APPENDICES

ORDINANCE APPENDIX A

STANDARD STORMWATER FACILITIES MAINTENANCE AND MONITORING AGREEMENT

THIS AGREEMENT, made and entered into this ____________ day of ________________, 20__, by and between ________________________________, (hereinafter the "Landowner"), and ______[Municipal Name]____, __ [County Name]__ County, Pennsylvania, (hereinafter "Municipality");

WITNESSETH

WHEREAS, the Landowner is the owner of certain real property as recorded by deed in the land records of [County Name]___County, Pennsylvania, Deed Book ___________ at Page ______, (hereinafter "Property").

WHEREAS, the Landowner is proceeding to build and develop the Property; and

WHEREAS, the Subdivision/Land Management Plan (hereinafter "Plan") for the ________________________________ Subdivision which is expressly made a part hereof, as approved or to be approved by the Municipality, provides for detention or retention of stormwater within the confines of the Property; and

WHEREAS, the Municipality and the Landowner, his successors and assigns agree that the health, safety, and welfare of the residents of the Municipality require that on-site stormwater management facilities be constructed and maintained on the Property: and

WHEREAS, the Municipality requires, through the implementation of the ________________________________ Watershed Stormwater Management Plan, that stormwater management facilities as shown on the Plan be constructed and adequately maintained by the Landowner, his successors and assigns.

NOW, THEREFORE, in consideration of the foregoing premises, the mutual covenants contained herein, and the following terms and conditions, the parties hereto agree as follows:

1. The on-site stormwater management facilities shall be constructed by the Landowner, his successors and assigns, in accordance with the terms, conditions and specifications identified in the Plan.

2. The Landowner, his successors and assigns, shall maintain the stormwater management facilities in good working condition, acceptable to the Municipality so that they are performing their design functions

3. The Landowner, his successors and assigns, hereby grants permission to the Municipality, his authorized agents and employees, upon presentation of proper identification, to enter upon the Property at reasonable times, and to inspect the stormwater management facilities whenever the Municipality deems necessary. The purpose of the

inspection is to assure safe and proper functioning of the facilities. The inspection shall cover the entire facilities, berms, outlet structures, pond areas, access roads, etc. When inspections are conducted, the Municipality shall give the Landowner, his successors and assigns, copies of the inspection report with findings and evaluations. At a minimum, maintenance inspections shall be performed in accordance with the following schedule:

- Annually for the first 5 years after the construction of the stormwater facilities,
- Once every 2 years thereafter, or
- During or immediately upon the cessation of a 100 year or greater precipitation event.

4. All reasonable costs for said inspections shall be born by the Landowner and payable to the Municipality.

5. The owner shall convey to the municipality easements and/or rights-of-way to assure access for periodic inspections by the municipality and maintenance, if required.

6. In the event the Landowner, his successors and assigns, fails to maintain the stormwater management facilities in good working condition acceptable to the Municipality, the Municipality may enter upon the Property and take such necessary and prudent action to maintain said stormwater management facilities and to charge the costs of the maintenance and/or repairs to the Landowner, his successors and assigns. This provision shall not be construed as to allow the Municipality to erect any structure of a permanent nature on the land of the Landowner, outside of any easement belonging to the Municipality. It is expressly understood and agreed that the Municipality is under no obligation to maintain or repair said facilities, and in no event shall this Agreement be construed to impose any such obligation on the Municipality.

7. The Landowner, his successors and assigns, will perform maintenance in accordance with the maintenance schedule for the stormwater management facilities including sediment removal as outlined on the approved schedule and/or Subdivision/Land Development Plan.

8. In the event the Municipality, pursuant to this Agreement, performs work of any nature, or expends any funds in performance of said work for labor, use of equipment, supplies, materials, and the like on account of the Landowner's or his successors' and assigns' failure to perform such work, the Landowner, his successors and assigns, shall reimburse the Municipality upon demand, within 30 days of receipt of invoice thereof, for all costs incurred by the Municipality hereunder. If not paid within said 30-day period, the Municipality may enter a lien against the property in the amount of such costs, or may proceed to recover his costs through proceedings in equity or at law as authorized under the provisions of the ______________________________ Code.

9. The Landowner, his successors and assigns, shall indemnify the Municipality and his agents and employees against any and all damages, accidents, casualties, occurrences or claims which might arise or be asserted against the Municipality for the construction, presence, existence or maintenance of the stormwater management facilities by the Landowner, his successors and assigns.

10. In the event a claim is asserted against the Municipality, his agents or employees, the Municipality shall promptly notify the Landowner, his successors and assigns, and they shall defend, at their own expense, any suit based on such claim. If any judgment or claims against the Municipality, his agents or employees shall be allowed, the Landowner, his successors and assigns shall pay all costs and expenses in connection therewith.

11. In the advent of an emergency or the occurrence of special or unusual circumstances or situations, the Municipality may enter the Property, if the Landowner is not immediately available, without notification or identification, to inspect and perform necessary maintenance and repairs, if needed, when the health, safety or welfare of the citizens is at jeopardy. However, the Municipality shall notify the landowner of any inspection, maintenance, or repair undertaken within 5 days of the activity. The Landowner shall reimburse the Municipality for his costs.

This Agreement shall be recorded among the land records of

___[County Name]___ County, Pennsylvania and shall constitute a covenant running with the Property and/or equitable servitude, and shall be binding on the Landowner, his administrators, executors, assigns, heirs and any other successors in interests, in perpetuity.

ATTEST:

WITNESS the following signatures and seals:

(SEAL) For the Municipality:

____

(SEAL) For the Landowner:

____

ATTEST:

______________________ (City, Borough, Township)

County of ___[County Name]___________, Pennsylvania

I, ______________________________, a Notary Public in and for the County and State aforesaid, whose commission expires on the _________ day of _______________, 20__, do hereby certify that ______________________________ whose name(s) is/are signed to the foregoing Agreement bearing date of the _________ day of _______________, 20__, has acknowledged the same before me in my said County and State.

GIVEN UNDER MY HAND THIS ___________ day of _______________, 19___.

____

NOTARY PUBLIC

(SEAL)

ORDINANCE APPENDIX B

STORMWATER MANAGEMENT DESIGN CRITERIA

TABLE B-1
DESIGN STORM RAINFALL AMOUNT
Source: "Field Manual of Pennsylvania Department of Transportation"
STORM INTENSITY-DURATION-FREQUENCY CHARTS
P D T - I D F May 1986.

FIGURE B-1
SCS TYPE II RAINFALL DISTRIBUTION
S-CURVE

FIGURE B-2
PENNDOT DELINEATED REGIONS
Source: "Field Manual of Pennsylvania Department of Transportation"
STORM INTENSITY-DURATION-FREQUENCY CHARTS
P D T - I D F May 1986.

FIGURE B-3
REGION 4 PENNDOT STORM INTENSITY-DURATION-FREQUENCY CURVE
Source: "Field Manual of Pennsylvania Department of Transportation"
STORM INTENSITY-DURATION-FREQUENCY CHARTS
P D T - I D F May 1986.

FIGURE B-4
REGION 5 PENNDOT STORM INTENSITY-DURATION-FREQUENCY CURVE
Source: "Field Manual of Pennsylvania Department of Transportation"
STORM INTENSITY-DURATION-FREQUENCY CHARTS
P D T - I D F May 1986.

TABLE B-2
RUNOFF CURVE NUMBERS
Source: NRCS (SCS) TR-55

TABLE B-3
RATIONAL RUNOFF COEFFICIENTS

TABLE B-4
MANNING ROUGHNESS COEFFICIENTS

TABLE B-5
24-HOUR STORM VALUES REPRESENTING 90% OF ANNUAL RAINFALL

TABLE B-1
DESIGN STORM RAINFALL AMOUNT (INCHES)

The design storm rainfall amount chosen for design should be obtained from the PennDOT region in which the site is located according to Figure B-2.

Source: "Field Manual of Pennsylvania Department of Transportation"
STORM INTENSITY-DURATION-FREQUENCY CHARTS
P D T - I D F May 1986.

Region 4

	Precipitation Depth (in)						
Duration	1 Yr	2 Yr	5 Yr	10 Yr	25 Yr	50 Yr	100 Yr
5 min	0.30	0.35	0.41	0.45	0.50	0.55	0.61
15 min	0.58	0.68	0.80	0.93	1.03	1.13	1.25
1 hr	1.01	1.22	1.48	1.70	1.91	2.16	2.41
2 hrs	1.24	1.50	1.84	2.14	2.46	2.80	3.18
3 hrs	1.38	1.71	2.10	2.43	2.82	3.24	3.69
6 hrs	1.68	2.04	2.52	3.06	3.60	4.14	4.74
12 hrs	2.04	2.52	3.00	3.84	4.56	5.16	6.00
24 hrs	2.40	2.88	3.60	4.56	5.76	6.48	7.44

Region 5

	Precipitation Depth (in)						
Duration	1 Yr	2 Yr	5 Yr	10 Yr	25 Yr	50 Yr	100 Yr
5 min	0.33	0.38	0.45	0.50	0.56	0.63	0.68
15 min	0.64	0.75	0.90	1.00	1.15	1.35	1.50
1 hr	1.10	1.35	1.61	1.85	2.15	2.60	2.98
2 hr	1.34	1.66	2.00	2.34	2.70	3.26	3.76
3 hr	1.50	1.86	2.28	2.67	3.09	3.69	4.29
6 hr	1.86	2.28	2.82	3.36	3.90	4.62	5.40
12 hr	2.28	2.76	3.48	4.20	4.92	5.76	6.72
24 hr	2.64	3.36	4.32	5.28	6.24	7.20	8.40

FIGURE B-1
NRCS (SCS) TYPE II RAINFALL DISTRIBUTION - S CURVE

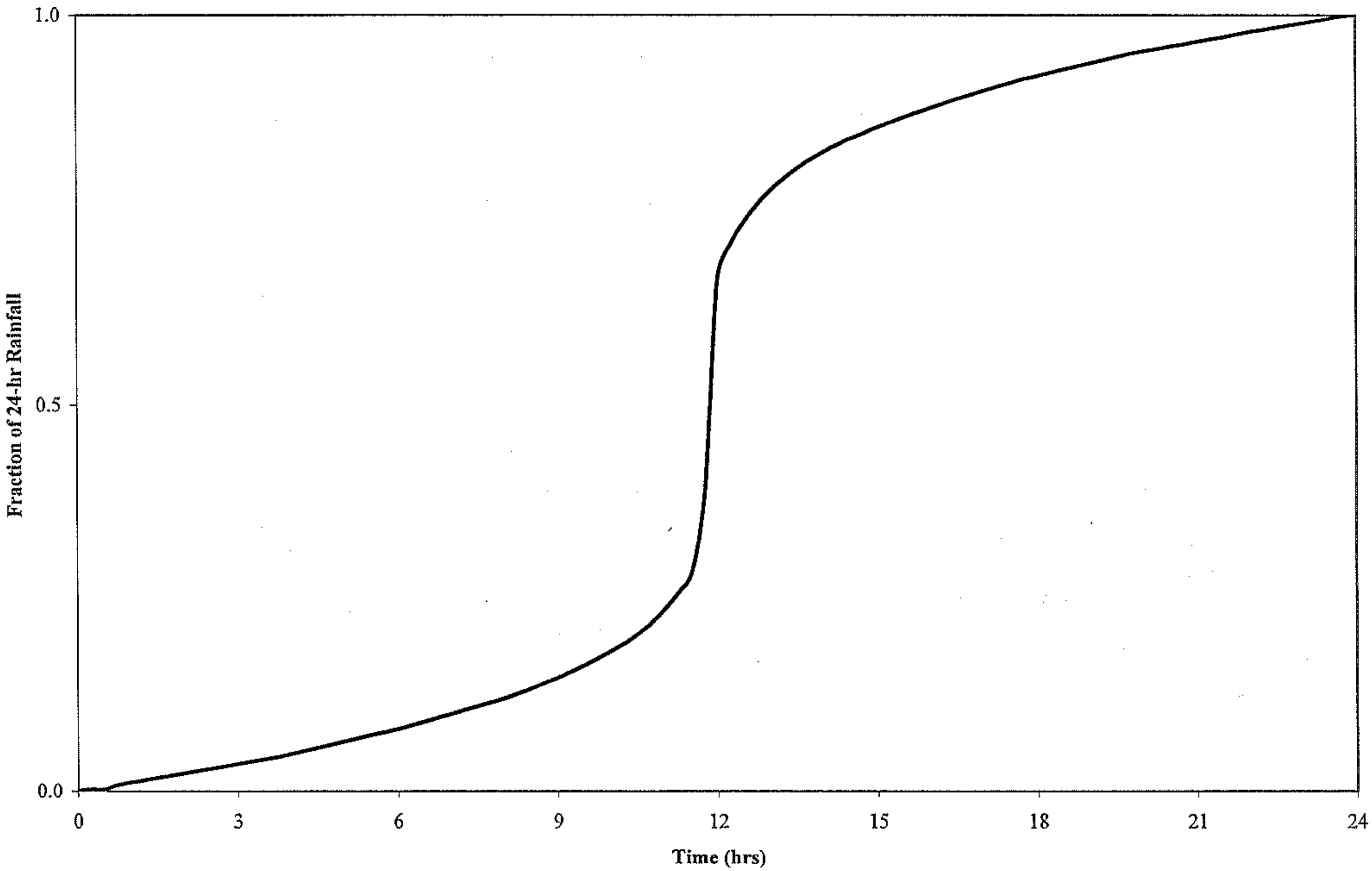


FIGURE B-2
PENNDOT DELINEATED REGIONS

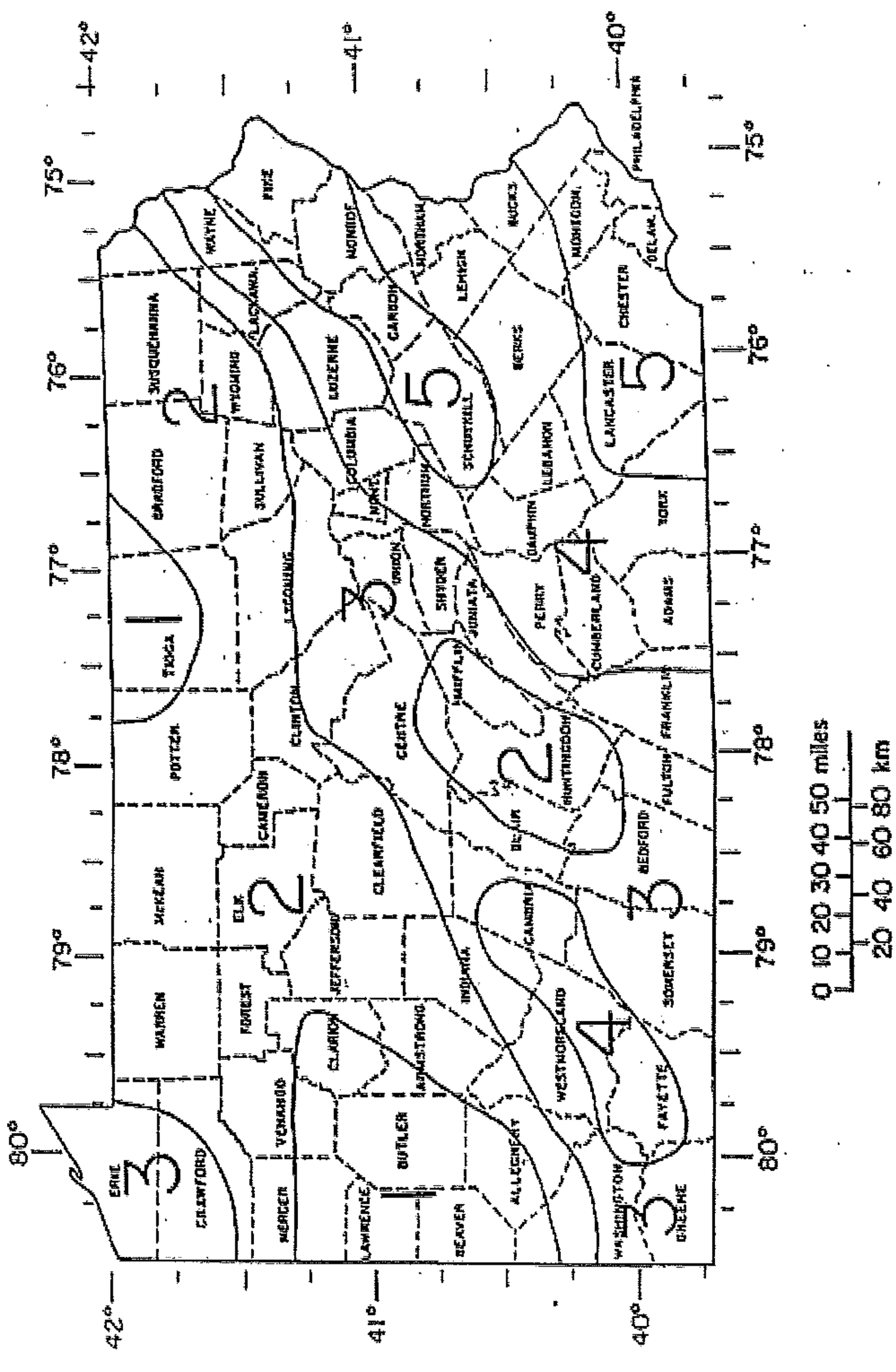
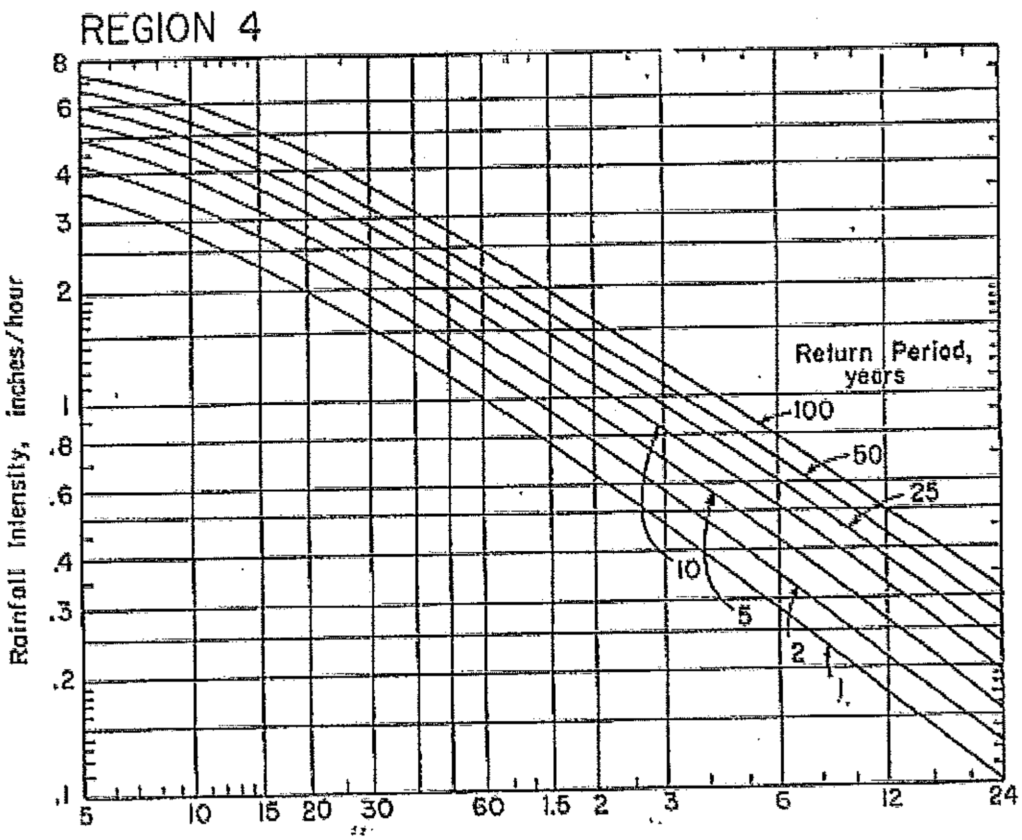


