DESIGN CALCULATIONS FOR WET DETENTION PONDS

prepared for

St. Paul Water Utility
and
Vadnais Lake Area Water Management Organization

by

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1. INTRODUCTION

This document is intended to assist engineers and planners in sizing wet detention ponds for reducing water quality impacts of urban runoff. The design criteria described below have been derived from the EPA's Nationwide Urban Runoff Program (NURP) and adopted by the Vadnais Lake Area Water Management Organization (VLAWMO) for application to future urban developments in the Vadnais Lake watershed. Based upon NURP and other monitoring studies, ponds designed according to these guidelines should have pollutant removal efficiencies similar to those shown in Figure 1. The calculations focus on sizing and shaping the permanent pool, which is necessary for water quality control purposes. Hydraulic design of outlet structures and sizing of temporary flood storage to limit peak discharge rate are not discussed.

Figure 1

TYPICAL WET DETENTION POND PERFORMANCE

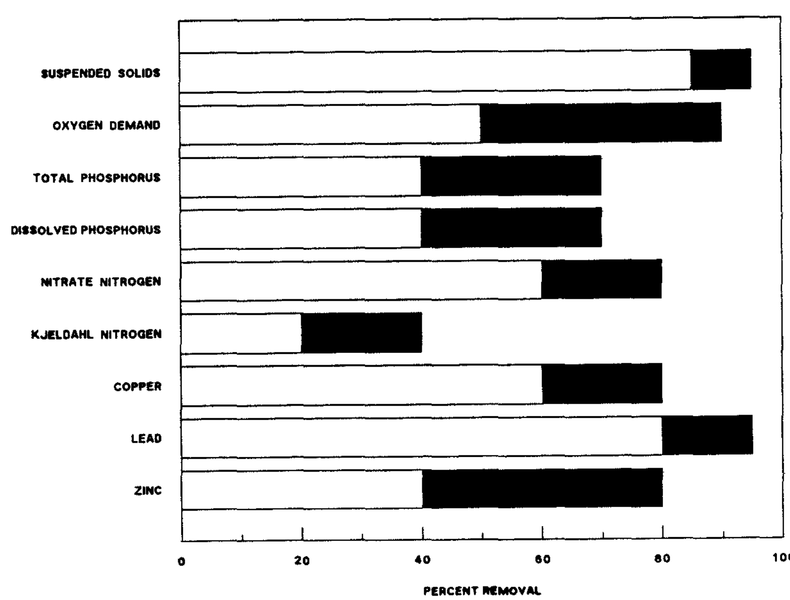
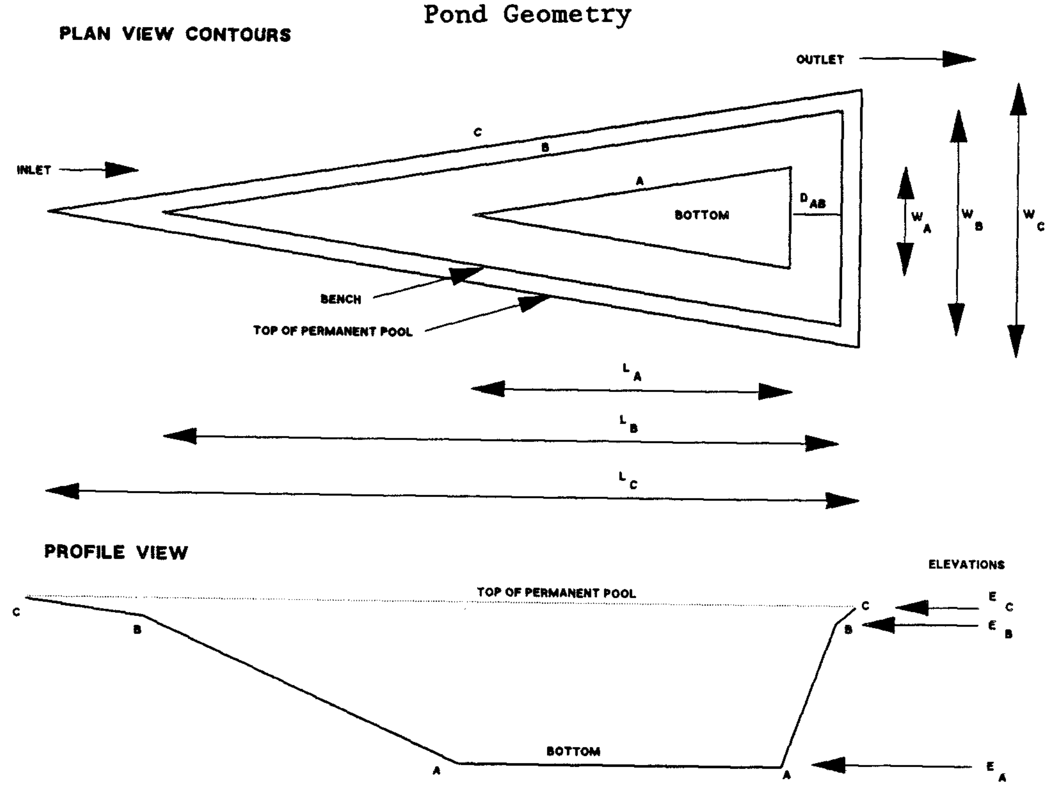


Figure 2
Pond Geometry



As illustrated in Figure 2, a triangular basin shape is preferred for wet detention ponds. Three elevation contours are defined:

C = top of permanent pool
B = aquatic bench (for safety and aquatic plant habitat)
A = pond bottom

Three congruent triangles are used to define contour shapes.

