simulation's input menu is shown in Display 6. Summary results are shown in Table 5. Compared with the initial run, the large detention pond substantially reduces nutrient loads. This reduction is associated with annual removal of accumulated nutrients in the pond.

```
Select one of the following :
      1       Create, modify or print RUNQUAL.DAT
      2       Run simulation
      3       Obtain output
      4       Stop (End)
? 2


Title of simulation? 70 ha Example - Large Wet Pond
Length of run in years? 10
Infiltration retention (Y/N) ? n
Vegetated filter (buffer) strip (Y/N) ? n
Detention basin (Y/N)? y
Basin capacity (m^3) = ? 50000
Basin dead storage (m^3) = ? 30000
Basin surface area (m^2) = ? 20000
Days to drain = ? 10
Clean basin annually (Y/N)? y
Cleaning month (1-12) = ? 7
```

Display 5.   Input Menu for Detention Pond Run.

These effects can be inferred from Table 6, which summarizes a comparable pond without annual cleaning. Nutrient removals are much lower. The dynamics of the pond behavior are evident from the annual nutrient discharges given in Table 7. In many years, nutrient discharges are relatively low as the settled material accumulates in the pond. However, during a year of exceptional runoff, such as year 8 of the simulation, the accumulated nutrients are flushed from the pond.

70 ha Example - No Controls
10 -year means
Retention of 0 cm runoff Filter width (m) = 0
Detention basin volume (m^3) = 0 Surface area (m^2) = 0
Dead storage (m^3) = 0 Days to drain = 0 Month cleaned = 0
Outlet Coefficient = 0.0000

	PRECIP	RUNOFF	DIS.Nitrog	TOT.Nitrog	DIS.Phosph	TOT.Phosph
	(cm)		(kg)			
Jan	6.3	2.2	12.0	39.2	1.7	4.8
Feb	6.0	3.6	13.9	45.7	2.0	5.6
Mar	7.2	5.1	17.9	58.7	2.5	7.2
Apr	7.9	2.9	12.3	40.3	1.7	4.9
May	9.4	1.9	11.2	36.0	1.5	4.3
June	10.7	3.1	13.4	43.5	1.8	5.2
July	8.7	2.4	11.4	37.0	1.5	4.4
Aug	10.9	3.5	12.3	40.0	1.7	4.8
Sept	11.3	3.7	12.7	41.2	1.7	5.0
Oct	8.5	1.8	10.4	33.3	1.4	4.0
Nov	7.9	2.3	12.9	42.1	1.7	5.1
Dec	8.6	3.8	16.9	55.4	2.4	6.8
ANNUAL	103.3	36.2	157.4	512.5	21.5	62.0

SOURCE	AREA	RUNOFF	DIS.Nitrog	TOT.Nitrog	DIS.Phosph	TOT.Phosph
	(ha)	(cm)	(kg)			
Residential	35.	15.5	44.2	157.9	7.6	20.6
Industrial	10.	48.9	38.4	128.1	3.0	14.3
Shop Center	25.	60.2	74.8	226.6	10.9	27.2
TOTAL FROM SITE			157.4	512.5	21.5	62.0

Table 3. Summary Results From Initial Run - No BMPs.

70 ha Example - Retention & Filter Strip
10 -year means
Retention of 1 cm runoff Filter width (m) = 10
Detention basin volume (m^3) = 0 Surface area (m^2) = 0
Dead storage (m^3) = 0 Days to drain = 0 Month cleaned = 0
Outlet Coefficient = 0.0000

	PRECIP (cm)	RUNOFF (cm)	DIS.Nitrog (kg)	TOT.Nitrog (kg)	DIS.Phosph (kg)	TOT.Phosph (kg)
Jan	6.3	0.3	0.8	2.0	0.1	0.3
Feb	6.0	0.7	1.6	4.0	0.2	0.5
Mar	7.2	1.4	1.9	4.8	0.3	0.6
Apr	7.9	0.5	1.4	3.6	0.2	0.5
May	9.4	0.4	0.8	2.0	0.1	0.3
June	10.7	0.9	1.3	3.4	0.2	0.5
July	8.7	0.6	1.2	3.1	0.2	0.4
Aug	10.9	1.1	1.9	4.8	0.3	0.6
Sept	11.3	1.2	1.1	2.9	0.2	0.4
Oct	8.5	0.2	0.6	1.5	0.1	0.2
Nov	7.9	0.2	0.3	0.7	0.0	0.1
Dec	8.6	0.7	1.8	4.6	0.3	0.6
ANNUAL	103.3	8.0	14.6	37.4	2.2	4.9

SOURCE	AREA (ha)	RUNOFF (cm)	DIS.Nitrog (kg)	TOT.Nitrog (kg)	DIS.Phosph (kg)	TOT.Phosph (kg)
Residential	35.	15.5	44.2	157.9	7.6	20.6
Industrial	10.	48.9	38.4	128.1	3.0	14.3
Shop Center	25.	60.2	74.8	226.6	10.9	27.2
TOTAL FROM SITE			14.6	37.4	2.2	4.9

Table 4. Summary Simulation Results - Infiltration/Retention and Filter Strip BMPs.