FIGURE B-3
PENNDOT STORM INTENSITY-DURATION-FREQUENCY CURVE



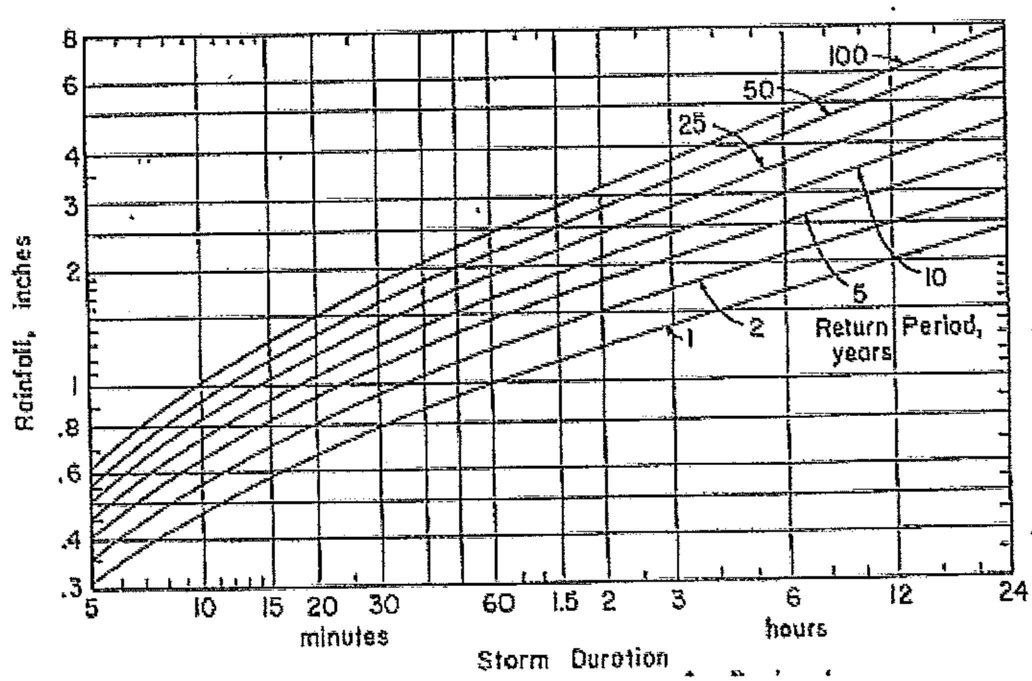


FIGURE B-4
PENNDOT STORM INTENSITY-DURATION-FREQUENCY CURVE

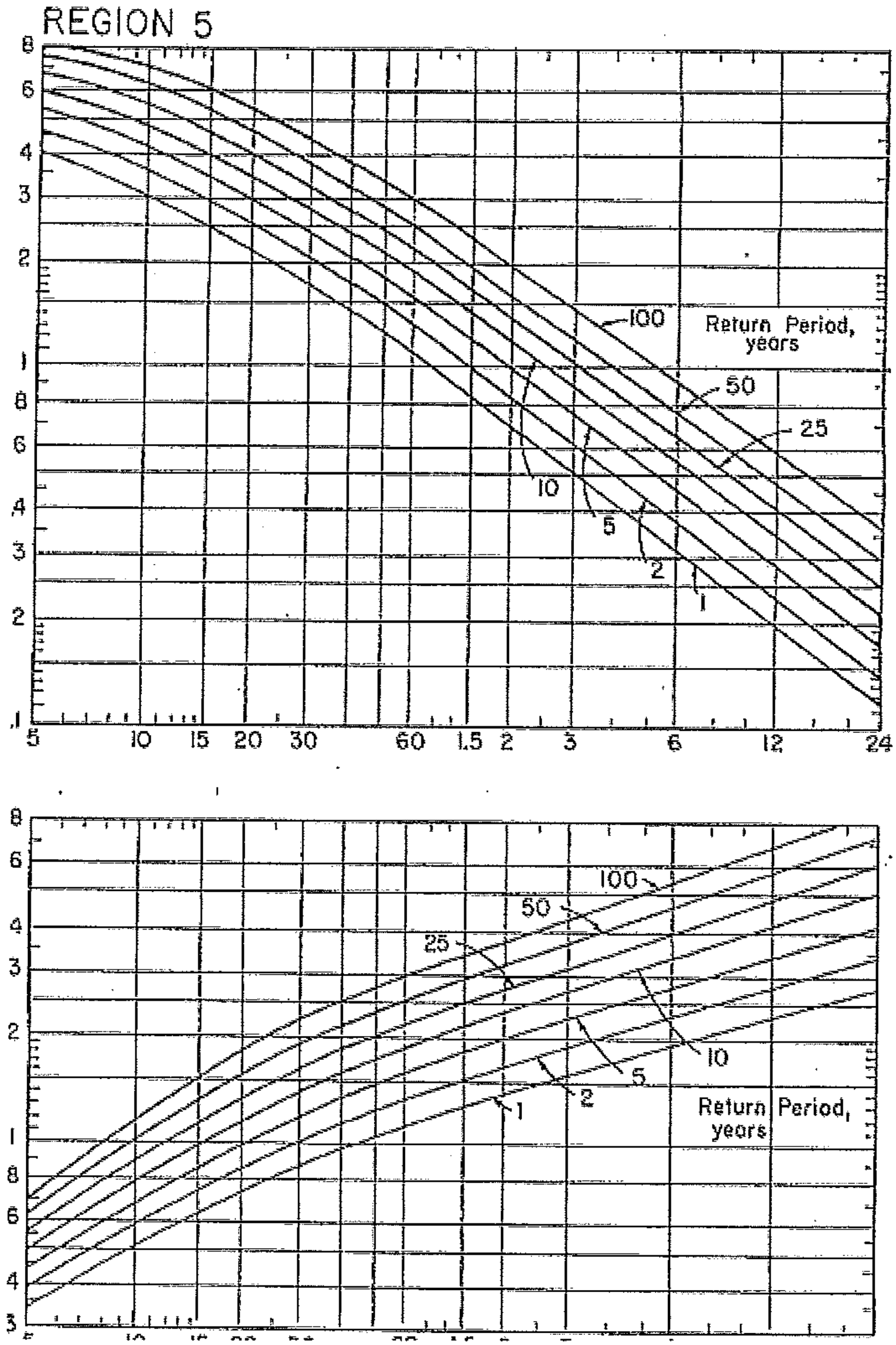


TABLE B-2
Runoff Curve Numbers
(From NRCS (SCS) TR-55)

LAND USE DESCRIPTION	Hydrologic Condition	HYDROLOGIC SOIL GROUP A	B	C	D
Open Space					
Grass cover < 50%	Poor	68	79	86	89
Grass cover 50% to 75%	Fair	49	69	79	84
Grass cover > 75%	Good	39	61	74	80
Meadow		30	58	71	78
Agricultural					
Pasture, grassland, or range – Continuous forage for grazing	Poor	68	79	86	89
Pasture, grassland, or range – Continuous forage for grazing.	Fair	49	69	79	84
Pasture, grassland, or range – Continuous forage for grazing	Good	39	61	74	80
Brush-brush-weed-grass mixture with brush the major element.	Poor	48	67	77	83
Brush-brush-weed-grass mixture with brush the major element.	Fair	35	56	70	77
Brush-brush-weed-grass mixture with brush the major element.	Good	30	48	65	73
Fallow Bare soil	-------	77	86	91	94
Crop residue cover (CR)	Poor	76	85	90	93
	Good	74	83	88	90
Woods – grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Commercial	(85% Impervious)	89	92	94	95
Industrial	(72% Impervious)	81	88	91	93
Institutional	(50% Impervious)	71	82	88	90
Residential districts by average lot size:	% Impervious				
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87

1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Farmstead		59	74	82	86
Smooth Surfaces (Concrete, Asphalt, Gravel or Bare Compacted Soil)		98	98	98	98
Water		98	98	98	98
Mining/Newly Graded Areas (Pervious Areas Only)		77	86	91	94

* Includes Multi-Family Housing unless justified lower density can be provided.

<u>Note</u>: Existing site conditions of bare earth or fallow ground shall be considered as meadow when choosing a CN value.

TABLE B-3
RATIONAL RUNOFF COEFFICIENTS

	HYDROLOGIC SOIL GROUP			
LAND USE DESCRIPTION	A	B	C	D
Cultivated Land : without conservation treatment	.49	.67	.81	.88
: with conservation treatment	.27	.43	.61	.67
Pasture or range land : poor condition	.38	.63	.78	.84
: good condition	---*	.25	.51	.65
Meadow : good condition	---*	---*	.44	.61
Wood or Forest Land : thin stand, poor cover, no mulch	---*	.34	.59	.70
: good cover	---*	---*	.45	.59
Open Spaces, lawns, parks, golf courses, cemeteries				
Good condition : grass cover on 75% or more of the area	---*	.25	.51	.65
Fair condition : grass cover on 50% to 75% of the area	---*	.45	.63	.74
Commercial and business areas (85% impervious)	.84	.90	.93	.96
Industrial districts (72% impervious)	.67	.81	.88	.92
Residential :				
Average lot size — Average % Impervious				
1/8 acre or less — 65	.59	.76	.86	.90
1/4 acre — 38	.25	.49	.67	.78
1/3 acre — 30	---*	.49	.67	.78
1/2 acre — 25	---*	.45	.65	.76
1 acre — 20	---*	.41	.63	.74
Paved parking lots, roofs, driveways, etc.	.99	.99	.99	.99
Streets and roads :				
Paved with curbs and storm sewers	.99	.99	.99	.99
Gravel	.57	.76	.84	.88
Dirt	.49	.69	.80	.84

Notes : Values are based on S.C.S. definitions and are average values.
Values indicated by "---" should be determined by the design engineer based on site characteristics.

Source : New Jersey Department of Transportation, Technical Manual for Stream Encroachment, August, 1984

TABLE B-4

Roughness Coefficients (Manning's "n") For Overland Flow (U.S. Army Corps Of Engineers, HEC-1 Users Manual)

Surface Description	**n**		
Dense Growth	0.4	-	0.5
Pasture	0.3	-	0.4
Lawns	0.2	-	0.3
Bluegrass Sod	0.2	-	0.5
Short Grass Prairie	0.1	-	0.2
Sparse Vegetation	0.05	-	0.13
Bare Clay-Loam Soil (eroded)	0.01	-	0.03
Concrete/Asphalt - very shallow depths (less than 1/4 inch)	0.10	-	0.15
- small depths (1/4 inch to several inches)	0.05	-	0.10

Roughness Coefficients (Manning's "n") For Channel Flow

Reach Description	**n**
Natural stream, clean, straight, no rifts or pools	0.03
Natural stream, clean, winding, some pools or shoals	0.04
Natural stream, winding, pools, shoals, stony with some weeds	0.05
Natural stream, sluggish deep pools and weeds	0.07
Natural stream or swale, very weedy or with timber underbrush	0.10
Concrete pipe, culvert or channel	0.012
Corrugated metal pipe	0.012-0.027(1)
High Density Polyethylene (HDPE) Pipe	
Corrugated	0.021-0.029(2)
Smooth Lined	0.012-0.020(2)

(1) Depending upon type, coating and diameter

(2) Values recommended by the American Concrete Pipe Association, check Manufacturer's recommended value.

TABLE B-5

24-Hour Storm Values Representing 90 % of Annual Rainfall

PennDOT Rainfall Region	P Inches
1	1.13
2	1.48
3	1.60
4	1.95
5	2.04

TABLE B-6
Nonstandard Stormwater Management
Stormwater Credits for Computing Proposed conditions Hydrograph

The developer may, subject to approval of the municipal engineer, use the stormwater credits, described in the following table, in computing proposed conditions hydrograph:

Nonstructural Stormwater Measure	Description
Natural Area Conservation	Conservation of natural areas such as forest, wetlands, or other sensitive areas in a protected easement thereby retaining their existing hydrologic and water quality characteristics.
Disconnection of Rooftop Runoff	Rooftop runoff is disconnected and then directed over a pervious area where it may either infiltrate into the soil or filter over it. This is typically obtained by grading the site to promote overland flow or by providing bioretention on single-family residential lots.
Disconnection of Non-Rooftop Runoff	Disconnect surface impervious cover by directing it to pervious areas where it is either infiltrated or filtered though the soil.
Buffers	Buffers effectively treat stormwater runoff. Effective treatment constitutes capturing runoff from pervious and impervious areas adjacent to the buffer and treating the runoff through overland flow across a grass or forested area.
Grass Channel (Open Section Roads)	Open grass channels are used to reduce the volume of runoff and pollutants during smaller storms.
Environmentally Sensitive Rural Development	Environmental site design techniques are applied to low density or rural residential development.

ORDINANCE APPENDIX C

SAMPLE DRAINAGE PLAN APPLICATION AND FEE SCHEDULE

(To be attached to the "land subdivision plan or development plan review application or "minor land subdivision plan review application")

Application is hereby made for review of the Stormwater Management and Erosion and Sedimentation Control Plan and related data as submitted herewith in accordance with the ______________________________Township Stormwater Management and Earth Disturbance Ordinance.