Pond dimensions calculated according to the following procedure are intended to provide approximate guidelines for final designs, which should also consider local topographic features. Generally, adherence to calculated shapes will be more feasible for ponds which are excavated, as compared with those which are created in natural depressions. Permanent pool volume is the most important design parameter influencing pollutant removal efficiency. Accordingly, volume constraints should apply to all designs.

For design purposes, the elevation of the lowest surface outlet determines the top of the permanent pool (C contour). Actual water levels may occasionally drop below this level because of infiltration and/or evaporation between storm events, particularly in areas with permeable soils. Such behavior would tend to improve overall pollutant removal efficiency, but may pose aesthetic problems.

The following design criteria are included in the VLAWMO Watershed Management Plan. They are listed in order of importance with respect to impact on expected pollutant removal efficiency:

(1) The permanent pool is important because it provides storage and treatment of runoff during and between storm events. Permanent pool volume should be greater than or equal to the volume of runoff from a 2.5-inch rainstorm under full projected watershed development. This value has been derived from design criteria developed under NURP, with a 25% increase in volume to allow for roughly 25 years of sediment accumulation. In the summer, St. Paul climate, this sizing rule provides a mean hydraulic residence time of about 15 days.

(2) To promote settling and provide space for sediment accumulation, the mean depth of the permanent pool (volume/surface area) should be greater than or equal to 4 feet. This constraint may be infeasible for small ponds (< approx. 3 acre-feet in volume, see below), where mean depths of 3-4 feet may be used.

(3) To prevent development of thermal stratification, loss of oxygen, and nutrient recycling from bottom sediments, the maximum depth of the permanent pool should be less than or equal to 10 feet.

(4) To promote plug flow behavior, the ratio of maximum length to maximum width (L_c/W_c) should be greater than or equal to 3. Expected performance is less sensitive to the length/width ratio than to volume or depth. This constraint may be infeasible for some site plans or for small ponds. In such situations, baffles may be installed to isolate the inflow area from the remainder of the pond. A desirable alternative (for all pond sizes) is to construct two or more separate ponds in series with a total volume equal to that specified above (1) (see Section 10).

(5) For safety purposes and to provide suitable habitat for rooted aquatic plants, the bench width (minimum distance between the B and C contours) should be at least 10 feet and the bench slope should not be steeper than 10:1 (horizontal:vertical).

(6) To provide stability, the side slopes (between A and B contours) should not be steeper than 3 feet horizontal to 1 foot vertical. Shallower slopes may be appropriate, depending upon soil engineering properties. Shallower slopes are more feasible for larger ponds.

Other design features include provision of a shoreline buffer zone and access for maintenance. Calculations for sizing and shaping ponds according to these rules are described below.

2. CALCULATE PERMANENT POOL VOLUME

The permanent pool volume is calculated to equal expected runoff from a 2.5-inch rainstorm under full watershed development. The calculation is based upon the SCS soil cover complex method; impervious and pervious portions of the watershed are treated separately. The impervious portion should include all impervious surfaces draining to stormwater conveyors (storm sewers, street gutters, and stream channels). Rooftops draining to lawns or other pervious surfaces should be included in the pervious portion of the watershed with a curve number of 98. Table 1 lists recommended curve numbers for typical soil types and cover complexes.

Specify Watershed Characteristics:

A_w = total watershed area (acres)

F_i = impervious fraction

CN = area-weighted-mean SCS curve number for pervious portion of watershed (based upon soil hydrologic group and coil cover, from SCS manuals)

P = design storm size = 2.5 inches (VLAWMO/NURP criterion)

Calculate maximum soil retention = S (inches):

$$S = 1000/CN - 10$$

Calculate runoff for design storm = R (inches):

$$R = P F_i + \frac{(P - .2 S)^2}{P + .8 S} (1 - F_i)$$

Calculate permanent pool volume = V (acre-feet)

$$V = R A_w / 12$$

Graphic solutions of equations for R and V are illustrated in Figures 3 and 4, respectively.

Table 1
Curve Numbers for Various Soil Types and Cover

Hydrologic Condition	Hydrologic Soil Group A	B	C	D	
Grassy Areas, Lawns, Parks, Golf Courses, Cemeteries, Etc.					
Good	39	61	74	80	(thick vegetative cover)
Fair	49	69	79	84	
Poor	68	79	86	89	(thin vegetative cover)
Woodlands					
Good	25	55	70	77	(thick stand, mulch)
Fair	36	60	73	79	
Poor	45	66	77	83	(thin stand, little mulch)
Impervious Surfaces, Streets, Rooftops, Driveways					
All	98	98	98	98	