70 ha Example - Large Wet Pond
10 -year means
Retention of 0 cm runoff Filter width (m) = 0
Detention basin volume (m^3) = 50000 Surface area (m^2) = 20000
Dead storage (m^3) = 30000 Days to drain = 10 Month cleaned = 7
Outlet Coefficient = 0.0088

	PRECIP (cm)	RUNOFF (cm)	DIS.Nitrog (kg)	TOT.Nitrog (kg)	DIS.Phosph (kg)	TOT.Phosph (kg)
Jan	6.3	2.4	10.3	11.7	1.4	1.6
Feb	6.0	3.4	14.5	15.9	2.0	2.2
Mar	7.2	5.4	18.8	22.8	2.6	3.1
Apr	7.9	3.1	12.4	14.3	1.7	1.9
May	9.4	2.1	9.0	11.9	1.2	1.6
June	10.7	2.8	12.4	24.5	1.7	3.1
July	8.7	2.4	4.4	4.7	0.6	0.6
Aug	10.9	3.1	7.1	9.1	1.0	1.2
Sept	11.3	4.2	11.1	19.3	1.5	2.4
Oct	8.5	1.9	6.6	6.6	0.9	0.9
Nov	7.9	2.8	11.4	11.4	1.5	1.5
Dec	8.6	3.8	16.6	18.7	2.3	2.5
ANNUAL	103.3	37.4	134.7	170.8	18.4	22.6

SOURCE	AREA (ha)	RUNOFF (cm)	DIS.Nitrog (kg)	TOT.Nitrog (kg)	DIS.Phosph (kg)	TOT.Phosph (kg)
Residential	35.	15.5	44.2	157.4	7.6	20.6
Industrial	10.	48.9	38.4	128.1	3.0	14.3
Shop Center	25.	60.2	74.8	226.6	10.9	27.2
TOTAL FROM SITE			134.7	170.8	18.4	22.6

Table 5. Summary Simulation Results - Large Wet Pond with Annual Removal of Accumulated Solids.

70 ha Example - Pond w/o Cleaning
10 -year means
Retention of 0 cm runoff Filter width (m) = 0
Detention basin volume (m^3) = 50000 Surface area (m^2) = 20000
Dead storage (m^3) = 30000 Days to drain = 10 Month cleaned = 0
Outlet Coefficient = 0.0088

	PRECIP (cm)	RUNOFF (cm)	DIS.Nitrog (kg)	TOT.Nitrog (kg)	DIS.Phosph (kg)	TOT.Phosph (kg)
Jan	6.3	2.4	10.8	19.6	1.5	2.5
Feb	6.0	3.4	14.8	19.2	2.1	2.6
Mar	7.2	5.4	19.0	38.8	2.7	4.9
Apr	7.9	3.1	12.4	21.0	1.7	2.7
May	9.4	2.1	9.0	21.5	1.2	2.7
June	10.7	2.8	12.4	56.3	1.7	6.7
July	8.7	2.4	10.4	32.9	1.4	4.0
Aug	10.9	3.1	12.0	37.6	1.6	4.5
Sept	11.3	4.2	15.3	121.6	2.1	14.2
Oct	8.5	1.9	8.4	8.4	1.1	1.1
Nov	7.9	2.8	13.0	13.0	1.7	1.7
Dec	8.6	3.8	17.8	33.4	2.4	4.2
ANNUAL	103.3	37.4	155.3	423.3	21.2	51.8

SOURCE	AREA (ha)	RUNOFF (cm)	DIS.Nitrog (kg)	TOT.Nitrog (kg)	DIS.Phosph (kg)	TOT.Phosph (kg)
Residential	35.	15.5	44.2	157.9	7.6	20.6
Industrial	10.	48.9	38.4	128.1	3.0	14.3
Shop Center	25.	60.2	74.8	226.6	10.9	27.2
TOTAL FROM SITE			155.3	423.3	21.2	51.8

Table 6. Summary Simulation Results - Large Wet Pond with No Removal of Accumulated Solids.

70 ha Example - Pond w/o Cleaning
Yearly Water Pollution Loads
Retention of 0 cm runoff   Filter width (m) = 0
Detention basin volume (m^3) = 50000   Surface area (m^2) = 20000
Dead storage (m^3) = 30000   Days to drain = 10   Month cleaned = 0
Outlet Coefficient = 0.0088

YEAR	PRECIP	RUNOFF	DIS.Nitro	TOT.Nitro	DIS.Phosp	TOT.Phosp
	(cm)		(kg)			
1	107.4	33.6	136.5	185.8	18.4	24.0
2	81.1	27.8	134.3	165.8	18.3	21.9
3	110.3	42.5	187.8	231.2	25.6	30.6
4	99.4	29.9	157.3	244.1	21.3	31.2
5	106.3	37.0	164.3	572.0	22.3	68.8
6	100.4	33.6	156.7	349.4	21.3	43.2
7	105.2	39.4	157.9	354.2	21.6	44.0
8	129.5	60.1	177.8	1071.9	24.8	126.9
9	84.1	28.9	122.7	224.6	16.7	28.3
10	108.9	41.3	157.6	833.9	21.6	98.9

Table 7. Annual Simulation Results - Large Wet Pond with No Removal of Accumulated Solids.

APPENDIX A
MATHEMATICAL DESCRIPTION OF RUNQUAL

Runoff Volumes

The general approach is an adaptation of the U.S. Soil Conservation Service curve number model described in *Technical Release 55* (U.S. Soil Conservation Service, 1986):

$$Q_t = \frac{(R_t + M_t - 0.2\ W_t)^2}{R_t + M_t + 0.8\ W_t} \qquad (1)$$

for $Q_t > R_t + M_t - 0.2\ W_t$. In this equation, Q_t = runoff on day t (cm), R_t = rain on day t (cm), M_t = snowmelt water on day t (cm) and W_t = detention parameter for day t (cm), given by

$$W_t = \frac{2540}{CN_t} - 25.4 \qquad (2)$$

where CN_t = curve number for day t.

Curve numbers are based on 5-day antecedent precipitation, A_t (cm):

$$A_t = \sum_{j=t-5}^{t-1} (R_j + M_j) \qquad (3)$$

When there is no snowmelt on day, curve numbers vary linearly between 3 values CN1, CN2 and CN3, which correspond to dry, wet and average antecedent moisture limits 0, AM1 and AM2 (cm). It is assumed that snowmelt corresponds to the wettest antecedent moisture conditions. Thus,

$$CN_t = \begin{cases} CN1 + [(CN2-CN1)/AM1]\ A_t; & A_t\ AM1,\ M_t = 0 \\ CN2 + [(CN3-CN2)/(AM2-AM1)]\ (A_t-AM1); & AM1 < A_t < AM2,\ M_t = 0 \\ CN3\ ; & A_t\ AM2 \text{ or } M_t > 0 \end{cases} \qquad (4)$$

The antecedent moisture limits AM1 and AM2 for dormant and growing seasons are: dormant - 1.3, 3.6 cm; and growing - 2.8, 5.3 cm, respectively. The two seasons correspond to periods of low and high evapotranspiration, respectively. A somewhat arbitrary classification based on average monthly air temperature is dormant: < 10°C; growing: 10°C.