_________Final Plan _______________Preliminary Plan ________________Sketch Plan

Date of Submission _______________________Submission No.________________________

1. Name of subdivision or development____

2. Name of Applicant _________________________________ Telephone No._____________

   (if corporation, list the corporation's name and the names of two officers of the corporation)
   ____Officer 1
   ____Officer 2

   Address____
   Zip____

   Applicants interest in subdivision or development
   (if other than property owner give owners name and address)

3. Name of property owner _____________________________Telephone No.______________

   Address____
   Zip____

4. Name of engineer or surveyor ________________________Telephone No.______________

   Address____
   Zip____

5. Type of subdivision or development proposed:

____ Single-Family Lots	____ Townhouses	____ Commercial(Multi-Lot)
____ Two Family Lots	____ Garden Apartments	____ Commercial (One-Lot)
____ Multi-Family Lots	____ Mobile-Home Park	____ Industrial (Multi-Lot)
____ Cluster Type Lots	____ Campground	____ Industrial (One-Lot)
____ Planned Residential Development	____ Other (____________________________)	

6. Lineal feet of new road proposed______________________________ L.F.

7. Area of proposed and existing conditions impervious area on entire tract.

   a. Existing (to remain) ____________ S.F. ____________% of Property
   b. Proposed ____________ S.F. ____________% of Property

8. Stormwater

   a. Does the peak rate of runoff from proposed conditions exceed that flow which occurred for existing conditions for the designated design storm?________________

   b. Design storm utilized (on-site conveyance systems) (24 hr.)________________
      No. of Subarea________________________
      Watershed Name______________________

      Explain:____
      ____
      ____

   c. Does the submission and/or district meet the release rate criteria for the applicable subarea?____

   d. Number of subarea(s) from Ordinance Appendix D of the Brodhead and McMichaels Creek Watershed Stormwater Management Plan.__________________

   e. Type of proposed runoff control__________________________________

   f. Does the proposed stormwater control criteria meet the requirement/guidelines of the Stormwater Ordinances?______________________________________

      If not, what variances/waivers are requested?______________________
      ____

      Reasons____

   g. Does the plan meet the requirements of Article iii of the Stormwater Ordinances?_____

      If not, what variances/waivers are requested?______________________

      Reasons Why ____
      ____
      ____

   h. Was TR-55, June 1986 utilized in determining the time of concentration?__________
      ____

   i. What hydrologic method was used in the stormwater computations?____________
      ____

j. Is a hydraulic routing through the stormwater control structure submitted?__________
____

k. Is a construction schedule or staging attached?______________________________

l. Is a recommended maintenance program attached?____________________________

9. Erosion and Sediment Pollution Control (E&S):

a. Has the stormwater management and E&S plan, supporting documentation and narrative been submitted to the ______[County Name]___County Conservation District?______

b. Total area of earth disturbance ____________________________________S.F.

10. Wetlands

a. Have the wetlands been delineated by someone trained in wetland delineation?_________

b. Have the wetland lines been verified by a state or federal permitting authority?______

c. Have the wetland lines been surveyed?_____________________________________

d. Total acreage of wetland within the property _______________________________

e. Total acreage of wetland disturbed_______________________________________

f. Supporting documentation____

11. Filing

a. Has the required fee been submitted?_____________________________________

Amount____

b. Has the proposed schedule of construction inspection to be performed by the Applicant's engineer been submitted?____

c. Name of individual who will be making the inspections________________________

d. General comments about stormwater management at the development____________
____
____

CERTIFICATE OF OWNERSHIP AND ACKNOWLEDGMENT OF APPLICATION:

COMMONWEALTH OF PENNSYLVANIA
COUNTY OF __[County Name]__.

On this the ________ day of ________________, 20_____, before me, the undersigned officer, personally appeared ______________________who being duly sworn, according to law, deposes and says that _________________________________owners of the property described in this application and that the application was made with _________________________ knowledge and/or direction and does hereby agree with the said application and to the submission of the same.

____Property Owner

My Commission Expires____20___________
Notary Public____

THE UNDERSIGNED HEREBY CERTIFIES THAT TO THE BEST OF HIS KNOWLEDGE AND BELIEF THE INFORMATION AND STATEMENTS GIVEN ABOVE ARE TRUE AND CORRECT.

SIGNATURE OF APPLICANT____

//

(Information Below This Line To Be Completed By The Municipality)

____________________________ (Name of) Municipality official submission receipt:

Date complete application received ________________Plan Number________________________

Fees _______________ date fees paid ______________ received by___________________________

Official submission receipt date ____

Received by______________________________

____
Municipality

Drainage Plan
Proposed Schedule Of Fees

Subdivision name________________________ Submittal No.____________________

Owner ________________________________ Date____________________________

Engineer____

1. Filing fee $________

2. Land use
   - 2a. Subdivision, campgrounds, mobile home parks, and multi-family dwelling where the units are located in the same local watershed. $________
   - 2b. Multi-family dwelling where the designated open space is located in a different local watershed from the proposed units. $________
   - 2c. Commercial/industrial. $________

3. Relative amount of earth disturbance
   - 3a. Residential
     - road <500 l.f. $________
     - road 500-2,640 l.f. $________
     - road >2,640 l.f. $________
   - 3b. Commercial/industrial and other
     - impervious area <3,500 s.f. $________
     - impervious area 3,500-43,460 s.f. $________
     - impervious area >43,560 s.f. $________

4. Relative size of project
   - 4a. Total tract area
     - <1 ac $________
     - 1-5 ac $________
     - 5-25 ac
     - 25-100 ac $________
     - 100-200 ac $________
     - >200 ac $________

5. Stormwater control measures
   - 5a. Detention basins & other controls which require a review of hydraulic routings ($ per control). $________
   - 5b. Other control facilities which require storage volume calculations but no hydraulic routings. ($ per control) $________

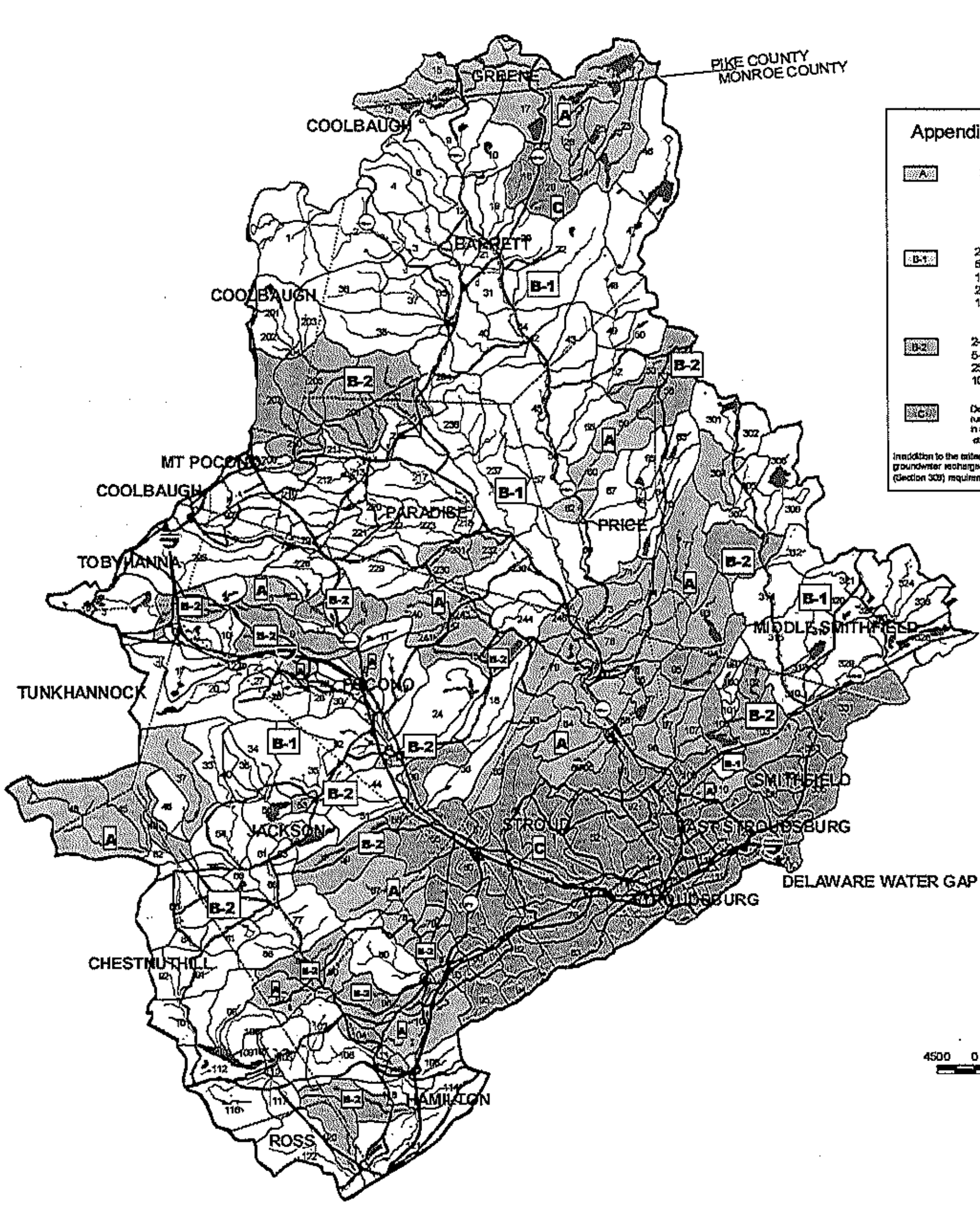
6. Site inspection ($ per inspection) $________

Total $________

All subsequent reviews shall be 1/4 the amount of the initial review fee unless a new application is required as per Section 406 of the stormwater ordinance. A new fee shall be submitted with each revision in accordance with this schedule.

ORDINANCE APPENDIX D

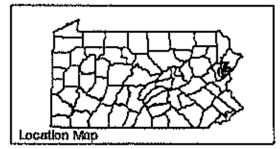
STORMWATER MANAGEMENT DISTRICT WATERSHED MAP



Appendix D-Managment Districts

District	Post Dev Flow	To Pre-Dev Flow
A	2- Year	1- Year
	5- Year	5- Year
	10- Year	10- Year
	25- Year	25- Year
	100- Year	100- Year
B-1	2- Year	1- Year
	5- Year	2- Year
	10- Year	5- Year
	25- Year	10- Year
	100- Year	100- Year
B-2	2- Year	1- Year
	5- Year	2- Year
	25- Year	5- Year
	100- Year	50- Year
C	Detention is not required if the increase in storm water runoff can be conveyed to a stream or watercourse in a safe manner (ordinance sections 303 F, G) otherwise district A requirements apply.	

In addition to the criteria specified above, the water quality (Section 303), groundwater recharge (Section 304), and streambank erosion control (Section 305) requirements shall be implemented.



Management Districts

Brodhead-McMichaels Watershed Monroe County, PA

ACT 167
Stormwater Management
Plan Update
Phase II

Appendix D

Map Legend

- Watershed Boundaries
- Municipal Boundaries
- County Boundaries
- Roads
- Streams
- Railroads
- Lakes

Prepared For:
Monroe County Planning Commission
&
Monroe County Conservation District

Notes:

Portions of these maps were generated from existing data sources as listed below. This existing data was utilized for base mapping purposes and is shown on the maps for spatial reference only. This data did not enter into any computations or affect the reliability of the hydrologic analysis. Borton-Lawson Engineering has found some inaccuracies in some of this data and has corrected the data in locations where these discrepancies were obvious, however, it was not a part of this Act 167 Plan to correct all the base data.

Data Sources:
Roads - PennDOT
Streams, Lakes - PennDOT
Municipal Boundaries - PennDOT

Borton Lawson Engineering

World Wide Web: http://www.borton-lawson.com

Prepared By: PAR	Checked By:
Project Number: 2001-1014-00	Date: August 2003

ORDINANCE APPENDIX E

West Nile Virus Guidance

**Monroe County Conservation District Guidance:
Stormwater Management and West Nile Virus**

The Monroe County Conservation District recognizes the need to address the problem of non-point source pollution impacts caused by runoff from impervious surfaces. The new stormwater policy being integrated into Act 167 Stormwater Management regulations by the PA Department of Environmental Protection (DEP) will make non-point pollution controls an important component of all future plans and updates to existing plans. In addition, to meet post-construction anti-degradation standards under the state National Pollution Discharge Elimination System (NPDES) permitting program, applicants will be required to employ Best Management Practices (BMPs) to address non-point pollution concerns.

Studies conducted throughout the United States have shown that wet basins and in particular constructed wetlands are effective in traditional stormwater management areas such as channel stability and flood control, and are one of the most effective ways to remove stormwater pollutants (United States Environmental Protection Agency 1991, Center for Watershed Protection 2000). From Maryland to Oregon, studies have shown that as urbanization and impervious surface increase in a watershed, the streams in those watersheds become degraded (CWP 2000). Although there is debate over the threshold of impervious cover when degradation becomes apparent (some studies show as little as 6% while others show closer to 20%), there is agreement that impervious surfaces cause nonpoint pollution in urban and urbanizing watersheds, and that degradation is ensured if stormwater BMPs are not implemented.

Although constructed wetlands and ponds are desirable from a water quality perspective there may be concerns about the possibility of these stormwater management structures becoming breeding grounds for mosquitoes. The Conservation District feels that although it may be a valid concern, **municipalities should not adopt ordinance provisions prohibiting wet basins for stormwater management.**

Mosquitoes

The questions surrounding mosquito production in wetlands and ponds have intensified in recent years by the outbreak of the mosquito-borne West Nile Virus. As is the case with all vector-borne maladies, the life cycle of West Nile Virus is complicated, traveling from mosquito to bird, back to mosquito and then to other animals including humans. *Culex pipiens* was identified as the vector species in the first documented cases from New York in 1999. This species is still considered the primary transmitter of the disease across its range. Today there are some 60 species of mosquitoes that inhabit Pennsylvania. Along with *C. pipiens*, three other species have been identified as vectors of West Nile Virus while four more have been identified as potential vectors.

The four known vectors in NE Pennsylvania are *Culex pipiens*, *C. restuans*, *C. salinarius* and *Ochlerotatus japonicus*. All four of these species prefer, and almost exclusively use, artificial containers (old tires, rain gutters, birdbaths, etc.) as larval habitats. In the case of *C. pipiens*, the most notorious of the vector mosquitoes, the dirtier the water the better they like it. The important factor is that these species do not thrive in functioning wetlands where competition for resources and predation by larger aquatic and terrestrial organisms is high.

The remaining four species, *Aedes vexans*, *Ochlerotatus Canadensis*, *O. triseriatus* and *O. trivittatus* are currently considered potential vectors due to laboratory tests (except the *O. trivittatus*, which did have one confirmed vector pool for West Nile Virus in PA during 2002). All four of these species prefer vernal habitats and ponded woodland areas following heavy summer rains. These species may be the greatest threat of disease transmission around stormwater basins that pond water for more than four days. This can be mitigated however by establishing ecologically functioning wetlands.

Stormwater Facilities

If a stormwater wetland or pond is constructed properly and a diverse ecological community develops, mosquitoes should not become a problem. Wet basins and wetlands constructed as stormwater management facilities, should be designed to attract a diverse wildlife community. If a wetland is planned, proper hydrologic soil conditions and the establishment of hydrophytic vegetation will promote the population of the wetland by amphibians and other mosquito predators. In natural wetlands, predatory insects and amphibians are effective at keeping mosquito populations in check during the larval stage of development while birds and bats prey on adult mosquitoes.

The design of a stormwater wetland must include the selection of hydrophytic plant species for their pollutant uptake capabilities and for not contributing to the potential for vector mosquito breeding. In particular, species of emergent vegetation with little submerged growth are preferable. By limiting the vegetation growing below the water surface, larvae lose protective cover and there is less chance of anaerobic conditions occurring in the water.

Stormwater ponds can be designed for multiple purposes. When incorporated into an open space design a pond can serve as a stormwater management facility and a community amenity. Aeration fountains and stocked fish should be added to keep larval mosquito populations in check.

Publications from the PA Department of Health and the Penn State Cooperative Extension concerning West Nile Virus identify aggressive public education about the risks posed by standing water in artificial containers (tires, trash cans, rain gutters, bird baths) as the most effective method to control vector mosquitoes.

Conclusion

The Conservation District understands the pressure faced by municipalities when dealing with multifaceted issues such as stormwater management and encourages the incorporation of water quality management techniques into stormwater designs. As Monroe County continues to grow, conservation design, groundwater recharge and constructed wetlands and ponds should be among the preferred design options to reduce the impacts of increases in impervious surfaces. When designed and constructed appropriately, the runoff mitigation benefits to the community from these design options will far out weigh their potential to become breeding grounds for mosquitoes.

ORDINANCE APPENDIX F

Consumptive Use Tracking

CONSUMPTIVE USE TRACKING REPORT

PROJECT NAME: ____________________ MUNICIPALITY: ____________________

Type of Project: ___ Residential ___ Commercial ___ Institutional
___ Recreational/Seasonal ___Industrial

1. In which watershed is this project located? If more than one, identify the percentage of the project in each watershed. (See Figure x.x.)

___ Appenzell
___ Brodhead – above Paradise
___ Brodhead – below Paradise
___ Marshalls
___ McMichael
___ Paradise
___ Pocono

2. Water Source

___ On-Site Well ___ Central (source watershed: ___________________________)
(utility company: ___________________________)

3. Sewage Disposal

___ Land Disposal ___ Stream Discharge

4. Stormwater

[_________ cubic feet - __________ cubic feet]/1.6728 = _________ gallons/day
(Required Infiltration)* (Proposed Infiltration) (Net Stormwater)

5. Water Use (*Industrial projects must use project-specific data, not App. J or Table x.x.*)

A. _________________ x ______gallons/unit/day = ________ gallons/day
(# of Units Proposed) (Value from App. J) (Gross Water Use)

B. _________ gallons/day x ________________ = ________ gallons/day
(Gross Water Use) (Table x.x Multiplier)(Water Use)

6. Consumptive Use

________ gallons/day + ________ gallons/day = ________ gallons/day
(Stormwater) (Water Use) (Consumptive Use)

*Calculated per Section 304

7. Example

10-Lot Subdivision with On-Site Wells and Central Sewage

Stormwater: -420 gal/day (calculated per Section 304)

Water Use: 10 units x 190 gal/unit/day = 1900 gal/day
1900 gal/day x 1.00 = 1900 gal/day

Consumptive Use: -420 gal/day + 1900 gal/day = 1480 gal/day

****

Table x.x. Multipliers for Water Use Calculation (*Do not use for industrial projects.*)

		Central Out of Watershed	Central Within Watershed	On-Site Well
Sewage Disposal	Land Disposal	0	0.14	0.14
	Stream Discharge	0	1.00	1.00

Water Source

NOTES: A multiplier of 0 will result in a debit to the source watershed *by the reviewing entity.* A multiplier of 0.14, derived from the Pocono Creek Goal-Based Watershed Management Project, is designed to protect aquatic habitat during summer low flows. A multiplier of 1.00 assumes that water is not available to sustain aquatic base flows.