Figure 3
Calculation of Runoff from Design Storm

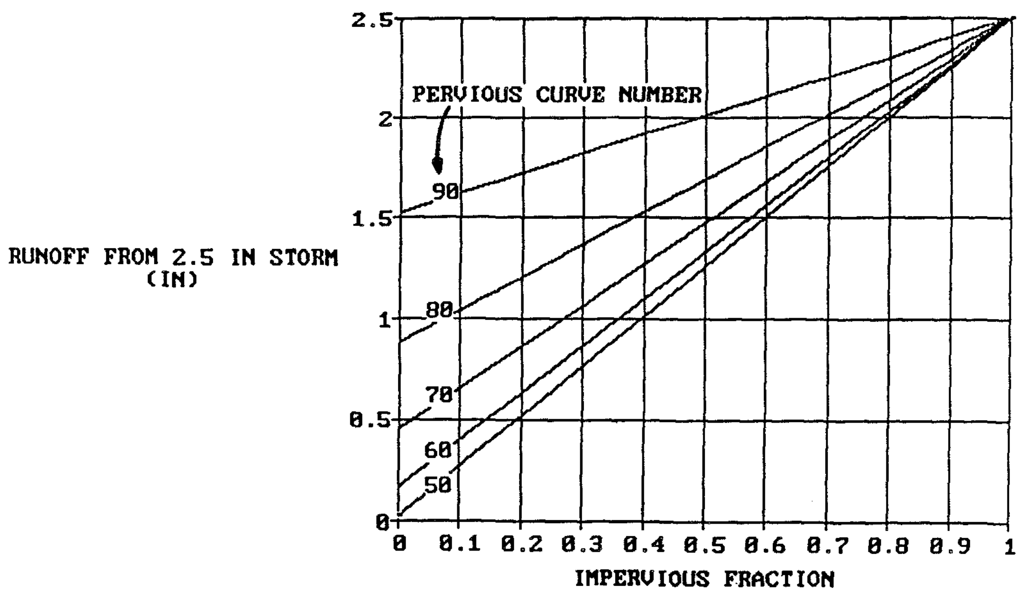
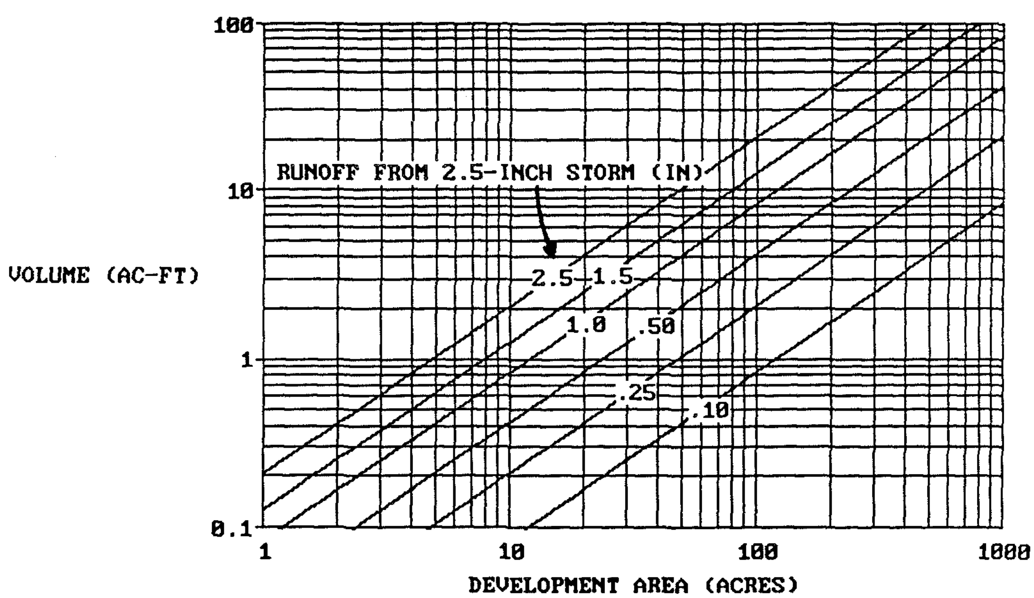


Figure 4
Calculation of Permanent Pool Volume



3. SPECIFY POND DESIGN CONSTRAINTS

For reasons stated above, the following constraints apply to pond dimensions (see Figure 2):

perm. pool volume	= V	calc. above, (acre-ft)
mean depth	= Z	>=4 ft
maximum depth	= Z_{max}	<= 10 ft
bench slope	= S_{bc}	>= 10 ft/ft
bench width	= D_{bc}	>= 10 ft
side slope	= S_{ab}	>= 3 ft/ft
surface elevation	= E_c	= 0 ft (arbitrary ref.)

Analytical solutions for pond dimensions satisfying the above constraints are cumbersome. Given these constraints and the geometry shown in Figure 2, all pond dimensions are fixed once a length/width ratio (K) and top length (L_c) have been selected. Accordingly, a trial-and-error procedure is employed to find K and L_c values which satisfy total volume and depth requirements. Three methods for performing these calculations are presented (manual, tabular, computer spreadsheet). The algorithm employed in each of these methods is described below.

4. SELECT TRIAL DIMENSIONS

Trial values for length/width ratio and top length are selected by the designer:

length/width ratio	= K	>=3
top length	= L_c	

Initial values of L_c and K may be estimated from Figure 5. For a given pool volume (Y-axis) and mean depth (dashed lines), Figure 5 permits estimation of top length (L_c, X-axis) and length/width ratio (K, dashed lines) for ponds adhering to above constraints (Section 3.). Site topographic features can also be considered in selecting initial values for L_c and K. As indicated in Figure 5, length/width ratios less than 3 and/or mean depths less than 4 feet will be necessary for small ponds (approx. less than 3 acre-feet total volume).