Values for CN1 and CN3 can be computed from CN2 as in Hawkins (1978):

$$CN1 = \frac{CN2}{2.334 - 0.01334\ CN2} \tag{5}$$

$$CN3 = \frac{CN2}{0.4036 + 0.0059\ CN2} \tag{6}$$

Snowmelt calculations are based on a daily mass balance for SN_t, snow water (cm) on the ground surface at the beginning of day t,

$$SN_{t+1} = SN_t + \Delta SN_t - M_t \tag{7}$$

in which ΔSN_t = new snow water (cm) on day t. Snowmelt is determined from the degree-day equation:

$$M_t = \begin{cases} \mathrm{MIN}\ (0.45\ T_t,\ SN_t) & ;\ T_t > 0 \\ 0 & ;\ T_t \geq 0 \end{cases} \tag{8}$$

where T_t = air temperature on day t (C).

Snow and rain are obtained from Pr_t, recorded precipitation on day t (cm):

$$R_t = \begin{cases} Pr_t & ;\ T_t > 0 \\ 0 & ;\ T_t \leq 0 \end{cases} \tag{9}$$

$$\Delta SN_t = \begin{cases} 0 & ;\ T_t > 0 \\ Pr_t & ;\ T_t \leq 0 \end{cases} \tag{10}$$

Water Pollutants in Runoff

The water quality model is based on general accumulation and wash off relationships proposed by Amy et al. (1974) and Sartor & Boyd (1972). The exponential accumulation function was subsequently used in SWMM (Huber & Dickinson, 1988) and the wash off function is used in both SWMM and STORM (Hydrologic Engineering Center, 1977). The mathematical development here follows that of Overton and Meadows (1976).

Accumulation. Pollution loads in runoff are based on daily accumulations of contaminants on the urban surfaces. If L(t) is the accumulated load on day t (kg/ha), then the rate of accumulation during dry periods is

$$\frac{dL}{dt} = m - \beta L \tag{11}$$

dt

where m is a constant mass accumulation rate (kg/ha-day) and ß is a depletion rate constant (1/day). Solving equation 11, we obtain

$$L(t) = L_0 e^{-ßt} + (m/ß)(1 - e^{-ßt}) \qquad (12)$$

in which $L_0 = L(t)$ at time $t = 0$.

Equation 12 approaches an asymptotic value L_{max}:

$$L_{max} = \lim_{t \to \infty} L(t) = m/ß \qquad (13)$$

Data given in Sartor & Boyd (1972) and shown in Figure 1 indicates that L(t) approaches its maximum value in approximately 12 days. If we conservatively assume that L(t) reaches 90% of L_{max} in 20 days, then for $L_0 = 0$,

$$0.90\,(m/ß) = (m/ß)(1 - e^{-20ß})$$
$$e^{-20ß} = 0.10;\ ß = -\,0.05\,\mathrm{Ln}\,(0.10) = 0.12$$

Equation 12 can also be written for a time interval $\Delta t = t_2 - t_1$ as

$$L(t_2) = L(t_1) e^{-0.12\Delta t} + (m/0.12)(1 - e^{-0.12\Delta t}) \qquad (14)$$