WATER USE FOR CONSUMPTIVE USE TRACKING		
TYPE OF ESTABLISHMENT	*UNIT*	*GALLONS/UNIT/DAY*
Residential		
Hotels and motels	Room	100
Multiple family dwellings and apartments, including townhouses, duplexes and condominiums	Unit	400
Rooming houses	Room	200
Residential Subdivisions (On-Lot Sewage)	Single family residences	400*
+Residential Subdivisions (Central Sewage)	Single family residences	190
*For units of 3 bedrooms or less; for each bedroom	over 3, add 100 gallons	
Commercial		
Airline catering	Meal served	3
Airports - not including food	Passenger	5
Airports	Employee	10
>Barber shops	Chair	54.6
One licensed operator beauty shops	Station	200
>Bowling alleys	Alley	133
Bus service areas - not including food	Patron and employee	5
>Bus/rail depots	Square foot	3.33
>Car washes	Inside square foot	4.78
Country clubs - not including food	Patron and employee	30
>Drive-in restaurants	Car stall	109
Drive-in theaters - not including food	Space	10
Factories and plants exclusive of industrial wastes	Employee	35
Laundries, self-service	Washer	400
>Laundries, non self-service	Square foot	0.25
>Medical Offices	Square foot	0.62
Mobile home parks, independent	Space	400
Movie theaters - not including food	Auditorium seat	5
>Night clubs	Person served	1.33
>Office buildings	Square foot	0.19
Offices	Employee	10
Restaurants (toilet and kitchen wastes)	Patron	10
Restaurants (additional for bars and cocktail lounges)	Patron	2
Restaurants (kitchen and toilet wastes, single-service utensils	Person	8.5
Restaurants (kitchen waste only, single-service utensils	Patron	3
>Service stations	Inside square foot	3.33
Stores	Public toilet	400
Warehouses	Employee	35
Work or construction camps (semipermanent) with flush	Employee	50

Toilets		
Work or construction camps (semipermanent) w/o flush Toilets	Employee	35
TYPE OF ESTABLISHMENT	*UNIT*	***GALLONS/UNIT/DAY***
Institutional		
Churches	Seat	3
Churches (additional kitchen waste)	Meal served	3
Churches (additional with paper service)	Meal served	1.5
Hospitals, with laundry	Bed space	300
Hospitals, without laundry	Bed space	220
Institutional food service	Meal	20
Institutions other than hospitals	Bed space	125
Schools, boarding	Resident	100
Schools, day (without cafeterias, gyms or showers)	Student & employee	15
Schools, day (with cafeterias, but no gyms or showers)	Student & employee	20
Schools, day (with cafeterias, gym and showers)	Student & employee	25
>YMCA/YWCA	Person	33.3
Recreational and Seasonal		
Camps, day (no meals served)	Person	10
Camps, hunting and summer residential (night and day) with limited plumbing including water-carried toilet wastes	Person	50
Campgrounds with individual sewer and water hookup	Space	100
Campgrounds with water hookup only and/or central comfort Station which includes water-carried toilet wastes	Space	50
Fairgrounds and parks, picnic - with bathhouses, showers and flush toilets	Person	15
Fairgrounds and parks, picnic - toilet wastes only	Person	5
Swimming pools and bathhouses	Person	10

NOTE: If type of establishment proposed is not listed or if more project specific values are available, supporting documentation must be provided.

SOURCE: PA Title 25§73.17. Sewage flows, unless otherwise indicated

> Crews, James E. and MaryAnn Miller, 1983. Forecasting Municipal and Industrial Water Use. IWR Research Report 83R-3. U.S. Army Corps of Engineers, Fort Belvoir, Virginia.

\+ Watershed Protection Advisory Committee Meeting #3 held at Monroe County Public Safety Center May 16, 2003.

ORDINANCE APPENDIX G
Selected Wetland BMP References

Article 98

Technical Note #23 from Watershed Protection Techniques. 1(2): 81-82

Practical Tips for Establishing Freshwater Wetlands

No shortage of books and manuals exist to design freshwater wetlands for mitigation, restoration or stormwater treatment. A recent series of articles by Garbisch and others, however, suggest that successful establishment of freshwater wetlands often hinges on writing practical and thorough construction specifications for the contractor who implements the design. Lack of attention to these important details can lead to serious problems in establishing a dense and diverse freshwater wetland.

Ed Garbisch founded the nonprofit corporation **Environmental Concern** (EC) in 1972 to educate, research, develop, and apply technology for the restoration and construction of wetlands. Over this period, EC has been involved in hundreds of tidal and non-tidal wetland establishment projects and has gained a great deal of experience in wetland propagation and creation techniques. Some of the practical lessons they have learned on how to construct successful wetlands are summarized in Table 1.

Matching the design hydrology of the planned wetland with the appropriate wetland plant species is perhaps the most critical task in the design of diverse pondscapes. However, many wetland construction drawings fail to even show the design hydrology on the plan. Without a good understanding of the future water surface elevations and the frequency of inundation it is nearly impossible make the right match. Therefore, it is important to clearly show design hydrology on all construction drawings (plan view and cross section).

Another frequently encountered problem is that while the planting plan may contain an extensive wetland plant list, most of the species may not be available in quantity from local wetland nurseries at the time of construction. As a consequence, plant species are substituted at the last minute that may not meet the

Table 1: Useful Construction Specifications for Freshwater Wetlands (Garbisch, 1993, 1994)

1. Always clearly specify the proposed wetland hydrology on construction plans and drawings to ensure that proper wetland plants are selected. Be wary of wetland projects that only rely on groundwater for water supply.
2. Consider procuring wetland plants through growing contracts with wetland nurseries. These contracts ensure that the desired species and quantities of wetland plants will be available to implement the planting plan.
3. Use care before automatically requiring topsoil amendments to prepare the substrate for planned wetlands. Topsoiling may not always be needed, can be expensive and may introduce undesirable species from the seedbank.
4. Although it is very important to quickly stabilize disturbed upland areas during construction, avoid specifying the use of Tall Fescue for this purpose, because of its allelopathic character.
5. Be careful when specifying hydroseeding to establish stormwater and other types of wetlands without strong confidence that seeds will germinate and root in the substrate before the site is inundated. Otherwise, both mulch and seeds will float away or be unevenly distributed through the marsh.
6. If seeding is to be used as the key propagation method to establish the wetland, be sure to specify the quantity of pure live seed needed, the commercial source of seed, seeding technique, filler, and window and other key aspects leading to a successful result.
7. Clearly specify watering requirements during the first growing season for seasonally or temporarily inundated wetland areas. Drought conditions can severely reduce growth and survivorship for these wetlands without initial watering by truck or by a shallow aquifer well.

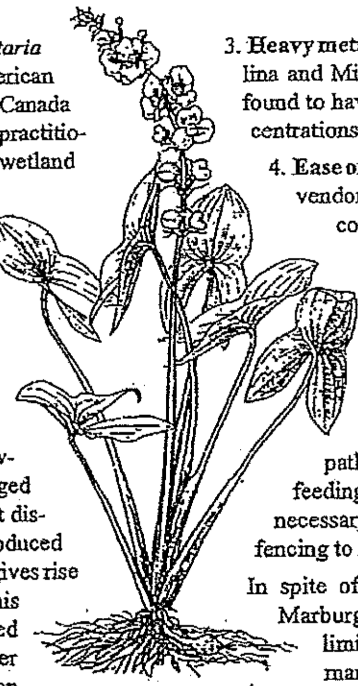
Article 99

Technical Note #24 from Watershed Protection Techniques. 1(2): 83

Broad-Leaf Arrowhead: A Workhorse of the Wetland

The broad-leaf arrowhead *(Sagittaria latifolia)* is a native North American wetland plant found in southern Canada and much of the United States. Many practitioners have found it especially useful for wetland enhancement, restoration, and creation projects because of several desirable characteristics. However, Marburger (1993) points out there is still much to be learned about its ecology and physiology before routinely investing in large scale planting and management schemes.

The plant is identified by its rosettes of arrowhead-shaped leaves. Flowers are white with three petals and arranged in whorls around a long stalk. Its most distinctive feature is the starchy tuber produced from the rhizomes. This phenomenon gives rise to its common name of *duck potato*. This "potato" portion of the plant is consumed by muskrats, porcupines, geese, and other animals. Native Americans and European settlers also used the tuber as a food source.



Adapted from Fassett, 1960

While its days as human food have long since past, other beneficial characteristics of broad-leaf arrowhead have propelled it into the field of wetland restoration. Special characteristics include the following.

1. **Adaptation to a wide range of conditions.** The plant persists under stabilized water levels of less than 50 cm and few drawdowns and survives in pHs from 5.9 to 8.8. It has been found in highly calcareous water and in a variety of soil types including sandy loams and silty clays. While it can withstand turbid conditions, it does not tolerate severe sediment deposition.

2. **Nutrient uptake.** Arrowhead rapidly takes up phosphorus from the sediments and retains it in its tissue. In one South Carolina study it had the highest leaf tissue composition of phosphorus of 17 wetland plants analyzed (Boyd, 1970). For this reason arrowhead is often selected for use in municipal and domestic wastewater treatment systems, constructed wetlands, and for stormwater runoff treatment.

3. **Heavy metal uptake.** In surveys in South Carolina and Michigan, broad-leaf arrowhead was found to have the highest leaf dry weight concentrations of several metals.

4. **Ease of plant propagation.** Wetland plant vendors can supply achnenes, tubers, and container-grown plants. Tubers are generally preferred because they require less site preparation. Plants are more costly, but survive a wider range of initial conditions.

5. **Resistance to disease and damage.** There are few reports of population reductions due to pathogens, insect pests, and animal feeding. In some limited situation it may be necessary to enclose areas with protective fencing to keep out muskrats and waterfowl.

In spite of many apparent field successes, Marburger points out there exists only a limited database on the installation and management of the broad-leaf arrowhead, especially for large-scale applications. Before incorporating the arrowhead in a wetland design the practitioner needs to work with plant vendor to identify the following:

- If the environmental factors at the site are more favorable for germinating/growing achenes, tubers, or seedlings
- If environmental factors are right for sustaining a mature population of arrowheads
- If pathogens, animal herbivory, and/or other plant species are likely to impact the plant

—*JS*

References

Boyd, C.E. 1970. "Chemical Analyses of Some Vascular Aquatic Plants." *Archiven für Hydrobiologie* 67:78-85.

Fassett, N.C. 1960. *A Manual of Aquatic Plants*. The U. of Wisconsin Press, 405 pp.

Marburger, J.E., 1993. "Biology and Management of *Sagittaria latifolia* Willd. (Broad-leaf Arrowhead) for Wetland Restoration and Creation." *Restoration Ecology* 1(4) 248-257.

original intent of the wetland plan. A new approach has been developed to ensure that the species and quantities of wetland plants are available at the time of construction.

This approach is termed *contract growing*. It involves executing an advance contract with a wetland nursery to grow and deliver a specified number and species of plants at a future date. An up-front deposit of 20 to 30% is normally required prior to growing. While contract growing means more planning and logistics, the practice does provide a better guarantee that the planned and most desirable wetland plant species will be available when needed.

Garbisch also questions the common specification to topsoil the surface of created herbaceous wetlands prior to planting. Topsoiling can be expensive, and may not always be needed at most sites. This is due to the fact that herbaceous wetland plants typically produce a great deal of below-ground organic matter and quickly dominate the composition of the substrate within a few years. Garbisch does suggest topsoiling in clay, rock, or pyritic soils and topsoiling or soil amendment for forested or scrub shrub wetlands. But generally, soil tests should be performed before recommending topsoil at a particular site.

Most wetland plans devote a great deal of attention to the selection of wetland plant species, but give relatively little thought to the ground covers used to vegetate disturbed areas around the pond or wetland. Many plans simply specify that these areas be stabilized through hydroseeding of KY-31 Tall Fescue *(Festuca aruninacea)*. Fescue has been widely specified for years for erosion control during and after construction. It does an admirable job of quickly establishing a dense turf cover. This cool season bunch grass also tolerates a wide range of moisture conditions and can invade many areas of the site.

Burchick (1993) questions the wisdom of specifying Tall Fescue as a ground cover around wetlands and ponds. He argues that Fescue frequently displaces native grass and meadow species, out-competes natural or planted tree seedlings, and can even invade portions of the wetland. Fescue is a tough competitor partly due to its allelopathic characteristics. It secretes organic acids that can impair the germination of native species. Consequently, Burchick recommends that less aggressive cool season grasses be utilized for erosion control purposes around pond and wetland areas.

Direct seeding is often the most economical technique to establish wetlands. Garbsich cautions that construction specifications should be very tight if direct seeding is called for. For example, many wetland seed mixes have relatively low purity and germination rates. Consequently, Garbisch observes that if a pound of pure, live seed is needed to establish a ground cover per unit area, and it has a 10% germination rate and 50% purity, then some 20 pounds will actually need to be broadcast to achieve the desired coverage. Consequently, it is recommended to express direct seeding rates in terms of pure, live seed (pls). The specifications should either require that the source(s) of the seed be indicated, or require that they be field collected and tested for purity and germination rate.

Of equal importance are the seeding *window* and *filler*. The window is the optimal seasons and dates for a successful result. The filler represents the sand dilution needed for small seeds to ensure they are uniformly distributed over the planting area. Seeding specifications should also clearly state the technique and implements for the seeding operation, and whether this operation will be done in the wet or the dry. Hydroseeding of wetlands should be avoided unless the contractor has confidence that the seeds will germinate and root before the next runoff event. Otherwise, the mulch, tack and seeds will float away or become unevenly distributed.

The establishment of a dense and diverse wetland is the joint product of the design engineer, landscape architect, wetland nursery, and planting contractor. Thoughtful and clear construction specifications help assure that each individual performs his or her role well.

—*TRS*

References

Burchick, M. 1993. "The Problems With Tall Fescue in Environmental Restoration." *Wetland Journal.* 5(2)-16.

Garbisch, E. 1993. "The Need to Topsoil With Mineral Loam Soils in Planned Wetland Projects." *Wetland Journal* 5(2): 18.

Garbisch, E, 1994. "The Do's and Don'ts of Wetland Planning." *Wetland Journal.* 6(1): 16-17.

Stormwater Management Fact Sheet: Stormwater Wetland

Description

Stormwater wetlands (a.k.a. constructed wetlands) are structural practices similar to wet ponds (see [illegible] Fact Sheet) that incorporate wetland plants in a shallow pool. As stormwater runoff flows through the wetland, pollutant removal is achieved by settling and biological uptake within the practice. Wetlands are among the most effective stormwater practices in terms of pollutant removal, and also offer aesthetic value. While natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems. Stormwater wetlands are designed specifically for the purpose of treating stormwater runoff, and typically have less biodiversity than natural wetlands both in terms of plant and animal life. There are several design variations of the stormwater wetland, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland.

Applicability

Wetlands are widely applicable stormwater treatment practices. While they have limited applicability in highly urbanized settings, and in arid climates, they have few other restrictions.

Regional Applicability
Stormwater wetlands can be applied in most regions of the United States, with the exception of arid climates. In arid, and even in semi-arid climates, it is difficult to design any stormwater practice that has a permanent pool. Because wetlands are relatively shallow, water losses due to evaporation can be high which can be critical for the wetland plants. This makes maintaining the permanent pool in wetlands both more challenging and more important than maintaining the pool of a wet pond (see Wet Pond Fact Sheet).

Ultra Urban Areas
Ultra urban areas are densely developed urban areas in which little pervious surface exists. It is difficult to use wet ponds in the ultra urban watershed because of the land area each wetland consumes. They can, however, be used in these environments if a relatively large area is available downstream of the site.

Stormwater Hotspots
Stormwater hotspots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. A typical example is a gas station. Wetlands can accept runoff from stormwater hotspots, but need significant separation from groundwater if they will be used for this purpose. Caution also needs to be exercised for stormwater wetlands to ensure that pollutants in stormwater runoff do not work their way up the food chain of aquatic organisms living in or near the wetland.

Stormwater Retrofit
A stormwater retrofit is a stormwater management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other watershed restoration objectives. When retrofitting an entire watershed, stormwater wetlands have the advantage of providing both educational and habitat value. One disadvantage to wetlands, however, is the difficulty storing large amounts of runoff without consuming a large amount of land. It is also possible to incorporate wetland elements into existing practices, such as wetland plantings (see Wet Pond and [illegible] Fact Sheets).