5. CALCULATE POND DIMENSIONS

Once trial K and L_c values have been selected, other pond dimensions can be calculated as described below:

C contour

width $= W_c = L_c/K$

area $= A_c = W_c\ L_c\ /\ 2$

B contour

** length $= L_b = L_c - D_{bc}\ [\ 1 + (1 + 4\ K^2)^{.5}\ ]$

width $= W_b = L_b/K$

area $= A_b = W_b\ L_b\ /\ 2$

elevation $= E_b = E_c - D_{bc}/S_{bc}$

A contour

slope length $= D_{ab} = (Z_{max} - E_c + E_b)\ S_{ab}$

** length $= L_a = L_b - D_{ab}\ [\ 1 + (1 + 4\ K^2)^{.5}\ ]$

width $= W_a = L_a/K$

area $= A_a = W_a\ L_a\ /\ 2$

elevation $= E_a = E_c - Z_{max}$

Volumes

BC volume $= V_{bc} = (E_c - E_b)[A_c+A_b+(A_b*A_c)^{.5}]\ /\ 3$

AB volume $= V_{ab} = (E_b - E_a)[A_b+A_a+(A_b*A_a)^{.5}]\ /\ 3$

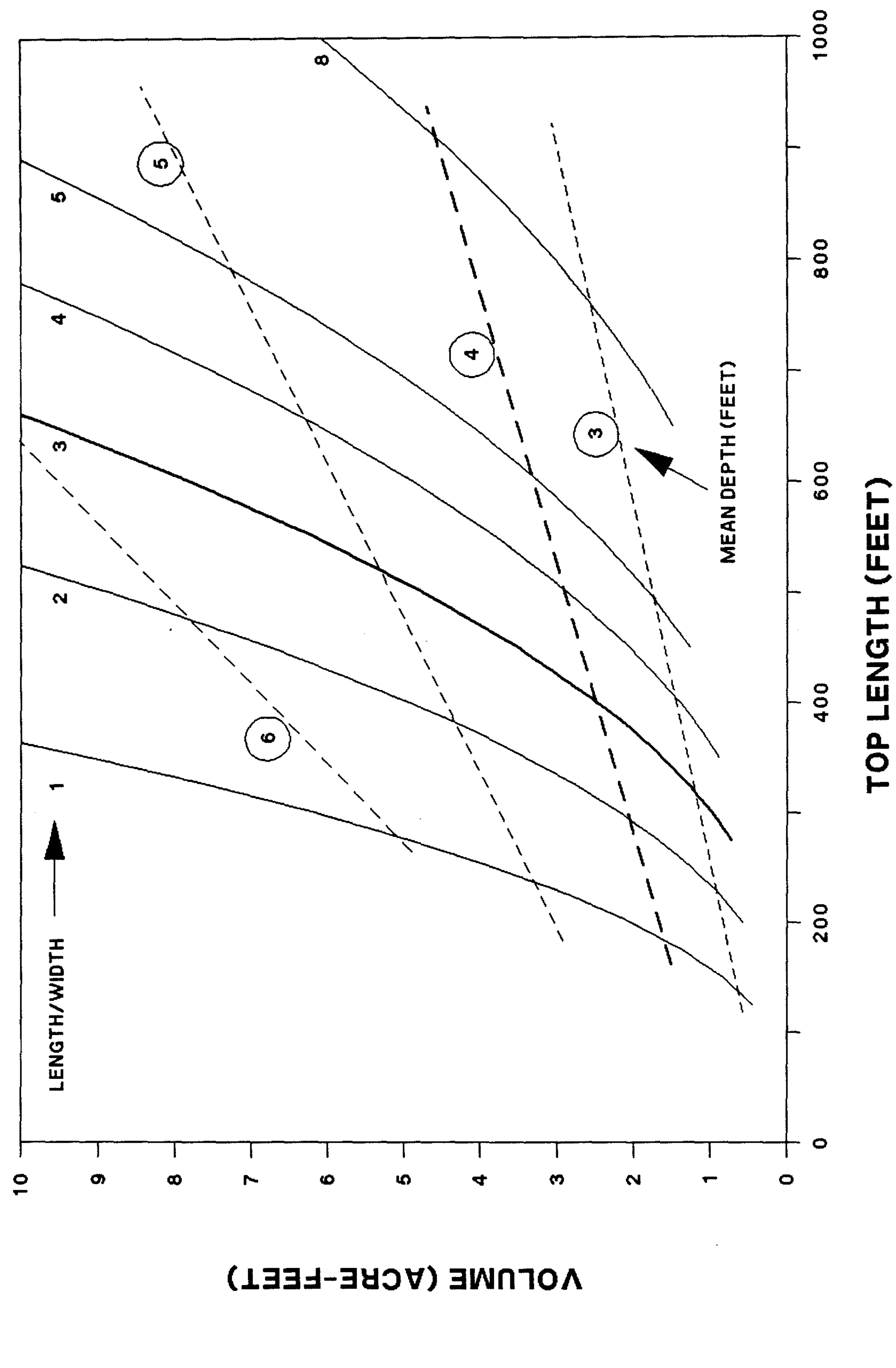
total $= V_{ac} = V_{ab} + V_{bc}$ (ft^3)

volume $= V_* = V_{ac}/43560$ (acre-ft)

mean depth $= Z_* = V_{ac}/A_c$ (ft)

** If calculated L_a or L_b values are less than zero, design constraints are infeasible. Return to Step 4 and adjust K downward and/or L_c upward. Maximum depth (Z_{max}) may also be reduced.

Figure 5
Numeric Solution
Volume, Top Length, Length/Width, and Mean Depth



6. TEST RESULTS

The final step is to determine whether the total volume and mean depth calculated above satisfy the design requirements.

If (V_* approx. = V) and (Z_* >= Z) quit. Otherwise, return to Step 4 and adjust trial values of L_c and/or K. To increase pool volume, adjust L_c upward and/or K downward.

Strict adherence to the triangular geometry will be rarely feasible in final engineering designs. Final contours should be checked for adherence to volume and mean depth constraints. The equations used above for calculating volume increments (V_{ab},V_{bc}) are also applicable to irregular contours. The required areas (A_a, A_b, A_c) can be estimated from contour maps by planimetry.