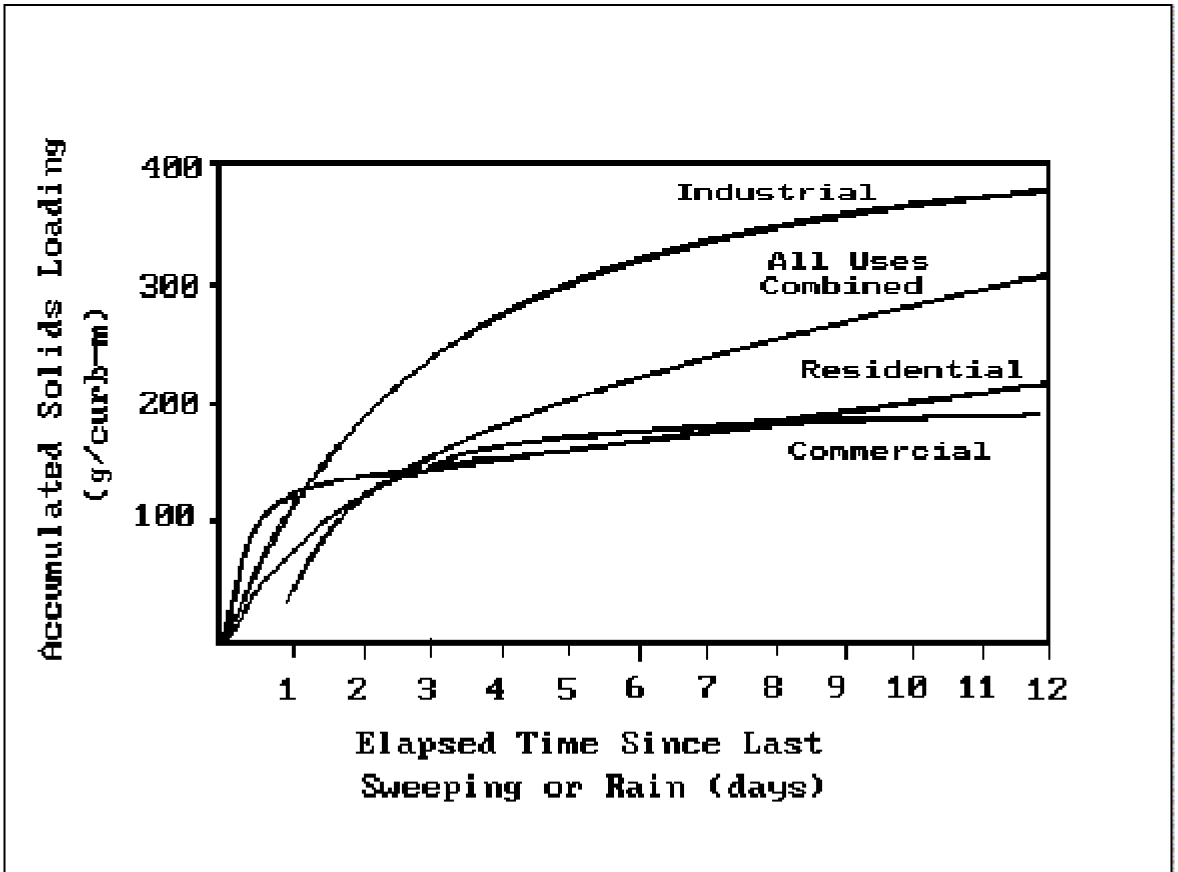

Figure 1. Accumulation of Pollutants on Urban surfaces (Sartor & Boyd, 1972).

or, for a time interval of one day,

$$L_{t+1} = L_t\ e^{-0.12} + (m/0.12)\ (1 - e^{-0.12}) \tag{15}$$

where L_t is the accumulation at the beginning of day t (kg).

Washoff. Equation 15 can be modified to include the effects of washoff by runoff:

$$L_{t+1} = L_t\ e^{-0.12} + (m/0.12)(1 - e^{-0.12}) - X_t \tag{16}$$

in which X_t = runoff contaminant load on day t(kg/ha), given by

$$X_t = w_t\ [L_t\ e^{-0.12} + (m/0.12)(1 - e^{-0.12})] \tag{17}$$

where w_t is the first-order washoff function suggested by Amy et al. (1974):

$$w_t = 1 - e^{-1.81Q}t \tag{18}$$

Equation 18 is based on the assumption that 0.5 in (1.27 cm) of runoff will wash off 90% of the accumulated pollutants.

Partitioning to Dissolved and Solid Phases. The model described in the preceding discussion will estimate total contaminant load in runoff. However, it is often important to determine the dissolved and particulate or solid portions of the runoff load in order to realistically evaluate control measures. For example, vegetated buffer strips are most effective in removal of chemicals adsorbed to sediment (particulate forms). Similarly, removal of runoff chemicals in dry detention ponds is primarily due to settling of particulates; dissolved chemicals are seldom significantly reduced.

Contaminant loads are partitioned to dissolved and solid-phase loads by assuming that the ratio of dissolved to total contaminant in runoff from each land use is a constant.

Total Site Runoff Volumes & Pollutant Loads

In addition to daily temperature and precipitation records and information regarding cleaning practices, areas and impervious area fractions must be determined for each land use. The pervious and impervious portions of each land use are modeled separately, and the resulting runoff loads summed to obtain the site total.

If we define the following: A_k = area of land use k (ha); I_k = impervious fraction of land use k; $Q_{i,k,t}$, $Q_{p,k,t}$ = runoff from the impervious and pervious portions, respectively, of land use k on day t (cm); $X_{i,k,t}$, $X_{p,k,t}$ = contaminant load in runoff from the impervious and pervious portions, respectively, of land use k on day t (kg/ha); Q_t = total site runoff on day t (cm); and, LU_t = total contaminant load in urban runoff from site on day t (kg), then,

$$Q_t = \frac{\sum_k [I_k A_k Q_{i,k,t} + (1-I_k) A_k Q_{p,k,t}]}{AT} \tag{19}$$

and,

$$LU_t = \sum_k [I_k A_k X_{i,k,t} + (1-I_k) A_k X_{p,k,t}] \tag{20}$$

where AT = total area for the site, as given by

$$AT = \sum_k A_k \tag{21}$$

Best Management Practices (BMPs)

Simple models are developed for 3 basic types of BMPs - detention basins, infiltration retention and vegetated filter strips.

Detention Basins

A general schematic of a detention basin is shown in Figure 2. An outlet is designed to retain flows for a specified period of time. When the storage capacity of the basin is exceeded, overflow occurs by means of an emergency spillway. Wet basins have a dead storage (a permanent pool) below the outlet.

Basin characteristics are specified by four parameters: capacity or maximum storage K (m^3), dead storage So (m^3), surface area Ab (m^3) and drainage time (days). Drainage time is the number of days required for the basin's active storage capacity (K - So) to drain. It is assumed that the basin surface area remains relatively constant.

Water Balance. The daily water balance for the basin is

$$S_{t+1} = S_t + I_t + 0.01\ Ab\ Pr_t - E_t - D_t - O_t \qquad (22)$$

where S_t = basin contents at the beginning of day t (m^3); and I_t, E_t, D_t and O_t = basin inflow, evaporation, outlet discharge and overflow during day t (m^3).

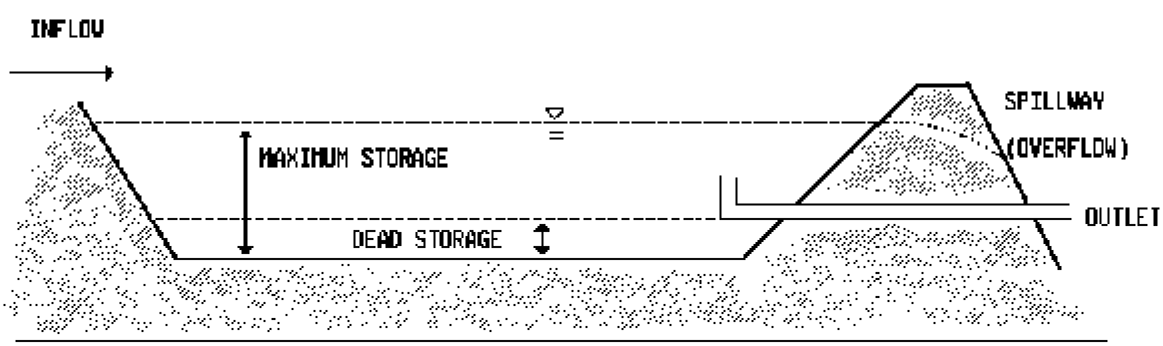

Figure 2. Runoff Detention Basin

In the absence of infiltration facilities, inflow is given by the product of site runoff and area:

$$I_t = 100\ Q_t\ AT. \qquad (23)$$

where Q_t is site runoff as given by Equation 19, modified if necessary by prior infiltration retention. If sufficient water is available, evaporation is assumed to occur at the potential rate as given by Hamon (1961):

$$PE_t = \frac{0.021\ d_t^2\ e_t)}{T_t + 273} \qquad (24)$$

In this equation, PE_t = potential evapotranspiration on day t (cm); d_t is the number of daylight hours per day during the month containing day t; and e_t is the saturated water vapor pressure in millibars on day t. When temperature T_t 0, PE_t is set to zero. Basin evapotranspiration is thus

$$E_t = \mathrm{Min}\ [0.01\ Ab\ PE_t;\ (S_t + I_t + 0.01\ Ab\ Pr_t)] \qquad (25)$$

Basin overflow O_t occurs when basin storage contents minus outlet discharge would otherwise exceed the storage capacity:

$$O_t = \mathrm{Max}\ [0;\ (S_t + I_t + 0.01\ Ab\ Pr_t - E_t - D_t - K)] \qquad (26)$$

The outlet discharge will in general vary with water elevation above the outlet. Assuming an orifice-type outlet, discharge in m^3/sec is

$$D_t' = k_o\ A_o\ (g\ h_t)^{0.5} \qquad (27)$$

where h_t is the elevation (m) above the dead storage pool at time t, k_o is the orifice coefficient and A_o is the outlet area (m^2). Converting to m^3/day and collecting the constant terms, we obtain

$$D_t = \mathrm{Max}\ [382{,}700\ a\ (h_t)^{0.5};\ (S_t + I_t + 0.01\ Ab\ Pr_t - E_t)] \qquad (28)$$

where $a = k_o\ A_o$. Based on the constant basin surface area assumption, $h_t = (S_t + I_t + 0.01\ Ab\ Pr_t - E_t) / Ab$, up to a maximum of (K - So) / Ab.

The constant "a" can be determined from the other design variables. In the absence of inflows the basin's active storage capacity must empty in θ days:

$$D_1 + D_2 + \ldots + D_\Theta = K - So \qquad (29)$$

where,

$$D_t = a\ [(S_t - So)/Ab]^{0.5} \qquad (30)$$

and,

$$S_1 = K$$
$$S_2 = K - D_1$$
$$S_3 = K - D_2$$
$$\ldots \tag{31}$$

Given the design parameters K, So and , Equations 29-31 are solved iteratively for "a".

Contaminant Balance. Contaminant removal in the basin is due to settling, and hence dissolved and solid-phase components must be modeled separately. The mass balances for the dissolved and solid-phase components are:

$$Md_{t+1} = Md_t + IMd_t - OMd_t \tag{32}$$
$$Ms_{t+1} = Ms_t + IMs_t - OMs_t \tag{33}$$

where Md_t, Ms_t = dissolved and solid contaminant mass, respectively, in the basin at the beginning of day t (kg); and IMd_t, IMs_t, OMd_t, OMs_t = dissolved and solid contaminant mass in basin inflow and outflow (outlet discharge + overflow), respectively, during day t (kg).

Mass outflows are based on complete mixing, and the fraction of accumulated contaminants leaving in outflow is equivalent to the fraction of total water which departs:

$$FO_t = \frac{D_t + O_t}{S_t + I_t + 0.01\ Ab\ Pr_t - E_t} \tag{34}$$

Dissolved contaminants do not settle, and hence are always well-mixed:

$$OMd_t = FO_t\ (Md_t + IMd_t) \tag{35}$$

Based on data from the National Urban Runoff Program (NURP), approximately 80% of the suspended solids in urban runoff have settling velocities which exceed 0.3 ft/hr (0.09 m/hr or 2.2 m/day) (Stahre & Urbonas, 1990). Typical detention basin depths are 1-3 m, and thus most solid-phase contaminants will have settled after 1 day. As a result, during a day with sufficient runoff to resuspend solids, all solid phase material in the basin is considered to be completely mixed and susceptible to loss. However, remaining solids are settled from the water column and will not leave the basin on succeeding days. It is assumed that basin inflows must exceed at least 10% of the basin's capacity or 50% of the current contents (S_t) in order for mixing to occur. Thus,

$$DMs_t = \begin{cases} FO_t\ (Ms_t + IMs_t), & I_t \geq 0.1\ K,\ I_t > 0.5\ S_t \\ 0 & \text{otherwise} \end{cases} \tag{36}$$

Note that there are no contaminant removal terms in this model. The detention basin only serves to modify the timing of contaminant discharges. However, if the basin is periodically cleaned, substantial removal of solid-phase contaminants can be achieved.

Infiltration Retention

Infiltration facilities are designed to remove a specified constant flow volume from runoff. Removal efficiency can be estimated by assuming a constant concentration of contaminant in runoff. If the BMP is designed to retain runoff volume Qo, then Fr_t, the fraction of retained dissolved or solid contaminant is

$$Fr_t = \begin{cases} Qo / Q_t & , Q_t > Qo \\ 1 & , Q_t \leq Qo \end{cases} \tag{37}$$

Vegetated Filter Strips

A vegetated filter strip is a grassed or wooded area through which runoff from a site is directed. Contaminant removal is achieved by physical filtering and settling of solid material. Research indicates that vegetated buffer or filter strips are highly effective at filtering solid materials (chemicals or other contaminants attached to sediment) from runoff. However, removal of dissolved contaminants is uncertain, and there is little consistent evidence of significant removal. For example, experimental studies by Dillaha et al. (1989) found that 70-93% of solid nutrients (nitrogen and phosphorus) in runoff were removed by a 30 ft filter strip. However, very little removal of dissolved nutrients was observed. Similar conclusions were reached by Magette et al. (1989) for 30 ft vegetated strips. Hayes et al. (1984) measured sediment removal rates of 90-100 % across a 40 ft buffer. Asmussen et al. (1977) observed sediment and solid-phase pesticide removals of 94-98% and 99%, respectively, across an 80 ft grassed waterway.