Cold Water (Trout) Streams
Wetlands pose a moderate risk to cold water systems because of their potential for stream warming. When water remains in the permanent pool, it is heated by the sun. A study in Prince Georges County, MD investigated the thermal impacts of a wide range of stormwater management practices. (Galli, 1990). In this study, only one wetland was investigated, which was an extended detention wetland (*see Design Variations*). The practice increased the average temperature of stormwater runoff that flowed through the practice by about 3 F. While this is less than the temperature increase associated with wet ponds (see [illegible]

Ponds Fact Sheet), it cannot be concluded from one study that wetlands necessarily increase temperatures less than wet ponds. In fact, wetlands may have a greater potential to increase temperature because the shallow portions of wetlands can easily be warmed by the sun.

Locational and Design Considerations

In addition to the broad concerns described above, designers need to consider conditions at the site level. In addition, they need to incorporate design features to improve the longevity and performance of the practice, while minimizing the maintenance burden.

Locational Considerations
Designers need to ensure that stormwater wetlands are feasible for a site. The following section provides basic guidelines for locating wetlands.

Drainage Area

Wetlands need sufficient drainage area to maintain a shallow permanent pool. In humid regions, about twenty-five acres of drainage area are needed, but a larger areas may be needed in regions with less rainfall.

Slope

Wetlands can be used on sites with an upstream slope up to about 15%. The local slope should be relatively shallow, however. While there is no minimum slope requirement, there does need to be enough elevation drop from the inlet to the outlet to ensure that hydraulic conveyance by gravity is feasible (generally about three to five feet).

Soils /Topography

Wetlands can be used in almost all soils and geology, with minor design adjustments for regions of karst topography. (See *Design Considerations*).

Groundwater

Unless they receive hotspot runoff, wetlands can often intersect the groundwater table. Some research suggests that pollutant removal is moderately reduced when groundwater contributes substantially to the pool volume (Schueler, 2000) (for more information see *Influence of Groundwater on Performance of Stormwater Ponds in Florida*, Article 78 in The Practice of Watershed Protection). It is assumed that wetlands would have a similar response.

Design Considerations
Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most wetland designs. These design features can be divided into five basic categories: *pretreatment, treatment, conveyance*, *maintenance reduction*, and *landscaping* (for more information see the Manual Builder Category).

Pretreatment

Pretreatment is used to settle out coarse sediment particles prior to entry in the main wetland cell. By removing sediments before they reach the wetland, the maintenance burden of the wetland is reduced. In wetlands, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10% of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge or clean out sediments from the entire wetland.

Treatment

Treatment design features help enhance the ability of a stormwater treatment practice to remove pollutants. Several features can enhance the ability of wetlands to remove pollutants from stormwater runoff. The purpose of most of these features is to increase the amount of time and flowpath that stormwater remains in the wetland. Some typical design features include:

- The surface area of wetlands should be at least 1% of the drainage area to the practice.
- Wetlands should have a length to width ratio of at least 1.5:1. Making the wetland longer than it is wide helps prevent "short circuiting" of the practice.
- Effective wetland design "complex microtopography". In other words, wetlands should have zones of both very shallow (<6") and moderately shallow (<18") wetlands are incorporated, using underwater earth berms to create the zones. This design will provide a longer flow path through the wetland to encourage settling, and provides two depth zones to encourage plant diversity.

Conveyance

Conveyance of runoff into and through a stormwater practice is a critical component of any stormwater design. Stormwater should be conveyed to and from practices safely and to minimize erosion potential. The outfall of pond systems should always be stabilized to prevent scour. In addition, an emergency spillway should be provided to safely convey large flood events. In order to prevent warming at the outlet channel, designers should provide shade around the channel at the wetlands outlet.

Maintenance Reduction

In addition to regular maintenance activities, several design features can be incorporated to ease the maintenance burden of stormwater wetlands.

One potential maintenance concern in stormwater wetlands is clogging of the outlet. Wetlands should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse slope pipe draws from below the micropool extending in a reverse angle up to the riser and establishes the water elevation of the micropool. Because these outlets draw water from below the level of the micropool, they are less likely to be clogged by floating debris. Another general rule is that no orifice should be less than 3" in diameter (smaller orifices are generally more susceptible to clogging, without specific design considerations to reduce this problem).

Wetlands should incorporate design features that make sediment cleanouts of both the forebay and the shallow pool easier. Wetlands should have direct maintenance access to the forebay, to allow this relatively routine (five to seven year) sediment cleanouts. In addition, the shallow pool should generally have a drain to draw down the wetland for the more infrequent dredging of the main cell of the wetland.

Landscaping

Landscaping of wetlands can make them an asset to a community, and can also enhance their pollutant removal. To ensure the establishment and survival of wetland plants, a landscaping plan should provide detailed information about the plants selected, when they will be planted, and a strategy for maintaining them. The plan should detail wetland plant species, as well as vegetation to be established adjacent to the wetland.

A variety of techniques can be used to establish wetland plants. The most effective technique is the use of nursery stock as dormant rhizomes, live potted plants, or bare root stock. A "wetland mulch," soil from a natural wetland or a designed "wetland mix," can be used to supplement wetland plantings or alone to establish wetland vegetation. Wetland mulch carries with it the seed bank from the original wetland, and can help to enhance diversity in the wetland. The least expensive option to establish wetlands is to allow the wetland to colonize itself. One disadvantage to this last technique is that invasive species such as cattails or *Phragmites* may dominate the wetland (for more information see *Nutrient Dynamics and Plant Diversity in Volunteer and Planted Stormwater Wetlands*, -).

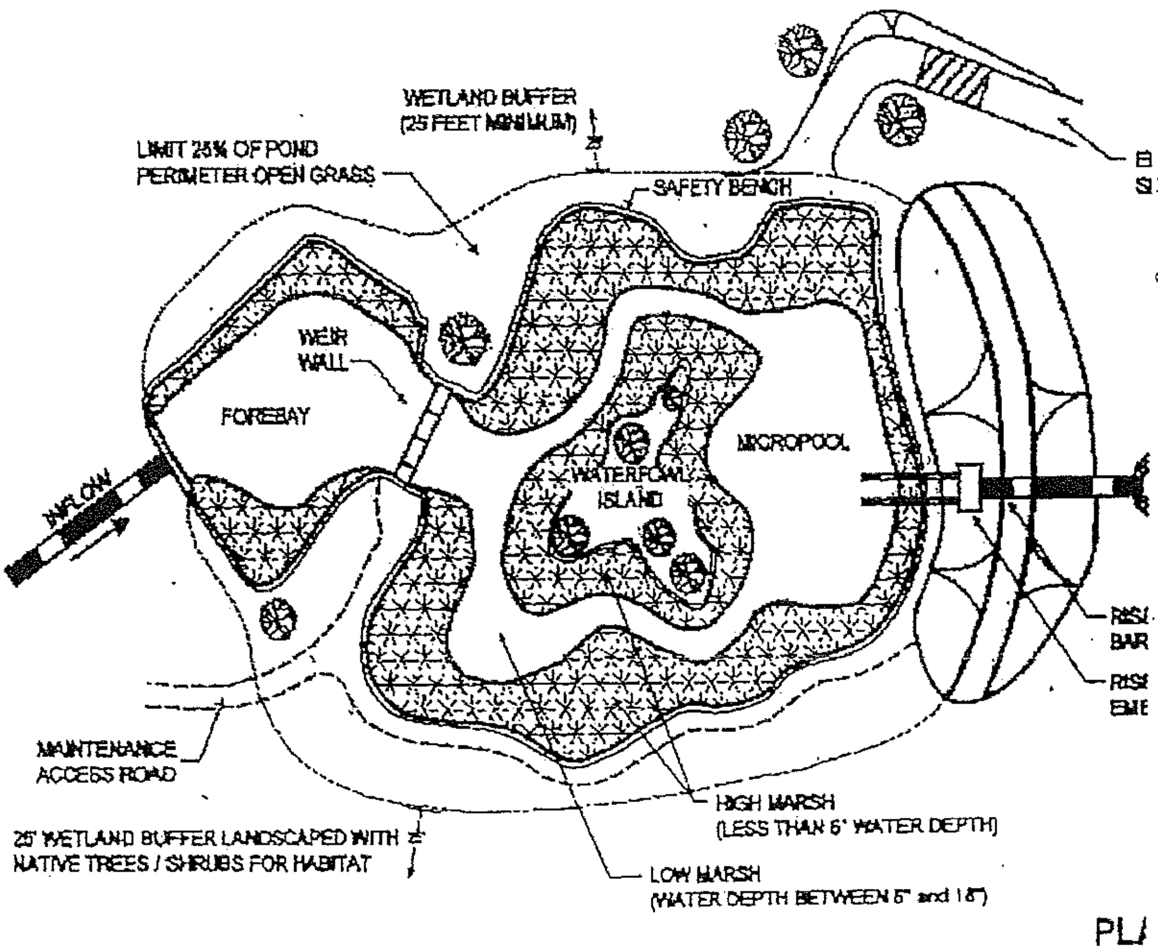
When developing a plan for wetland planting, care needs to be taken to ensure that plants are established in the proper depth and within the planting season. This season varies regionally, and is generally between two and three months long in the spring to early summer. Plant lists are available for various regions of the United States through wetland nurseries, extension services, or conservation districts.

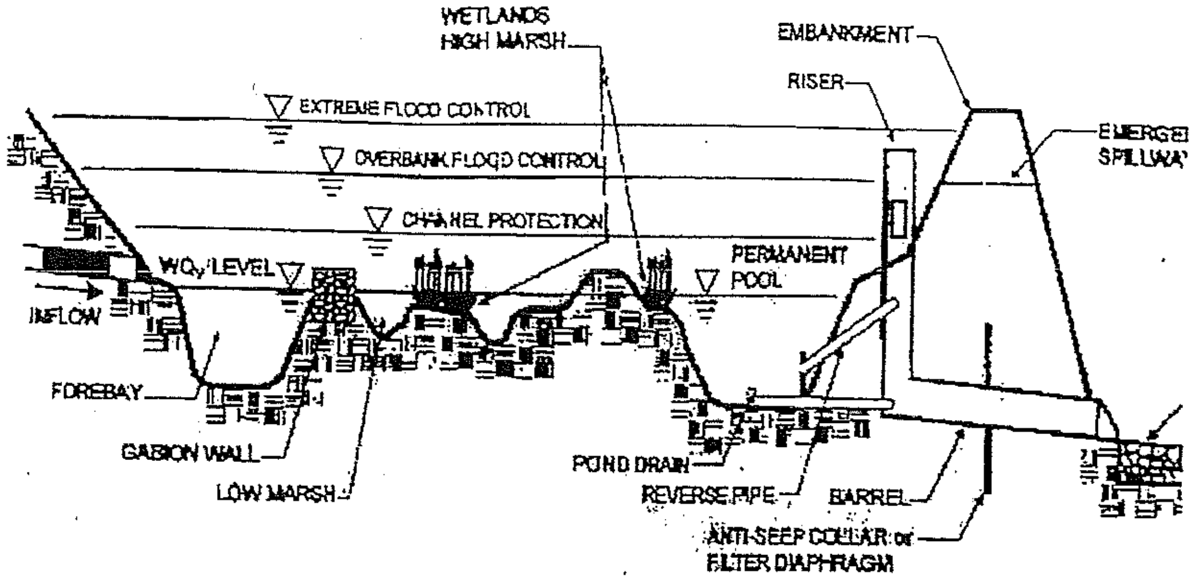
Design Variations

There are several variations of the wetland design. The designs differ in the proportion of the volume of the wetland in deep pool, high marsh, low marsh, and whether volume is provided for extended detention above the wetland surface. Other design variations help to make wetland designs practical in cold climates.

Shallow Marsh

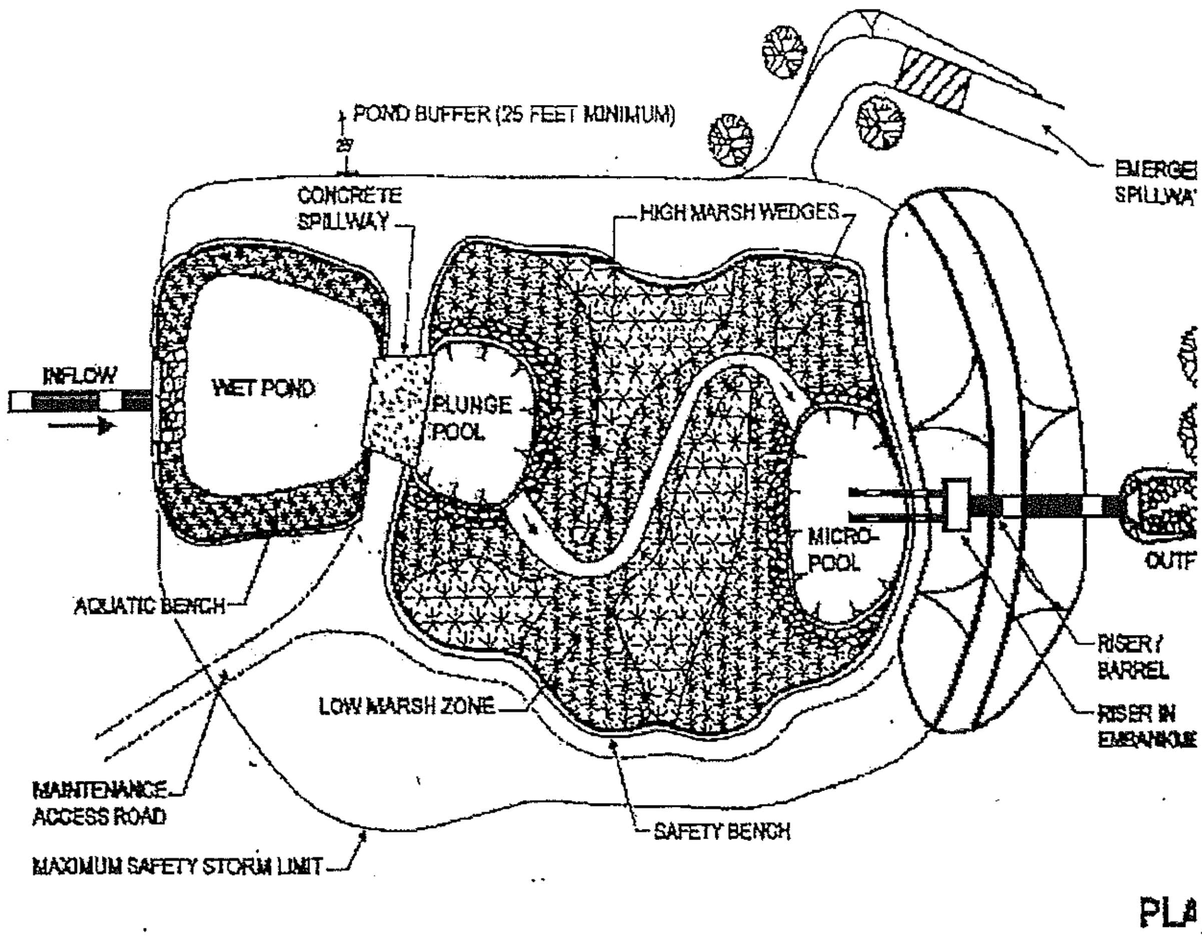
In the shallow marsh design, most of the wetland volume is in the relatively shallow high marsh or low marsh depths. The only deep areas of the shallow wetland design are the forebay at the inlet to the wetland, and the micropool at the outlet. One disadvantage of the shallow marsh design is that the pool is very shallow and a large amount of land is typically needed to store the water quality volume (i.e., the volume of runoff to be treated in the wetland) (see Figure 1).