7. LOOKUP TABLE

To facilitate applications, solutions to the above equations are listed in Table 2 for the design constraints listed in Section 3. The table lists contour dimensions, mean depths, pool volumes, and pool surface areas for ponds with length/width ratios (K) between 1 and 8 and top lengths (L_c) between 125 and 1200 feet. To apply this table, first calculate the required permanent pool volume (V), based upon watershed characteristics. Search the table for a pond which provides this volume, preferably at a high length/width ratio (>3) and mean depth >= 4 feet. Interpolate between rows to find dimensions which correspond to desired design volume.

8. SPREADSHEET

A LOTUS-123 (Version 2.0) spreadsheet (PONDSIZ.WK1) has been written to implement the above calculations (Table 3). The user inputs 10 watershed variables and pond design constraints. The program calculates contour dimensions, areas, and pond volume. Graphic output illustrating contour shapes is also generated (Figure 6). The spreadsheet greatly facilitates the iterative calculations required to meet design volume requirements but adjusting top length and/or length/width ratio.

A floppy disk containing the spreadsheet has been provided. Table 4 lists the equations involved (minus graphics), for those interested in entering the equations into a different spreadsheet program.

Table 2
Lookup Table of Alternative Pond Designs

DESIGN CONSTRAINTS:

Maximum Depth =	Ec - Ea	= 10	feet
Bench Width =	Dbc	= 10	feet
Bench Slope =	Dbc/(Ec-Eb)	= 10	ft/ft
Side Slope =	Dab/(Eb-Ea)	= 3	ft/ft
Slope Width =	Dab	= 27	feet

ELEVATIONS:

Top of Pool	= Ec	=	0 feet
Bench Contour	= Eb	=	-1 feet
Bottom Contour	= Ea	=	-10 feet

Contour Dimensions (Feet): Top of Pool Lc	Top of Pool Wc	Bench Lb	Bench Wb	Bottom La	Bottom Wa	Mean Depth Feet	Volume Ac-Ft	Area Acres
LENGTH/WIDTH = 1								
125	125	93	93	5	5	2.5	0.5	0.18
150	150	118	118	30	30	3.2	0.8	0.26
175	175	143	143	55	55	3.9	1.4	0.35
200	200	168	168	80	80	4.4	2.0	0.46
225	225	193	193	105	105	4.9	2.9	0.58
250	250	218	218	130	130	5.3	3.8	0.72
275	275	243	243	155	155	5.7	4.9	0.87
300	300	268	268	180	180	6.0	6.2	1.03
325	325	293	293	205	205	6.2	7.6	1.21
350	350	318	318	230	230	6.5	9.1	1.41
375	375	343	343	255	255	6.7	10.8	1.61
400	400	368	368	280	280	6.9	12.6	1.84
450	450	418	418	330	330	7.2	16.7	2.32
500	500	468	468	380	380	7.4	21.3	2.87
550	550	518	518	430	430	7.6	26.5	3.47
600	600	568	568	480	480	7.8	32.3	4.13
650	650	618	618	530	530	8.0	38.7	4.85
700	700	668	668	580	580	8.1	45.7	5.62
750	750	718	718	630	630	8.2	53.2	6.46
800	800	768	768	680	680	8.3	61.3	7.35
850	850	818	818	730	730	8.4	69.9	8.29
900	900	868	868	780	780	8.5	79.2	9.30
1000	1000	968	968	880	880	8.7	99.4	11.48
LENGTH/WIDTH = 2								
200	100	149	74	10	5	2.6	0.6	0.23
225	113	174	87	35	18	3.0	0.9	0.29
250	125	199	99	60	30	3.5	1.2	0.36
275	138	224	112	85	43	3.9	1.7	0.43
300	150	249	124	110	55	4.2	2.2	0.52
325	163	274	137	135	68	4.6	2.8	0.61
350	175	299	149	160	80	4.9	3.4	0.70
375	188	324	162	185	93	5.1	4.1	0.81
400	200	349	174	210	105	5.4	4.9	0.92
450	225	399	199	260	130	5.8	6.7	1.16
500	250	449	224	310	155	6.1	8.8	1.43
550	275	499	249	360	180	6.4	11.2	1.74
600	300	549	274	410	205	6.7	13.9	2.07
650	325	599	299	460	230	6.9	16.8	2.42
700	350	649	324	510	255	7.1	20.0	2.81
750	375	699	349	560	280	7.3	23.6	3.23
800	400	749	374	610	305	7.5	27.4	3.67
850	425	799	399	660	330	7.6	31.5	4.15
900	450	849	424	710	355	7.7	35.9	4.65
1000	500	949	474	810	405	7.9	45.5	5.74
LENGTH/WIDTH = 3								
275	92	204	68	13	4	2.5	0.7	0.29
300	100	229	76	38	13	2.9	1.0	0.34
325	108	254	85	63	21	3.2	1.3	0.40
350	117	279	93	88	29	3.5	1.6	0.47
375	125	304	101	113	38	3.8	2.0	0.54
400	133	329	110	138	46	4.1	2.5	0.61
450	150	379	126	188	63	4.6	3.5	0.77
500	167	429	143	238	79	5.0	4.8	0.96
550	183	479	160	288	96	5.3	6.2	1.16
600	200	529	176	338	113	5.7	7.8	1.38
650	217	579	193	388	129	5.9	9.6	1.62
700	233	629	210	438	146	6.2	11.6	1.87
750	250	679	226	488	163	6.4	13.8	2.15
800	267	729	243	538	179	6.6	16.2	2.45
850	283	779	260	588	196	6.8	18.7	2.76
900	300	829	276	638	213	6.9	21.5	3.10
1000	333	929	310	738	246	7.2	27.6	3.83
1100	367	1029	343	838	279	7.4	34.5	4.63
1200	400	1129	376	938	313	7.6	42.1	5.51
LENGTH/WIDTH = 4								
350	88	259	65	15	4	2.5	0.9	0.35
375	94	284	71	40	10	2.8	1.1	0.40
400	100	309	77	65	16	3.0	1.4	0.46
450	113	359	90	115	29	3.5	2.1	0.58
500	125	409	102	165	41	4.0	2.9	0.72
550	138	459	115	215	54	4.4	3.8	0.87
600	150	509	127	265	66	4.7	4.9	1.03
650	163	559	140	315	79	5.0	6.1	1.21
700	175	609	152	365	91	5.3	7.5	1.41
750	188	659	165	415	104	5.6	9.0	1.61
800	200	709	177	465	116	5.8	10.7	1.84
850	213	759	190	515	129	6.0	12.5	2.07
900	225	809	202	565	141	6.2	14.4	2.32
1000	250	909	227	665	166	6.5	18.7	2.87
1100	275	1009	252	765	191	6.8	23.6	3.47
1200	300	1109	277	865	216	7.0	29.1	4.13
LENGTH/WIDTH = 5								
450	90	340	68	41	8	2.7	1.3	0.46
500	100	390	78	91	18	3.1	1.8	0.57
550	110	440	88	141	28	3.5	2.5	0.69
600	120	490	98	191	38	3.9	3.2	0.83
650	130	540	108	241	48	4.2	4.1	0.97
700	140	590	118	291	58	4.5	5.1	1.12
750	150	640	128	341	68	4.8	6.2	1.29
800	160	690	138	391	78	5.1	7.5	1.47
850	170	740	148	441	88	5.3	8.8	1.66
900	180	790	158	491	98	5.5	10.3	1.86
1000	200	890	178	591	118	5.9	13.5	2.30
1100	220	990	198	691	138	6.2	17.3	2.78
1200	240	1090	218	791	158	6.5	21.4	3.31
LENGTH/WIDTH = 6								
500	83	370	62	17	3	2.5	1.2	0.48
550	92	420	70	67	11	2.9	1.7	0.58
600	100	470	78	117	20	3.2	2.2	0.69
650	108	520	87	167	28	3.5	2.9	0.81
700	117	570	95	217	36	3.9	3.6	0.94
750	125	620	103	267	45	4.1	4.5	1.08
800	133	670	112	317	53	4.4	5.4	1.22
850	142	720	120	367	61	4.7	6.4	1.38
900	150	770	128	417	70	4.9	7.6	1.55
1000	167	870	145	517	86	5.3	10.1	1.91
1100	183	970	162	617	103	5.6	13.1	2.31
1200	200	1070	178	717	120	5.9	16.4	2.75
LENGTH/WIDTH = 8								
650	81	480	60	20	2	2.5	1.5	0.61
700	88	530	66	70	9	2.8	1.9	0.70
750	94	580	72	120	15	3.0	2.4	0.81
800	100	630	79	170	21	3.3	3.0	0.92
850	106	680	85	220	27	3.6	3.7	1.04
900	113	730	91	270	34	3.8	4.4	1.16
1000	125	830	104	370	46	4.2	6.1	1.43
1100	138	930	116	470	59	4.6	8.0	1.74
1200	150	1030	129	570	71	5.0	10.3	2.07