The general conclusion from these studies is that vegetated filter strips of somewhat less than 100 ft (30 m) are sufficient to remove essentially all contaminants associated with sediment. However, channelized flows must be prevented to achieve this level of effectiveness. Filter strips on steeper slopes require flow distribution measures to maintain sheet flow and frequent inspections to eliminate incipient channels.

Based on these studies it is assumed that no dissolved contaminants will be removed by vegetated filter strips. Removal efficiency for solid contaminants is

$$Fe = \begin{cases} 1 & , W \geq 30 \\ W / 30 & , W \leq 30 \end{cases} \tag{38}$$

where W is buffer width (m).

APPENDIX B
INPUT DATA SOURCES

Curve Numbers

Curve numbers for average antecedent moisture conditions (CN2) can be obtained from Table 8, which was abstracted from *Technical Release 55*. The impervious surface curve numbers in Table 8 assume that impervious areas drain directly to the drainage system by lined conduits or other channelized paths; i.e., these flows are not dissipated on the pervious surfaces.

Daylight Hours

Monthly values for daylight hours (d_t for Equation 24) are given in Table 9.

Contaminant Accumulation Rates & Partitioning.

The contaminant accumulation rate m should in principle be measured for the area of interest or determined by model calibration. However, when such approaches are infeasible, default values may be used, such as those given in Table 10 for Northern Virginia Areas.

Nutrients can be approximately partitioned into dissolved and solid forms using the summary information from the National Urban Runoff Program given in Tables 11 and 12.

In a similar fashion, the data in Table 11 can also be used to extend the information in Table 10 to the additional contaminants COD, Pb, Cu and Zn. Assuming the concentration ratios between these chemicals and total suspended solids also apply to accumulation rates, we can multiply the suspended solids rates in Table 10 by the appropriate ratios to obtain the new accumulation rates.

Land Use	Soil Hydrologic Group A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.):				
Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50-75%)	49	69	79	84
Good condition (grass cover > 75%)	39	61	74	80
Impervious areas:				
Paved parking lots, roofs, driveways, etc.)	98	98	98	98
Streets and roads:				
Paved with curbs & storm sewers	98	98	98	98
Paved with open ditches	83	89	92	93
Gravel	76	85	89	91
Dirt	72	82	87	89
Western desert urban areas:				
Natural desert landscaping (pervious areas, only)	63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1-2 in sand or gravel mulch and basin borders)	96	96	96	96

Table 8. Urban Curve Numbers for Average Antecedent Moisture Condition (CN2). (Source: *Technical Release 55* (U.S. Soil Conservation Service, 1986)).

	Latitude North (°)						
	48	46	44	42	40	38	36
				(hr/day)			
Jan	8.7	8.9	9.2	9.3	9.5	9.7	9.9
Feb	10.0	10.2	10.3	10.4	10.5	10.6	10.7
Mar	11.7	11.7	11.7	11.7	11.8	11.8	11.8
Apr	13.4	13.3	13.2	13.1	13.0	13.0	12.9
May	14.9	14.7	14.5	14.3	14.1	14.0	13.8
Jun	15.7	15.4	15.2	15.0	14.7	14.5	14.3
Jul	15.3	15.0	14.8	14.6	14.4	14.3	14.1
Aug	14.0	13.8	13.7	13.6	13.6	13.4	13.3
Sep	12.3	12.3	12.3	12.3	12.2	12.2	12.2
Oct	10.6	10.7	10.8	10.9	11.0	11.0	11.1
Nov	9.1	9.3	9.5	9.7	9.8	10.0	10.1
Dec	8.3	8.5	8.8	9.0	9.2	9.4	9.6
	34	32	30	28	26	24	
Jan	10.0	10.2	10.3	10.5	10.6	10.7	
Feb	10.8	10.9	11.0	11.1	11.1	11.2	
Mar	11.8	11.8	11.8	11.8	11.8	11.9	
Apr	12.8	12.8	12.7	12.7	12.6	12.6	
May	13.7	13.6	13.5	13.4	13.2	13.1	
Jun	14.2	14.0	13.9	13.7	13.6	13.4	
Jul	14.0	13.8	13.7	13.5	13.4	13.3	
Aug	13.2	13.3	13.0	13.0	12.9	12.8	
Sep	12.2	12.2	12.2	12.1	12.1	12.1	
Oct	11.2	11.2	11.3	11.3	11.4	11.4	
Nov	10.2	10.4	10.5	10.6	10.7	10.9	
Dec	9.8	10.0	10.1	10.3	10.4	10.6	

Table 9. Mean Daylight Hours (Mills et al., 1985).

Land Use	Suspended Solids	BOD	Total Nitrogen	Total Phosphorus
		(kg/ha-day)		
Impervious Surfaces				
Single Family Residential				
Low density (units/ha < 0.5)	2.5	0.15	0.045	0.0045
Medium density (units/ha >= 0.5)	6.2	0.22	0.090	0.0112
Townhouses & Apartments	6.2	0.22	0.090	0.0112
High Rise Residential	3.9	0.71	0.056	0.0067
Institutional	2.8	0.39	0.056	0.0067
Industrial	2.8	0.71	0.101	0.0112
Suburban Shopping Center	2.8	0.71	0.056	0.0067
Central Business District	2.8	0.85	0.101	0.0112
Pervious Surfaces				
Single Family Residential				
Low density (units/ha < 0.5)	1.3	0.08	0.012	0.0016
Medium density (units/ha >=0.5)	1.1	0.15	0.022	0.0039
Townhouses & Apartments	2.2	0.29	0.045	0.0078
High Rise Residential	0.8	0.08	0.012	0.0019
Institutional	0.8	0.08	0.012	0.0019
Industrial	0.8	0.08	0.012	0.0019
Suburban Shopping Center	0.8	0.08	0.012	0.0019
Central Business District	0.8	0.08	0.012	0.0019

Table 10. Contaminant Accumulation Rates for Northern Virginia Urban Areas (Kuo, et al., 1988).