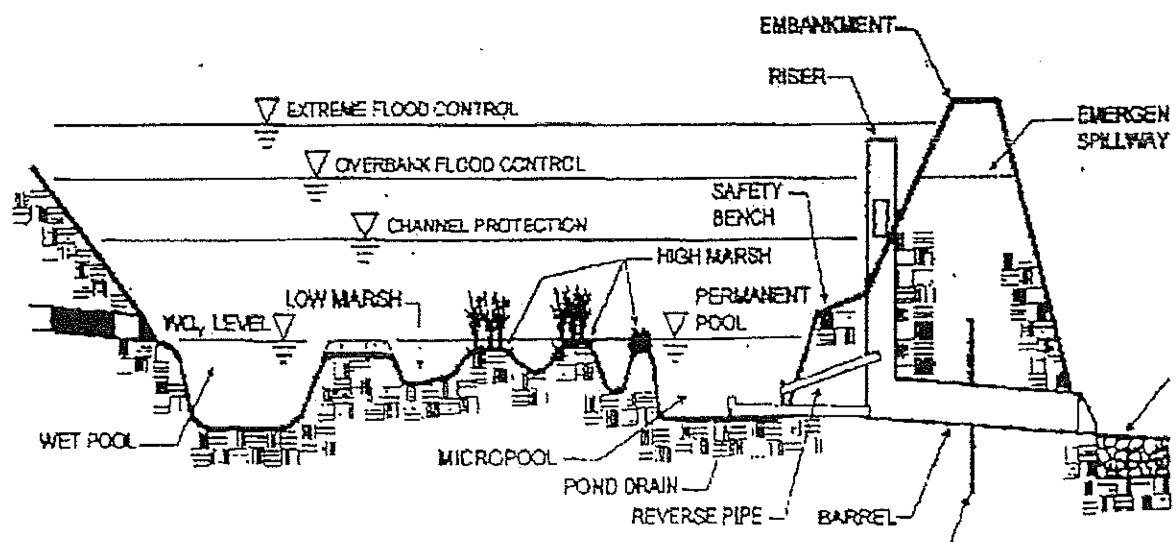




Pond/Wetland System

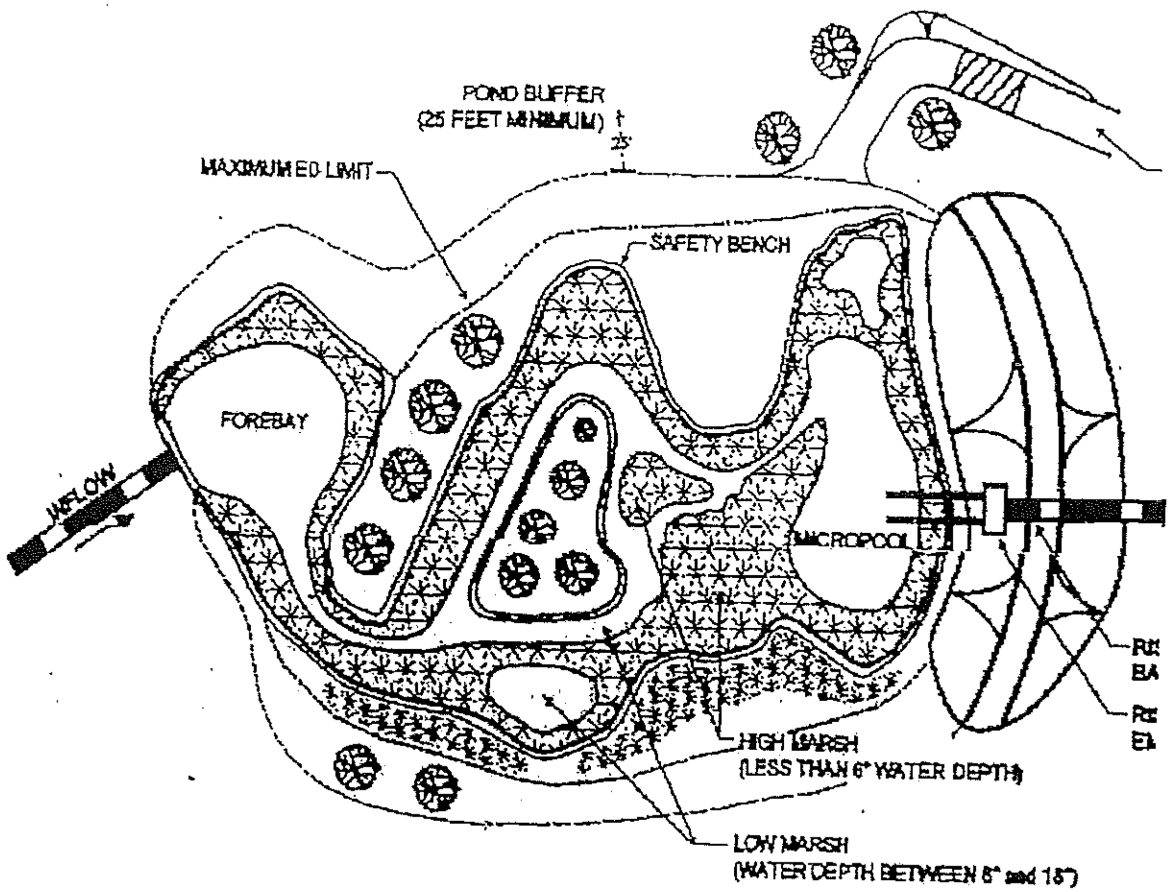
The pond/wetland system combines a wet pond (see Wet Pond Fact Sheet) and a shallow marsh. Stormwater runoff flows through the wet pond and into the shallow marsh. Like the extended detention wetland, this design requires less surface area than the shallow marsh because much of the practice is relatively deep (i.e., six to eight feet) (see Figure 3).


POND BUFFER (25 FEET MINIMUM)
25'
CONCRETE SPILLWAY
HIGH MARSH WEDGES
EMERGE SPILLWA
INFLOW
WET POND
PLUNGE POOL
MICRO-POOL
OUTF
AQUATIC BENCH
RISER / BARREL
RISER IN EMBANKME
LOW MARSH ZONE
MAINTENANCE ACCESS ROAD
SAFETY BENCH
MAXIMUM SAFETY STORM LIMIT
PLA


EMBANKMENT
RISER
EXTREME FLOOD CONTROL
EMERGEN SPILLWAY
OVERBANK FLOOD CONTROL
SAFETY BENCH
CHANNEL PROTECTION
HIGH MARSH
LOW MARSH
PERMANENT POOL
WQ_v LEVEL
WET POOL
MICROPOOL
POND DRAIN
REVERSE PIPE
BARREL
ANTI-SEEP COLLAR or

Extended Detention Wetland

This design is similar to the shallow marsn, but with more storage above the surface of the marsh. Stormwater is temporarily ponded above the surface in the *extended detention zone* for between twelve and twenty-four hours. This extended detention wetland can treat a greater volume of stormwater in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate wet and dry periods should be planted along the shorelines of the wetlands. (See Figure 2).



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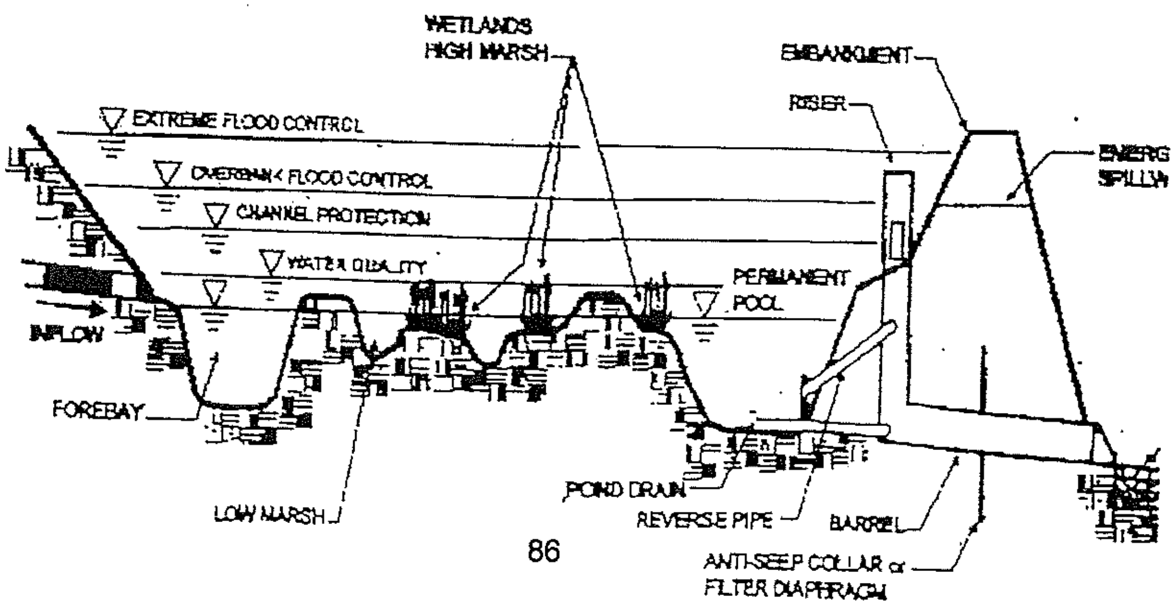
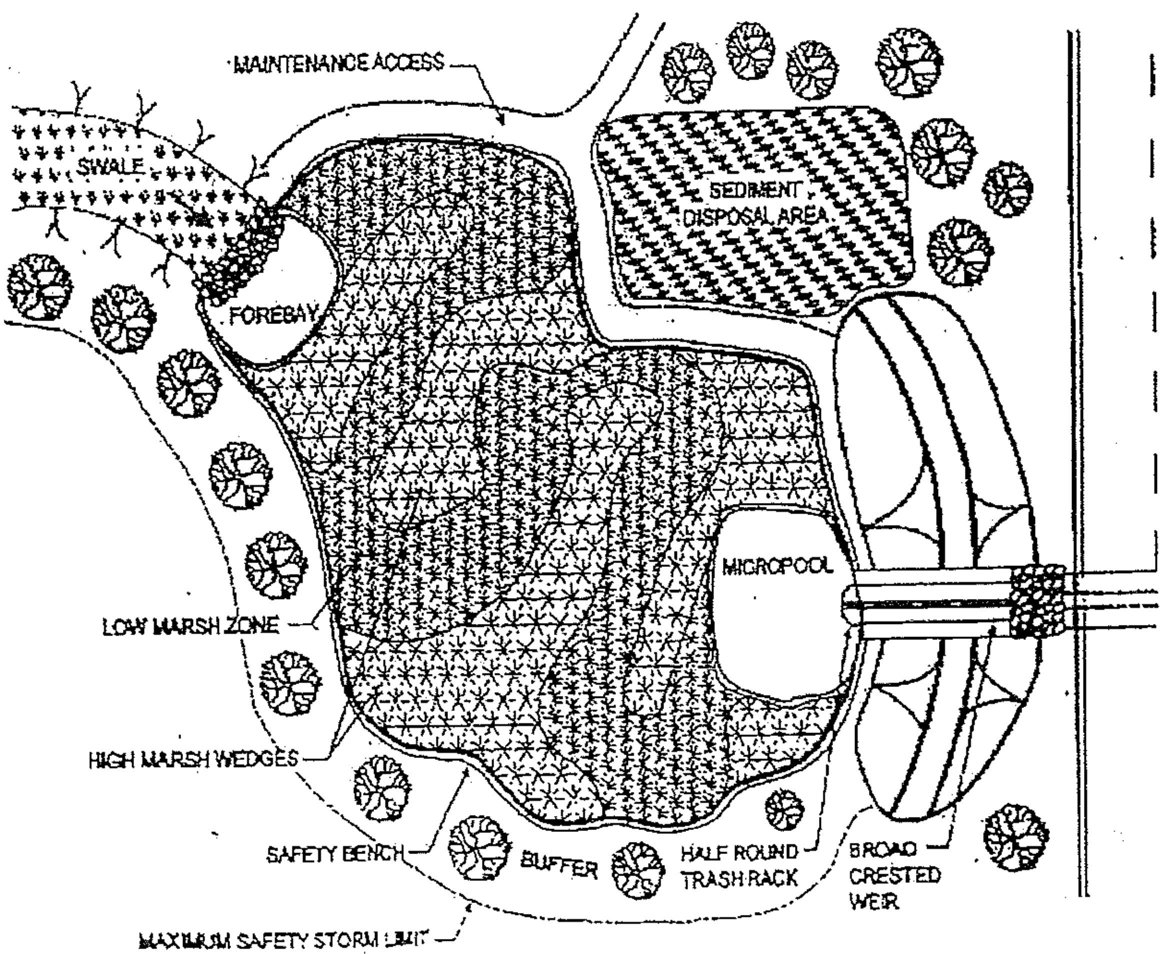


FILTER DIAPHRAGM

F

Pocket Wetland

This design is very similar to the Pocket Pond (see [illegible]). In this design, the bottom of the wetland intersects the groundwater, which helps to maintain the permanent pool. Some evidence suggests that groundwater flows may reduce the overall effectiveness of stormwater management practices (Schueler, 2000). This option may be used when there is not significant drainage area to maintain a permanent pool for the stormwater wetland (see Figure 4).



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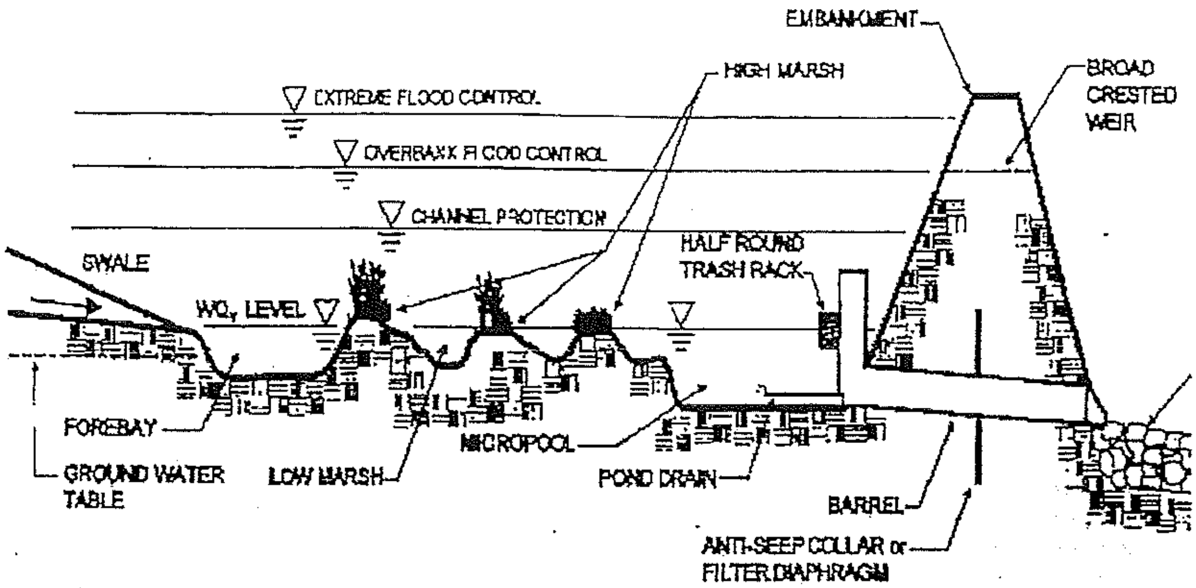

Gravel-Based Wetlands

In this design, runoff flows through a rock filter with wetland plants at the surface. Pollutants are removed through biological activity on the surface of the rocks, as well as by pollutant uptake of the plants. This practice is fundamentally different from other wetland designs because, while most wetland designs behave like *Wet Ponds* with differences in grading and landscaping, gravel-based wetlands are more similar to a filtering system. A proprietary version of the gravel-based wetland, StormTreat©, operates on a similar principle (for more information see The StormTreat System: A New Technology for Treating Stormwater Runoff, Article 96 in The Practice of Watershed Protection).

Regional Variations

Cold Climates

Cold climates present many challenges to designers of wetlands. During the spring snowmelt, a large volume of runoff occurs in a short time, which carries a relatively high pollutant load. In addition, cold winter temperatures cause freezing of the shallow pool as well as freezing up inlet and outlet structures. Finally, high salt concentrations are spread by road salting which can impact wetland vegetation. Also sediment loads from road sanding can be high, and cause premature loss of treatment capacity.

A key problem with stormwater wetlands (particularly shallow marshes), is that the practice has very shallow water depths. Therefore, much of the volume in the wetland can be lost when the surface ices over. One study found that the performance of a wetland system was moderately diminished during the spring snowmelt because the outlet and surface of the wetland had frozen. Sediment and pollutants in snowmelt and rainfall events "skated" over the surface of the wetland, depositing at the outlet of the wetland. When the ice melted, this sediment was washed away by storm events (Oberts, 2000) (for more information see

Performance of Stormwater Ponds and Wetlands in Winter, Article 71 and *Pollutant Removal Dynamics of Three Canadian Wet Ponds*, Article 75 in The Practice of Watershed Protection). Several design features can help minimize this problem, including:

- Design wetlands "on-line," so that flow continuously moves through the system. This can help prevent outlets from freezing.
- Design wetlands with multiple cells, and a berm or weir separating each cell. This modification helps to retain storage for treatment above the ice layer during the winter season.
- Use outlets that are resistant to freezing. Some examples include weirs, or pipes with large diameters.

The salt and sand used to remove ice from roads and parking lots may also create a problem for wetlands in cold climates. When wetlands receive highway runoff, or parking lots, salt tolerant wetland plant species, such as Pickerelweed or Cord Grass should be used. (Contact a local nursery or extension agency for more information in your region). In addition, designers should consider increasing the size of the sediment forebay to capture the increased sediment load from road sanding.

Karst Topography

In karst (i.e., limestone) topography, the bottom of wetlands should incorporate an impermeable liner to prevent groundwater contamination or sinkhole formation, and to help maintain the shallow pool.

Limitations

Some limitations of stormwater wetlands include:

- Wetlands consume a relatively large amount of space, making them an impractical option on many sites where surface land area is constrained or land prices are high.
- Although design features can minimize the potential of wetlands to become a breeding area for mosquitoes (McLean, 2000), there can be public perception that wetlands are a mosquito source (for more information see *Mosquitos in Constructed Wetlands - A Management Bugaboo?*, Article 100 in The Practice of Watershed Protection).
- Wetlands require careful design and planning to ensure that wetland plants survive and flourish after construction.
- Some evidence exists that stormwater wetlands can release some nutrients during the non-growing season.
- Designers should ensure that wetlands are not built in natural wetlands or high quality forest.