Table 3
PONDSIZ.WK1 Spreadsheet

USER INPUT AREA

DETENTION POND DESIGN	W. WALKER		PRESS 'ALT-G' FOR GRAPHS
INPUT VARIABLE:	UNITS	INPUTS	NOTES
Watershed Area	acres	30	
Pervious Curve Number	-	80	(scs soil cover complex)
Impervious Fraction	-	0.2	
Design Storm	inches	2.5	(= 2.5 in, VLAWMO criterion)
Maximum Depth	feet	10	<= 10 ft
Bench Width bc	feet	10	>= 10 ft
Bench Slope bc	ft/ft	10	>= 10 ft horiz / ft vertical
Side Slope ab	ft/ft	3	>= 3 ft horiz / ft vertical
Length/Width Ratio	-	3	>= 3
Top Length c	feet	430	(adjust to achieve volume)
OUTPUT VARIABLE:	UNITS	VALUE	
Target Volume	acre-ft	3.027777	(= design storm runoff volume)
Design Volume	acre-ft	3.094183	(should be >= target volume)
Design Mean Depth	feet	4.373692	(should be >= 4 feet)
Maximum Retention	inches	2.5	
Design Storm Runoff	inches	1.211111	
Permanent Pool Volume	acre-ft	3.027777	
TOP CONTOUR - c			
Length c	feet	430	
Width c	feet	143.3333	
Area c	feet^2	30816.66	
BENCH COUNTOUR - b			
Depth b	feet	1	
Length b	feet	359.1723	
Width b	feet	119.7241	
Elevation b	feet	-1	
Area b	feet^2	21500.79	
BOTTOM CONTOUR - a			
Elevation a	feet	-10	
Slope Length ab	feet	27	
Length a	feet	167.9377	
Width a	feet	55.97926	
Area a	feet^2	4700.516	
Volume bc	feet^3	26019.38	
Volume ab	feet^3	108763.2	
Volume ac	feet^3	134782.6	
Pond Volume	acre-ft	3.094183	
Mean Depth	feet	4.373692	
Pond Area	acres	0.707453	