Contaminant	Residential	Mixed	Commercial	Open/ Nonurban
		(mg/*l*)		
BOD	10.0	7.8	9.3	-
COD	73.0	65.0	57.0	40.0
TSS	101.0	67.0	69.0	70.0
Pb	0.144	0.114	0.104	0.03
Cu	0.033	0.027	0.029	-
Zn	0.135	0.154	0.226	0.195
TKN	1.9	1.29	1.18	0.965
NO_3,NO_2-N	0.736	0.558	0.572	0.543
Total P	0.383	0.263	0.201	0.121
Soluble P	0.143	0.056	0.080	0.026

Table 11. Median Event Mean Concentrations in Urban Runoff Measured in National Urban Runoff Program (U.S. Environmental Protection Agency, 1983, as cited in Stahre & Urbonas, 1990).

Contaminant	Residential	Mixed	Commercial	Open/Nonurban
Nitrogen[a/]	0.28	0.30	0.33	0.36
Phosphorus	0.37	0.21	0.40	0.21

[a/] Ratio of NO_3,NO_2-N to (TKN + NO_3,NO_2-N)

Table 12. Ratio of Dissolved to Total Nutrient Median Event Mean Concentration from National Urban Runoff Program.

APPENDIX C
INPUT & OUTPUT DATA FILE LISTINGS

The first listings in this appendix are the sequential data input files **RUNQUAL.DAT** and **WEATHER.DAT** used in the Example. The weather file is arranged by months (January - December, in this application) with the first entry for each month being the number of days in the month, and subsequent entries being temperature (°C) and precipitation (cm) for each day. Only a partial listing of **WEATHER.DAT** is given.

The remaining listings are text files for the input data (**RUNQUAL.TXT**) and yearly and monthly simulation results (**YRLOADS.TXT** and **MONLOADS.TXT**) for the detention basin application of the Example. Only the first 3 years of the **MONLOADS.TXT** file are given. The summary file **SUMLOADS.TXT** was given previously as Table 5 in the main body of the report.

RUNQUAL.DAT

```
3
"Jan",9.3,0
"Feb",10.4,0
"Mar",11.7,0
"Apr",13.1,0
"May",14.3,1
"June",15,1
"July",14.6,1
"Aug",13.6,1
"Sept",12.3,1
"Oct",10.9,1
"Nov",9.7,0
"Dec",9,0
"Residential",35,.4,92,74
"Industrial",10,.7,98,79
"Shop Center",25,.9,98,79
2
"Nitrogen"
"Phosphorus"
.09 .022 .28
.0112 .0039 .37
.101 .012 .3
.0112 .0019 .21
.056 .012 .33
.0067 .0019 .4
```

WEATHER.DAT

```
31
-13,0
-12,0
-8,.2
-7,.1
-8,.1
-9,0
-10,.1
-14,0
-16,.1
-11,.1
-8,0
-9,.3
-6,.1
-11,.3
-14,0
-5,0
1,.6
-7,.6
-14,0
-16,.1
-16,.3
-16,0
-13,.1
-13,0
-4,.1
0,.5
-2,.1
2,.2
5,0
-5,.1
-5,0
28
3,0
6,.2
-5,.6
-18,0
-5,.1
1,0
1,0
0,0
1,0
.
.
.
.
```

RUNQUAL.TXT

RUNQUAL DATA

LAND USE	AREA(ha)	IMPER. FRACT.	CURVE NO IMPERV.	PERV.
Residential	35.	0.40	92.0	74.0
Industrial	10.	0.70	98.0	79.0
Shop Center	25.	0.90	98.0	79.0

MONTH	DAY HRS	GROW. SEASON
Jan	9.3	0
Feb	10.4	0
Mar	11.7	0
Apr	13.1	0
May	14.3	1
June	15	1
July	14.6	1
Aug	13.6	1
Sept	12.3	1
Oct	10.9	1
Nov	9.7	0
Dec	9	0

SITE LAND USE	Nitrogen (kg/ha-day) IMPERV.	PERV.	DISSOLVED FRACTION	Phosphorus (kg/ha-day) IMPERV.	PERV.	DISSOLVED FRACTION
Residential	0.09000	0.02200	0.280	0.01120	0.00390	0.370
Industrial	0.10100	0.01200	0.300	0.01120	0.00190	0.210
Shop Center	0.05600	0.01200	0.330	0.00670	0.00190	0.400

YRLOADS.TXT

70 ha Example - Large Wet Pond
Yearly Water Pollution Loads
Retention of 0 cm runoff Filter width (m) = 0
Detention basin volume (m^3) = 50000 Surface area (m^2) = 20000
Dead storage (m^3) = 30000 Days to drain = 10 Month cleaned = 7
Outlet Coefficient = 0.0088

YEAR	PRECIP (cm)	RUNOFF (cm)	DIS.Nitro (kg)	TOT.Nitro (kg)	DIS.Phosp (kg)	TOT.Phosp (kg)
1	107.4	33.6	109.6	121.5	14.8	16.2
2	81.1	27.8	117.5	140.4	16.0	18.6
3	110.3	42.5	169.4	182.9	23.1	24.6
4	99.4	29.9	135.8	145.5	18.4	19.5
5	106.3	37.0	148.3	247.1	20.1	31.4
6	100.4	33.6	141.4	165.4	19.2	21.9
7	105.2	39.4	136.0	155.1	18.7	20.9
8	129.5	60.1	152.8	218.2	21.5	29.0
9	84.1	28.9	101.9	125.5	13.9	16.7
10	108.9	41.3	133.8	206.4	18.5	26.8