Maintenance Considerations

Several regular maintenance and inspection practices are needed for stormwater wetlands as outlined below:

Table 1. Regular Maintenance Activities for Wetlands
(Source: Adapted from WMI, 1997 and CWP, 1998)

Activity	Schedule
Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season.	One-Time (after construction)
Inspect for invasive vegetation and remove where possible.	Semi-Annual Inspection

Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. Note signs of hydrocarbon build-up, and deal with appropriately. Monitor for sediment accumulation in the facility and forebay. Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual Inspection
Repair undercut or eroded areas.	As Needed Maintenance
Clean and remove debris form inlet and outlet structures Mow side slopes.	Frequent (3-4 times/year) Maintenance
Supplement wetland plants if a significant portion have not established (at least 50% of the surface area). Harvest wetland plants that have been "choked out" by sediment build-up.	Annual Maintenance (if needed)
Removal of sediment form the forebay.	5 to 7 year Maintenance
Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.	20 to 50 year Maintenance

Effectiveness

Stormwater treatment practices can be used to achieve four broad resource protection goals. These include: *Flood Control, Channel Protection, Groundwater Recharge,* and *Pollutant Removal* (see the Manual Builder Category for more information). Wetlands, however can only meet flood control and channel protection, and pollutant removal goals.

Flood Control

One objective of stormwater treatment practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Wetlands can easily be designed for flood control, by providing flood storage above the level of the wetland surface.

Channel Protection

One result of urbanization is the channel erosion caused by increased stormwater runoff. When used for channel protection, wetlands have traditionally been designed to control the *two-year storm*. It appears that this design storm has not been effective in preventing channel erosion, and recent research suggests that control of a smaller storm may be more appropriate (MacRae, 1996). Choosing a smaller design storm (one-year) and providing longer detention time (12 to 24 hours) are thought to be the best methods to reduce channel erosion.

Groundwater Recharge

Wetlands usually cannot provide groundwater recharge. The build-up of sediment and organic matter debris at the bottom of the wetland prevents the downward movement of water into the subsoil.

Pollutant Removal

Wetlands are among the most effective practices for removing stormwater pollutants. Over thirty-five research studies have estimated the effectiveness of wetlands. Wetlands have high pollutant removal rates, and are more effective than any other practice at removing nitrate and bacteria. Table 2 provides pollutant removal data derived from the CWP's National Pollutant Removal Database for Stormwater Treatment Practices:

Table 2. Typical Pollutant Removal Rates of Wetlands (%) (Winer, 2000)

Pollutant	Stormwater Treatment Practice Design Variation			
	Shallow Marsh	ED Wetland[1]	Pond/Wetland System	Submerged Gravel Wetland[1]
TSS	83±51	69	71±35	83
TP	43±40	39	56±35	64
TN	26±49	56	19±29	19
NOx	73±49	35	40±68	81
Metals	36 - 85	(-80) - 63	0 - 57	21 - 83
Bacteria	76[1]	NA	NA	78

1:Data based on fewer than five data points

There is considerable variability in the effectiveness of wetlands, but it is believed that proper design and maintenance may help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wetlands.

Cost Considerations

Wetlands are a relatively inexpensive stormwater practice. Construction cost data for wetlands are rare, but one simplifying assumption is that they are typically about 25% more expensive than stormwater ponds of an equivalent volume. Using this assumption, an equation developed by Brown and Schueler (1997) to estimate the cost of Wet Ponds can be modified to estimate the cost of stormwater wetlands using the equation:

$C = 30.6V^{0.705}$

Where:

C = Construction, Design and Permitting Cost
V = Wetland Volume needed to control the 10-year storm (cubic feet)
Using this equation, typical construction costs are:
$ 57,100 for a 1 acre-foot facility
$ 289,000 for a 10 acre-foot facility
$ 1,470,000 for a 100 acre-foot facility

Wetlands consume about 3% to 5% of the land that drains to them, which is relatively high compared with other stormwater management practices. In areas where land value is high, this may make wetlands an infeasible option.

For wetlands, the annual cost of routine maintenance is typically estimated at about 3% to 5% of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Wetlands are long-lived facilities (typically longer than 20 years). Thus, the initial investment into these systems may be spread over a relatively long time period.

While no studies are available on wetlands in particular, there is some evidence to suggest that wet ponds may provide an economic benefit by increasing property values. The results of one study suggests that "pond frontage" property can increase the selling price of new properties by about 10% (US EPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25% when located near a wet pond (Emmerling-Dinovo, 1995). It is anticipated that well-designed wetlands, which incorporate additional aesthetic features, would have the same benefit.

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Stormwater Management Fact Sheet: Wet Pond

Description

Wet ponds (a.k.a. stormwater ponds, retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). Ponds treat incoming stormwater runoff by settling and algal uptake. The primary removal mechanism is settling while stormwater runoff resides in the pool. Nutrient uptake also occurs through biological activity in the pond. Wet ponds are among the most cost-effective and widely used stormwater treatment practices. While there are several different versions of the wet pond design, the most common modification is the extended detention wet pond, where storage is provided above the permanent pool in order to detain stormwater runoff in order to provide greater settling.

Applicability

Wet ponds are a widely applicable stormwater treatment practice. While they may not always be feasible in ultra-urban areas or arid climates, they otherwise have few restrictions on their use.

Regional Applicability
Wet extended detention ponds can be applied in most regions of the United States, with the exception of arid climates. In arid regions, it is difficult to justify the supplemental water needed to maintain a permanent pool because of the scarcity of water. Even in semi-arid Austin, TX one study found that 2.6 acre-feet per year of supplemental water were needed to maintain a permanent pool of only 0.29 acre-feet (Saunders and Gilroy, 1997). Other modifications and design variations are needed in semi-arid and cold climates, and karst (i.e., limestone) topography (for more information see *Stormwater Strategies for Arid and Semiarid Watersheds* , Article 66 in the Practice of Watershed Protection and *Performance of Stormwater Ponds in Central Texas*, Article 74 in the Practice of Watershed Protection).

Ultra Urban Areas
Ultra urban areas are densely developed urban areas in which little pervious surface exists. It is difficult to use wet ponds in ultra urban areas because enough land area may not be available for the pond. Wet ponds can, however, be used in an ultra-urban environment if a relatively large area is available downstream of the site.

Stormwater Hotspots
Stormwater hotspots are land use or activities that generate highly contaminated runoff that has pollutant concentrations that exceed those typically found in stormwater. A typical example is a gas station or convenience store. Wet ponds can accept runoff from stormwater hotspots, but need significant separation from groundwater if they are used to treat hotspot runoff.

Stormwater Retrofit
A stormwater retrofit is a stormwater treatment practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other watershed restoration objectives. Wet ponds are widely used for stormwater retrofits, and have two primary applications as a retrofit design. In many communities, dry detention ponds have been designed for flood control in the past. It is possible to modify these facilities to develop a permanent wet pool to provide water quality treatment (see "Treatment" under *Design Considerations*), and modify the outlet structure to provide channel protection. Alternatively, new wet ponds may be installed in streams, or in open areas as a part of a comprehensive watershed retrofit inventory.

Cold Water (Trout) Streams
Wet ponds pose a risk to cold water streams because of their potential to warm streams. When water remains in the permanent pool, it is heated by the sun. A study in Prince Georges County, MD found that wet ponds increased temperatures by about 9 F from the inlet to the outlet (Galli, 1990).

Siting and Design Considerations

Siting Considerations
Designers need to ensure wet ponds are feasible for the site in question. The following section provides basic guidelines for locating wet ponds.

- Drainage Area

Wet ponds need sufficient drainage area to maintain a permanent pool. In humid regions, a drainage area of about twenty-five acres is typically needed, but greater drainage areas are needed in arid and semi-arid regions.

Slope

Wet ponds can be used on sites with an upstream slope up to about 15%. The local slope within the pond should be relatively shallow, however. While there is no minimum slope requirement, there must be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system by gravity.

Soils /Topography

Wet ponds can be used in almost all soils and geology, with minor design adjustments for regions of karst topography (see *Design Considerations*).

Groundwater

Unless they receive hotspot runoff, ponds can often intersect the groundwater table. However, some research suggests that pollutant removal is moderately reduced when groundwater contributes substantially to the pool volume (Schueler, 1997) (for more information, see *Influence of Groundwater on Performance of Stormwater Ponds in Florida*, Article 78 in The Practice of Watershed Protection.

Design Considerations
There are some design features that should be incorporated into all wet pond designs (see Figure 1). These design features can be divided into five basic categories: *pretreatment, treatment, conveyance, maintenance reduction, and landscaping* (for more information, see the Manual Builder Category).

Pretreatment

Pretreatment features are designed to settle out coarse sediment particles before they reach the main pool. By trapping these sediments in the forebay, it is possible to greatly reduce the maintenance burden of the pond. A sediment forebay is a small pool (typically about 10% of the volume of the permanent pool) located near the pond inlet. Coarse sediments are trapped in the forebay, and these sediments are removed from the smaller pool on a five to seven year cycle.

Treatment

Treatment design features help enhance the ability of a stormwater treatment practice to remove pollutants. Several features can enhance the ability of wet ponds to remove pollutants from stormwater runoff. The purpose of most of these features is to increase the amount of time that stormwater remains in the pond.

One technique to increase pond pollutant removal is to increase the volume of the permanent pool. Typically, ponds are sized to be equal to the water quality volume (i.e., the volume of water treated for pollutant removal). Designers may consider using a larger volume to meet specific watershed objectives, such as phosphorous removal. Regardless of the pool size, designers need to conduct a water balance analysis to ensure that sufficient inflow is available to sustain a permanent pool.

Other design features can increase the amount of time stormwater remains in the pond, and help to eliminate short circuiting. Wet ponds should always be designed with a length to width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer flow path through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system.

Conveyance

Stormwater should be conveyed to and from all wet ponds safely and to minimize downstream erosion potential. The outfall of pond systems should always be stabilized to prevent scour. In addition, an emergency spillway should be provided to safely convey large flood events. In order to prevent warming at the outlet channel, designers should provide shade around the channel at the pond outlet.

Maintenance Reduction

Several design features can be incorporated to ease the maintenance burden of wet ponds. Maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One maintenance concern in wet ponds is potential clogging of the pond outlet. Ponds should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no low flow orifice should be less than 3" in diameter (smaller orifices are more susceptible to clogging).

Direct access is needed to allow maintenance of both the forebay and the main pool of ponds. In addition, ponds should generally have a drain to draw down the pond or forebay to enable periodic sediment clean outs.

Landscaping

Landscaping of wet ponds can make them an asset to a community, and can also enhance the pollutant removal. A vegetated buffer should be created around the pond to protect the banks from erosion, and provide some pollutant removal before runoff enters the pond by overland flow. In addition, ponds should incorporate an *aquatic bench* (a shallow shelf with wetland plants) around the edge of the pond. This feature provides some pollutant uptake, and also helps to stabilize the soil at the edge of the pond and enhance habitat and aesthetic value.

Design Variations

There are several variations of the wet pond design. Some of these design alternatives are intended to make the practice adaptable to various sites and to account for regional constraints and opportunities.

Wet Extended Detention Pond

The Wet Extended Detention Pond combines the treatment concepts of the dry extended detention pond (for more information see Dry Extended Detention Pond Fact Sheet) and the wet pond (see Figure 2). In this design, the water quality volume is split between the permanent pool and detention storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 12 to 48 hours. This design has similar pollutant removal to a traditional wet pond, and consumes less space. Wet Extended Detention Ponds should be designed to maintain at least half the treatment volume in the permanent pool. In addition, designers need to carefully select vegetation planted in the extended detention zone to ensure that it can withstand both wet and dry periods.

Pocket Pond

In this design variation, a pond drains a smaller area than a traditional wet pond, and the permanent pool is maintained by intercepting the groundwater. While this design variation achieves less pollutant removal than a traditional wet pond, it may be an acceptable alternative on sites where space is at a premium, or in a retrofit situation.

Water Reuse Pond

Some designers have used wet ponds to act as a water source, usually for irrigation. In this case, the water balance should account for the water that will be taken from the pond. One study conducted in Florida estimated that a water reuse pond could provide irrigation for a 100-acre golf course at about one seventh the cost of the market rate of the equivalent amount of water ($40,000 versus $300,000).

Regional Adaptations

Semi-Arid Climates

In arid climates, wet ponds are not a feasible option (see *Application*), but they may be possible in semi-arid climates if the permanent pool is maintained with a supplemental water source, or if the pool is allowed to vary seasonally. This choice needs to be seriously evaluated, however. Saunders and Gilroy (1997) reported that 2.6 acre-feet per year of supplemental water were needed to maintain a permanent pool of only 0.29 acre-feet in Austin, TX (for more information see *Stormwater Strategies for Arid and Semiarid Watersheds*, Article 66 in The Practice of Watershed Protection).

Cold Climates

Cold climates present many challenges to designers of wet ponds. The spring snowmelt may have a high pollutant load, and large volume to be treated. In addition, cold winters may cause freezing of the permanent pool or freezing at inlets and outlets. Also, high salt concentrations in runoff resulting from road salting may impact pond vegetation, and sediment loads from road sanding may quickly reduce pond capacity.

One means of effectively dealing with spring snowmelt is to use a seasonally operated pond to capture extra snowmelt during the spring, but retain a smaller permanent pool during warmer seasons. In this option, proposed by Oberts (1994), a wet pond has two water quality outlets, both equipped with gate valves. In the summer, the lower outlet is closed. During the fall and throughout the winter, the lower outlet is opened to draw down the permanent pool. As the spring melt begins, the lower outlet is closed to provide detention for the melt event. This method can act as a substitute to using a minimum extended detention storage volume. When wetlands preservation is a downstream objective, seasonal manipulation of pond levels may not be desired (for more information, see *Performance of Stormwater Ponds and Wetlands in Winter*, Article 71 in The Practice of Watershed Protection). An analysis of the effects on downstream hydrology should be conducted before considering this option. In addition, the manipulation of this system requires some labor and vigilance; a careful maintenance agreement should be confirmed.

Several other modifications help to improve the performance of ponds in cold climates. Designers should consider planting the aquatic buffer with salt-tolerant vegetation if the pond receives road runoff. In order to counteract the effects of freezing on inlet and outlet structures, weirs and larger diameter pipes that are resistant to frost can be used. Designing ponds on-line, which create a continuous flow of water through the pond, also helps prevent freezing of outlet structures. Finally, since freezing of the permanent pool can reduce the effectiveness of pond systems, it may be useful to incorporate extended detention into the design to retain usable treatment area above the permanent pool while it is frozen (for more information, see *Performance of Stormwater Ponds and Wetlands in Winter*, Article 71 in The Practice of Watershed Protection).

Karst Topography

In karst (i.e., limestone) topography, wet ponds should be designed with an impermeable liner to prevent groundwater contamination or sinkhole formation, and to help maintain the permanent pool.

Limitations

Limitations of wet ponds include:

- When improperly located, wet pond construction may cause loss of natural wetlands or high quality forest.
- Although wet ponds consume a small amount of space relative to their drainage areas, they are often inappropriate in dense urban areas because each pond is generally quite large.
- Use of ponds is restricted in arid and semi-arid regions due to the need to supplement the permanent pool.
- In cold water streams, wet ponds are not a feasible due to the potential for stream warming.
- Wet ponds may cause some community concerns regarding safety.

Maintenance Considerations

In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed. The table below outlines these practices.

Table 1. Typical Maintenance Activities for Wet Ponds (Source: WMI, 1997)

Activity	Schedule
• Inspect for damage. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational	Annual Inspection
• Repair undercut or eroded areas.	As Needed Maintenance
• Clean and remove debris form inlet and outlet structures. • Mow side slopes.	Monthly Maintenance
• Removal of sediment form the forebay	5 to 7 year Maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, or the pond becomes eutrophic.	20 to 50 year Maintenance

Effectiveness

Stormwater treatment practices can be used to achieve four broad resource protection goals. These include:

Flood Control, Channel Protection, Groundwater Recharge, and *Pollutant Removal* (for more information, see the Manual Builder Category.) Wet ponds can generally provide flood control channel protection, and pollutant removal functions.

Flood Control
One objective of stormwater treatment practices is to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Wet ponds can easily be designed for flood control, by providing flood storage above the level of the permanent pool.

Channel Protection
One result of urbanization is channel erosion caused by increased stormwater runoff. Traditionally wet ponds have been designed to provide control of the two-year storm . It appears that this design storm has not been effective in preventing channel erosion, and recent research suggests that control of a smaller storm may be more appropriate (MacRae, 1996). Choosing a smaller design storm (one-year) and providing longer detention time (12 to 24 hours) is now thought to be the best method to reduce channel erosion.

Groundwater Recharge
Wet ponds generally cannot provide groundwater recharge, as infiltration is impeded by the accumulation of organic debris on the bottom of the pond.