Figure 6
Sample Graphic Output from PONDSIZ.WK1 Spreadsheet

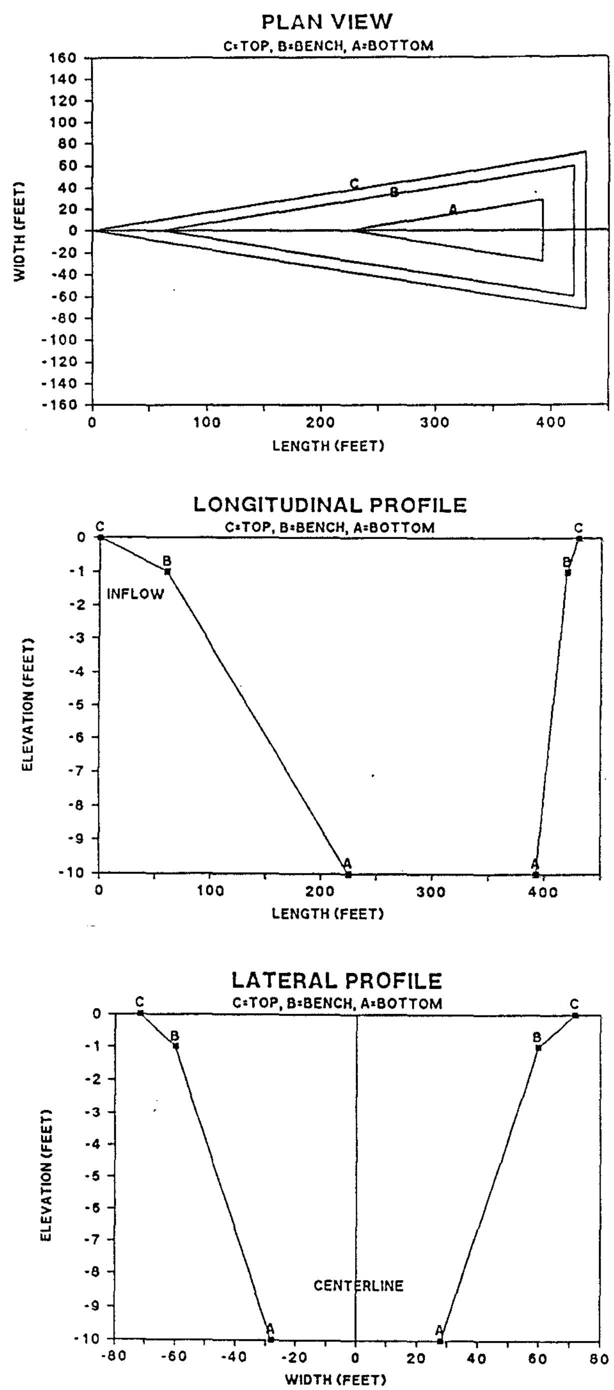


Table 4
PONDSIZ.WK1 Spreadsheet Equations

ROW	INPUT VARIABLE:	UNITS	INPUTS
3	Watershed Area	acres	30
4	Pervious Curve Number	-	80
5	Impervious Fraction	-	0.2
6	Design Storm	inches	2.5
7			
8	Maximum Depth	feet	10
9	Bench Width bc	feet	10
10	Bench Slope bc	ft/ft	10
11	Side Slope ab	ft/ft	3
12			
13	Length/Width Ratio	-	3
14	Top Length c	feet	430
15			
16	OUTPUT VARIABLE:	UNITS	VALUE
17	Target Volume	acre-ft	+D24
18	Design Volume	acre-ft	@IF(D33>0#AND#D41>0,D49,0)
19			
20	Design Mean Depth	feet	@IF(D33>0#AND#D41>0,D50,0)
21			
22	Maximum Retention	inches	1000/D4-10
23	Design Storm Runoff	inches	+D6*D5+(1-D5)*(D6-0.2*D22)^2/(D6+0.8*D22)
24	Permanent Pool Volume	acre-ft	+D23*D3/12
25			
26	TOP CONTOUR - c		
27	Length c	feet	+D14
28	Width c	feet	+D27/D13
29	Area c	feet^2	+D27*D28/2
30			
31	BENCH COUNTOUR - b		
32	Depth b	feet	+D9/D10
33	Length b	feet	+D27-D9*(1+@SQRT(1+4*D13^2))
34	Width b	feet	+D33/D13
35	Elevation b	feet	-D32
36	Area b	feet^2	+D33*D34/2
37			
38	BOTTOM CONTOUR - a		
39	Elevation a	feet	-D8
40	Slope Length ab	feet	(D35-D39)*D11
41	Length a	feet	+D33-D40*(1+@SQRT(1+4*D13^2))
42	Width a	feet	+D41/D13
43	Area a	feet^2	+D41*D42/2
44			
45	Volume bc	feet^3	+D32*(D36+D29+@SQRT(D36*D29))/3
46	Volume ab	feet^3	(D35-D39)*(D43+D36+@SQRT(D43*D36))/3
47	Volume ac	feet^3	+D45+D46
48			
49	Pond Volume	acre-ft	+D47/43560
50	Mean Depth	feet	+D47/D29
51	Pond Area	acres	+D49/D50

9. SAMPLE CALCULATION

The following illustrates pond design calculations for an urban development with the following characteristics:

Subwatershed	Area (acres)
1 Lawns - Soil Group C - Fair Hydrol. Cond.	17.7
2 Lawns - Soil Group B - Fair Hydrol. Cond.	3.3
3 Rooftops draining to lawns	3.0
4 Other Impervious Surfaces	6.0
Total	30.0

Calculate mean curve number for pervious subwatersheds:

Subwatershed	Area	Table 1 Curve No.	Product
1	17.7	79	1398
2	3.3	69	228
3	3.0	98	294
Total	24.0		1920

Weighted-mean curve number = 1920 / 24 = 80

Maximum retention = S = 1000/80 - 10 = 2.5 inches

Impervious Watershed Fraction = F_i = 6/30 = .2

Design Storm Runoff = R (inches) =

$$= 2.5 \times .2 + (2.5 - .2 \times 2.5)^2 \times (1 - .2)/(2.5 + .8 \times 2.5)$$

$$= .50 + .71 = 1.21 \text{ inches}$$ (see Fig. 3)

Pool Volume = V (ac-ft) = 1.21 x 30 /12 = 3.02 ac-ft (Fig. 4)

Assume design constraints listed in Section 3.