MONLOADS.TXT (Years 1-3, only)

```
70 ha Example - Large Wet Pond   YEAR 1
Monthly Water Pollution Loads
Retention of  0  cm runoff  Filter width (m) =  0
Detention basin volume (m^3) =  50000   Surface area (m^2) =  20000
Dead storage (m^3) =  30000 Days to drain =  10   Month cleaned =  7
Outlet Coefficient =  0.0088

        PRECIP     RUNOFF      DIS.Nitrog  TOT.Nitrog   DIS.Phosph TOT.Phosph
--------------(cm)-------+-------------(kg)--------------------------------
Jan        4.1       1.8            3.0         3.0          0.4         0.4
Feb        5.7       1.7            4.4         4.4          0.6         0.6
Mar        3.8       2.8           10.8        10.8          1.5         1.5
Apr        6.4       1.8            8.9         8.9          1.2         1.2
May        9.6       1.7            9.6         9.6          1.3         1.3
June       7.7       1.6            9.9         9.9          1.3         1.3
July       7.4       1.3            1.7         1.7          0.2         0.2
Aug       15.7       4.0            8.8        20.8          1.2         2.6
Sept      12.3       6.0           15.4        15.4          2.1         2.1
Oct       14.2       1.8            6.6         6.6          0.9         0.9
Nov       12.4       7.7           24.6        24.6          3.4         3.4
Dec        8.1       1.5            6.0         6.0          0.8         0.8
---------------------------------------------------------------------------
YEAR     107.4     33.6           109.6       121.5         14.8        16.2

SOURCE        AREA    RUNOFF   DIS.Nitrog  TOT.Nitrog   DIS.Phosph TOT.Phosph
--------------(ha)-----(cm)-------------(kg)--------------------------------
Residential     35.    12.0       40.4       144.4          6.9        18.6
Industrial      10.    44.7       39.1       130.4          3.0        14.5
Shop Center     25.    55.7       76.3       231.1         11.1        27.7
----------------------------------------------------------------------------
TOTAL FROM SITE                  109.6       121.5         14.8        16.2
```

70 ha Example - Large Wet Pond YEAR 2
Monthly Water Pollution Loads
Retention of 0 cm runoff Filter width (m) = 0
Detention basin volume (m^3) = 50000 Surface area (m^2) = 20000
Dead storage (m^3) = 30000 Days to drain = 10 Month cleaned = 7
Outlet Coefficient = 0.0088

	PRECIP	RUNOFF	DIS.Nitrog	TOT.Nitrog	DIS.Phosph	TOT.Phosph
	(cm)		(kg)			
Jan	3.5	2.4	11.5	11.5	1.6	1.6
Feb	6.6	4.7	21.3	21.3	3.0	3.0
Mar	4.9	4.1	15.2	15.2	2.1	2.1
Apr	3.3	0.3	1.5	1.5	0.2	0.2
May	4.9	0.4	2.4	2.4	0.3	0.3
June	13.2	2.6	14.5	37.4	1.9	4.6
July	12.5	5.8	16.7	16.7	2.3	2.3
Aug	6.4	1.4	4.1	4.1	0.6	0.6
Sept	7.9	1.6	6.4	6.4	0.8	0.8
Oct	3.6	0.2	1.0	1.0	0.1	0.1
Nov	6.7	1.2	6.5	6.5	0.8	0.8
Dec	7.6	3.1	16.3	16.3	2.2	2.2
YEAR	81.1	27.8	117.5	140.4	16.0	18.6

SOURCE	AREA	RUNOFF	DIS.Nitrog	TOT.Nitrog	DIS.Phosph	TOT.Phosph
	(ha)	(cm)	(kg)			
Residential	35.	11.2	38.0	135.7	6.5	17.7
Industrial	10.	37.0	34.4	114.8	2.7	12.8
Shop Center	25.	45.7	67.0	203.1	9.7	24.4
TOTAL FROM SITE			117.5	140.4	16.0	18.6

70 ha Example - Large Wet Pond   YEAR 3
Monthly Water Pollution Loads
Retention of 0 cm runoff Filter width (m) = 0
Detention basin volume (m^3) = 50000   Surface area (m^2) = 20000
Dead storage (m^3) = 30000   Days to drain = 10   Month cleaned = 7
Outlet Coefficient = 0.0088

	PRECIP (cm)	RUNOFF (cm)	DIS.Nitrog (kg)	TOT.Nitrog (kg)	DIS.Phosph (kg)	TOT.Phosph (kg)
Jan	4.0	3.2	17.0	17.0	2.3	2.3
Feb	9.4	3.7	17.4	30.9	2.4	4.0
Mar	6.9	7.1	22.8	22.8	3.2	3.2
Apr	9.0	3.8	15.8	15.8	2.2	2.2
May	15.4	3.9	15.6	15.6	2.1	2.1
June	14.8	4.6	17.5	17.5	2.4	2.4
July	4.4	1.7	4.6	4.6	0.6	0.6
Aug	7.7	1.1	2.4	2.4	0.3	0.3
Sept	9.8	1.6	6.0	6.0	0.8	0.8
Oct	9.3	2.9	11.9	11.9	1.6	1.6
Nov	12.2	4.9	20.6	20.6	2.8	2.8
Dec	7.4	3.9	17.8	17.8	2.4	2.4
YEAR	110.3	42.5	169.4	182.9	23.1	24.6

SOURCE	AREA (ha)	RUNOFF (cm)	DIS.Nitrog (kg)	TOT.Nitrog (kg)	DIS.Phosph (kg)	TOT.Phosph (kg)
Residential	35.	16.3	53.4	190.6	9.1	24.7
Industrial	10.	55.9	44.5	148.4	3.5	16.5
Shop Center	25.	69.4	86.6	262.5	12.6	31.5
TOTAL FROM SITE			169.4	182.9	23.1	24.6

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