For length/width ratio = 3.0, top length of 430 feet should provide required volume and mean depth > 4 feet (Fig. 5).

Calculate remaining pond dimensions (Section 5):

$$W_c = 430 / 3 = 143.3 \text{ ft}$$

$$A_c = 143.3 \times 430/2 = 30{,}817 \text{ ft}^2$$

$$L_b = 430 - 10 \times (1 + (1 + 4 \times 3^2)^{.5}) = 359.2 \text{ ft}$$

$$W_b = 359.2 / 3 = 119.7 \text{ ft}$$

$$A_b = 119.7 \times 359.2 / 2 = 21{,}504 \text{ ft}^2$$

$$E_b = 0 - 10/10 = -1 \text{ ft}$$

D_{ab} = (10 - 0 + 1) x 3 = 27 ft

L_a = 359.2 - 27 x (1 + (1 + 4 x 3^2)$^{.5}$) = 167.9 ft

W_a = 167.9 / 3 = 56.0 ft

A_a = 56 x 167.9 / 2 = 4701 ft^2

E_a = 0 - 10 = -10 ft

Calculate volume increments:

V_{bc} = (0 + 1)x(30817 + 21504 + (30817 x 21504)$^{.5}$) / 3

= 26,020 ft^3

V_{ab} = (-1 + 10)x(21504 + 4701 + (21504 x 4701)$^{.5}$) / 3

= 108,778 ft^3

V_{ac} = 26,020 + 108,778 = 134,789 ft^3

V_* = 3.09 acre-ft

Z_* = 134,789 / 30,817 = 4.37 ft

Test results (Section 6):

Design Volume = 3.09 ac-ft > Target Volume = 3.02 ac-ft

Design Mean Depth = 4.37 ft > 4 ft

Design requirements are met.

Spreadsheet outputs for this case are shown in Table 3 and Figure 6.

A length/width ratio of 4 and top length of 510 feet would also satisfy design requirements.

10. STAGED DESIGNS

Detention ponds and wetlands can be placed in series, as illustrated in Figure 7. Staged designs offer a number of advantages over single cell designs, in terms of pollutant removal efficiency, longevity, and ease of maintenance. Basic elements include the following:

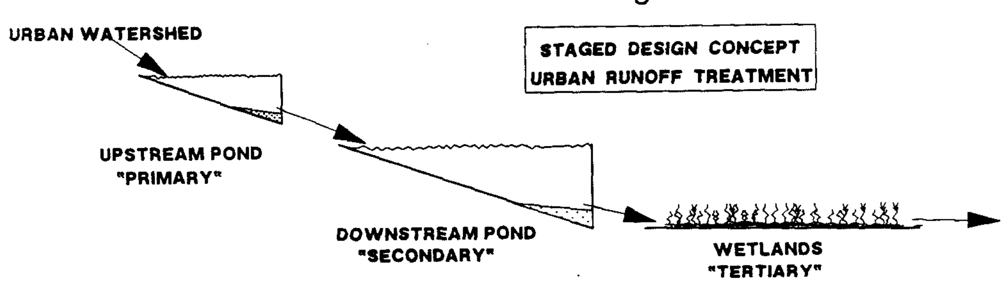
Upstream Pond: "Primary Treatment".
Coarse particulate materials (usually most of total sediment volume) are removed. This protects the downstream ponds and wetlands from erosion and rapid sediment accumulation. First pond can be dredged with minimal disruption to biological communities in downstream ponds and wetlands.

Downstream Pond: "Secondary Treatment".
Medium and some fine particulate materials are removed via sedimentation. A pond-like biological community is established to assist in removal of soluble pollutants. This pond provides most of the permanent pool volume and hydraulic residence time required for runoff treatment.

Wetland Cell(s): "Tertiary Treatment".
For final "polishing", flow passes through a natural or artificial wetland at controlled rates. Filtration, uptake, adsorption, and decay mechanisms operate in wetland organic soils, plant communities, and attached growths. Maintenance of sheet flow (vs. channelized flow) through the wetland is important to promote water contact with vegetation and soils. The wetland is protected from sediment accumulation and erosion by upstream detention ponds.

To provide adequate residence time, the total permanent pool volumes in the upstream and downstream ponds can be based upon the sizing rule discussed in Section 2. Roughly two thirds of the total volume should be contained in the downstream pond. To prevent back-mixing, permanent pool and flood pool elevations should step down from one pond to the next. In a staged design, performance is very insensitive to pond shape (length/width ratio), provided that inlets and outlets are not adjacent. For typical runoff characteristics, model results (Walker,1986), indicate that a two-cell design (upstream and downstream pond) increases average phosphorus removal efficiency from about 60 to 70%, as compared with a one-cell design with the same total permanent pool volume. Additional phosphorus removal would expected in downstream wetland cells, if also included in a staged design.

Figure 7



11. REFERENCES

The following publications provide additional useful information on detention basin design and performance:

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