Pollutant Removal
Wet ponds are among the most effective stormwater treatment practices at removing stormwater pollutants. A wide range of research is available to estimate the effectiveness of wet ponds. Table 2 provides pollutant removal estimates derived from CWP's National Pollutant Removal Performance Database for Stormwater Treatment Practices:

Table 2. Pollutant Removal Efficiency of Stormwater Wet Ponds (Winer, 2000)

Pollutant	Removal Efficiency (%)
TSS	80±27[1]
TP	51±21
TN	33±20
NOx	43±38
Metals	29-73
Bacteria	70±32

1: ± values represent one standard deviation

There is considerable variability in the effectiveness of wet ponds, and it is believed that properly designing and maintaining ponds may help to improve their performance. The locational and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wet ponds. A recent joint project between the American Society of Civil Engineers (ASCE) and the US EPA Office of Water may help to isolate specific design features that can improve performance. **The National Stormwater Best Management Practice (BMP)** database is a compilation of stormwater practices which includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. For more information on this database, access the ASCE web page at http://www.asce.org.

Cost Considerations

Wet ponds are relatively inexpensive stormwater practices. The construction costs associated with these facilities range considerably. A recent study (Brown and Schueler, 1997) estimated the cost of a variety of stormwater management practices. The study resulted in the following cost equation, adjusting for inflation:

$C = 24.5V^{0.705}$

Where:

C = Construction, Design and Permitting Cost
V = Volume in the Pond to Include the 10-Year Storm (cubic feet)
Using this equation, a typical construction costs are:
$ 45,700 for a 1 acre-foot facility
$ 232,000 for a 10 acre-foot facility
$ 1,170,000 for a 100 acre-foot facility

Ponds do not consume a large area (typically 2-3% of the contributing drainage area). Therefore, the land consumed to design the pond will not be very large. It is important to note, however, that these facilities are generally large. Other practices, such as filters or swales, may be "squeezed" into relatively unusable land, but ponds need a relatively large continuous area.

For ponds, the annual cost of routine maintenance is typically estimated at about 3 to 5% of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment into ponds systems may be spread over a relatively long time period.

In addition to water resource protection benefits of wet ponds, there is some evidence to suggest that they may provide an economic benefit by increasing property values. The results of one study suggest that "pond front" property can increase the selling price of new properties by about 10% (US EPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25% when located near a wet pond (Emmerling-Dinovo, 1995).

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NAME: Constructed Treatment Wetland

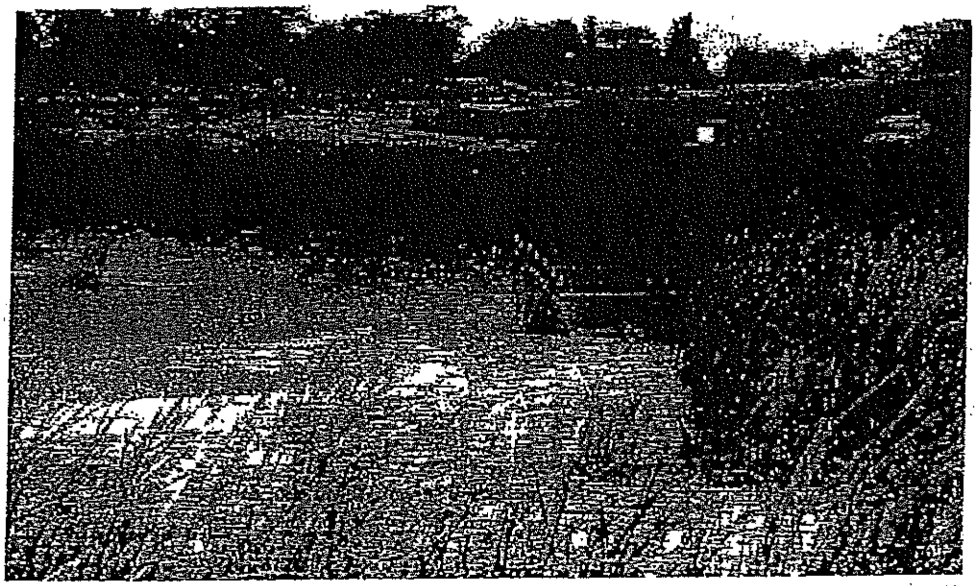
DEFINITION: Constructed treatment wetlands are artificial shallow water-filled basins that have been planted with emergent plant vegetation. Constructed treatment wetlands are designed to achieve specific stormwater water-quality objectives before the water is discharged.

PURPOSE: Constructed treatment wetlands can be an efficient method for removing a wide variety of pollutants, such as suspended solids, nutrients (nitrogen and phosphorus), heavy metals, toxic organic pollutants, and petroleum compounds. Wetlands also are an effective means of reducing peak runoff rates and stabilizing flow to adjacent natural wetlands and streams.

PERMANENT

COMPANION BMPS:
- DRY POND
- FILTER STRIP
- CRITICAL AREA PLANTING
- GRASS SWALE
- OUTLET STABILIZATION STRUCTURE

ALTERNATIVE BMPS:
- WET POND
- RIPARIAN FORESTED BUFFER
- BIORETENTION



Source: CH2M HILL

APPLICATION: Constructed treatment wetlands require an area sufficiently large for impounding stormwater in shallow basins. In sloping terrain, wetland cells can be arranged in series on terraces. Treatment wetlands can be completely artificial. Alternatively, for limited applications, existing natural wetlands can be used to accept pretreated runoff from watersheds that are adversely affected by urbanization or agricultural land use. Constructed wetlands are appropriately located at the lower parts of sites.

RECOMMENDED DESIGN CRITERIA:

Requirements for Regulatory Compliance

Stormwater wetlands that are constructed entirely outside of the Waters of the United States (33 CFR Part 328), and are explicitly designed for stormwater management, are not subject to the provisions of Sections 401 and 404 of the Clean Water Act. However, when the stormwater wetlands are abandoned, they may be regulated as wetlands.

Existing wetlands may be used as part of a stormwater management system if the wetland can be considered an "urban or degraded nontidal wetland" and no feasible alternatives exist (U.S. Army Corps of Engineers (USCOE), 1997). When the specific conditions established by USEPA are satisfied, construction in an existing wetland for creating or enhancing stormwater management functions is permitted under the Clean Water Act, Section 404(b)(1). In addition, the provisions of 25 Pennsylvania Chapter 105 must be considered before initiating any project that will influence existing wetlands.

Wetlands that 1) will have a contributing drainage area exceeding 100 acres, 2) will have embankments higher than 15 feet, measured from the downstream toe, or 3) will impound more than 50 acre-feet of runoff during the high-water condition, may be regulated as dams PADEP. The designer should consult 25 Pennsylvania Chapter 105 to determine which provisions may apply to a specific project.

Performance-Based Guidelines

Pretreatment Requirements

Most raw stormwater must be pretreated to maximize the treatment effectiveness and ancillary wildlife benefits of treatment wetlands. In particular, highly variable water levels and high hydraulic loading rates (HLRs) are not conducive to wetland plant survival and treatment efficiency. In many instances, stormwater flows should be attenuated and equalized in a preliminary DRY POND, or forebay, to optimize pollutant assimilation in the wetland. Pretreatment in stormwater pond systems or conveyance facilities such as grass swales also may be important for reducing high sediment and pollutant loads before they are discharged to the treatment wetland. Approaches for implementing pretreatment are presented in the BMP descriptions for WET POND and GRASS SWALE.

Area Requirements

The design of constructed treatment wetlands requires knowledge of pollutant influent concentrations, base flow and stormwater flow rate characteristics, and effluent goals. Constructed treatment wetlands typically are designed to achieve a specific HLR, computed as the design inflow rate divided by the surface area of the wetland. For stormwater wetlands, the water quality design storm should be used as the basis for computing the design inflow rate (see Section 5.3 of the Handbook). A conservative approach is to use the time-weighted average of the highest inflow rates occurring during a 1-hour time period.

The North American Wetland Treatment System Database (USEPA, 1993) and other similar data, are a basis for designing most wetland treatment systems. Kadlec and Knight (1996) have developed area-based, first-order wetland design models to predict treatment area requirements. HLRs computed using this method will vary widely, because of site-specific differences in runoff quality, discharge requirements, seasonal low temperatures, and stormwater flow characteristics.

Depth Requirements

The water balance for the facility, including infiltration, percolation and evapotranspiration losses must be calculated to determine the expected range of pool levels. Wetland plants are dependent upon saturated soil conditions for varying time periods. The plants typically incorporated in constructed wetlands will require some standing water in deep zones during all but the driest periods. Shallow water zones can be dry at the surface for longer periods, but not exceeding

1 month. The permeability of the wetland base may need to be reduced by introducing a clay layer to maintain the required hydroperiod for wetland plant communities.

The wetland vegetation depends greatly on water depth. Shallow areas, typically 1 foot in depth, enable emergent plant vegetation to grow, whereas submerged plants prefer deeper water. Large unvegetated open-water areas near the wetland outlet should be avoided so the potential planktonic algae growing is reduced. As a "rule-of-thumb," the shallow water zone should comprise at least 80 percent of the total wetland area.

In addition to the treatment objectives, consideration must be given to the ability of the vegetation to accommodate the range of inundation depths anticipated in the wetland. Some wetland systems have failed because of transient hydraulic problems. To prevent the disruption of the wetland plant communities and to improve the pollutant-removal efficiency, wetlands may be constructed in combination with stormwater detention facilities. In this way, the peak flow rate to the wetlands during rainfall events can be reduced and flows equalized.

As an alternative, so-called extended detention wetlands can be designed by providing adequate wetland area and embankment freeboard to impound the design storm. If the base elevation of the supplemental detention area is approximately equal to the normal pool elevation, a new growth zone is created in which water is ephemerally ponded adjacent to the margins of the permanent pool.

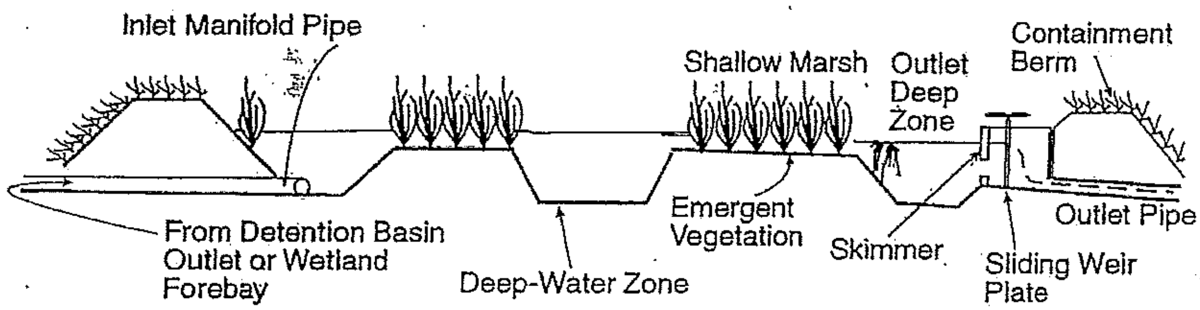


Figure 1. Schematic cross section of constructed treatment wetland.

Hydraulic Requirements

Stormwater wetlands are likely to have periods without inflow between storm events. However, a regular supply of inflow water is preferred for the biological health of the system. Flow equalization ponds upstream of treatment wetlands should be designed with outlet structures that detain flow over the longest practical interval to help maintain a steady flow to the wetland. If the inflow of water is not reliable, episodes of stagnant water will interfere with the treatment function of the wetland and increase the likelihood of mosquitoes and nuisance odors. A method for manually adjusting the normal water level should be provided. Being able to adjust the water level is important for assisting plant growth in the early phases of development and for optimizing performance in response to seasonal variations in inflow rate. The outlet design must be resistant to fouling by floating or submerged plant material and accessible to operators.

Even distribution of flow is vital for achieving the treatment function of wetlands. Narrow, deep water zones should be at the inlet and outlet to balance head conditions and evenly distribute flow.

Inlets also may incorporate pipe manifolds to enhance flow distribution. Deep water zones, oriented transverse to the direction of flow, and internal berms, oriented parallel to flow, also can be used to minimize the potential for short-circuiting of flow.

Embankments must be designed to accommodate:

1. High water events associated with large rainfall events
2. Head loss through the system under varying operating conditions

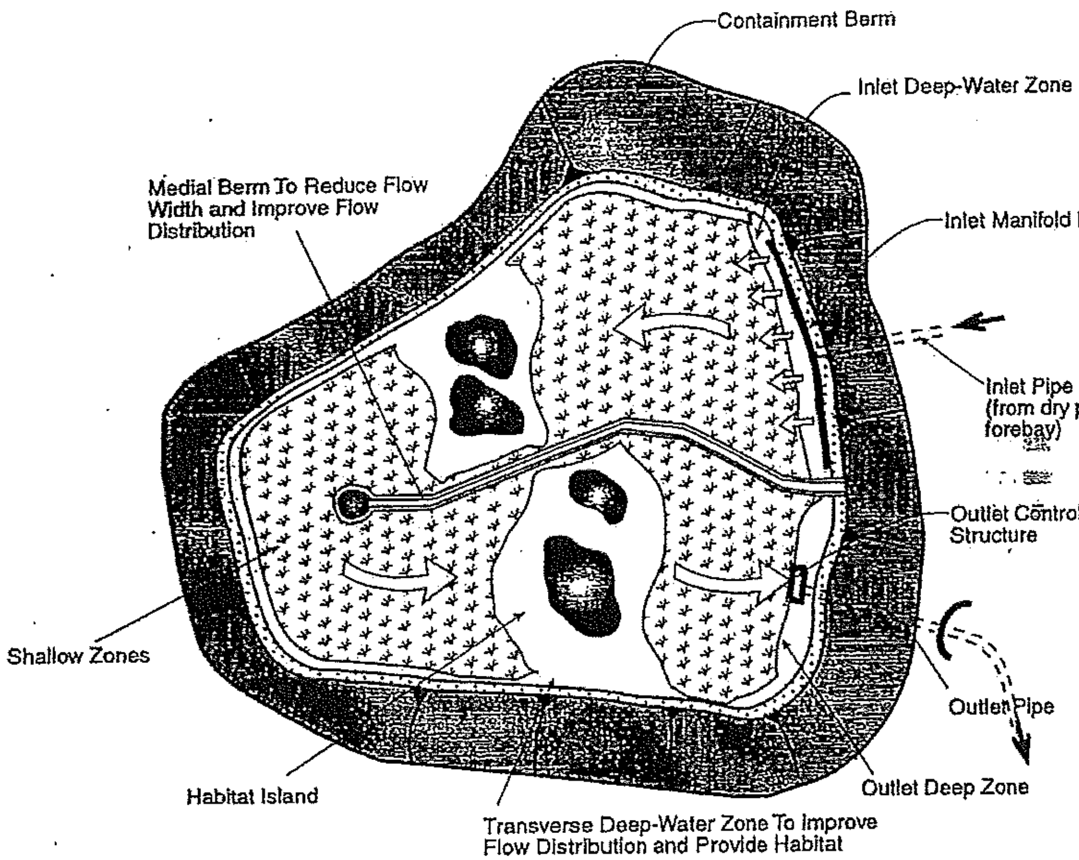


Figure 2. Conceptual layout of constructed treatment wetland.

Head loss is an especially important consideration for stormwater treatment wetlands where a large range in flow rates are encountered. Mathematical descriptions are often adaptations of open-channel flow formulae. The formulae are discussed in detail in a number of texts (for example, French, 1985) and empirical constants from treatment wetlands are available (Kadlec and Knight, 1996). The general approach uses equations for mass, energy, and momentum conservation coupled with an equation for frictional resistance. Examples of the equations are in the "Specifications and Methodology" section. All wetlands must have a high-level outlet to pass large runoffs from storm events.

Plant Requirements

High pollutant-removal efficiencies are dependent on a dense cover of emergent plant vegetation. Actual plant species do not appear to be as important as plant growth habit. In particular, species should be used that have high colonization and growth rates, can establish large surface areas that continue through the winter dormant season, have high potential for treating pollutants, and are very robust in continuously flooded environments. Noninvasive native species should be emphasized. Examples include bulrush (*Scirpus sp.*), arrowhead (*Sagittaria latifolia*), soft rush (*Junus effusus*), and pickerelweed (*Pontederia cordata*). Other plant species can be incorporated in constructed treatment wetlands to enhance ecosystem diversity and to create greater wildlife value. A comprehensive list of wetland plant species adapted for incorporation in constructed treatment wetlands is provided in Appendix H.

OPERATION AND MAINTENANCE: The designer should understand the biological requirements of the plants and manage water levels to provide for their needs. Optimum conditions are not always required. The plants' environment is most critical during seed germination and early establishment of plants.

Wetland plants can be drowned by excessive water depth. Usually, initial growth is best with transplanted plants in wet, but well-aerated soil. Leaving the majority of the growing plants exposed, and occasionally inundating, will enable the plants to obtain oxygen and grow fastest. On the other hand, frequent soil saturation is important for wetland plant survival.

Plant cover needs to be assessed periodically and documented. Dramatic shifts can occur as plant succession proceeds. The plant community reflects management and can indicate improvement or problems. For example, submergent aquatic plants such as pondweed (*Potamogeton pectinatos*) require that light penetrate into the water column. The disappearance of these plants indicates problems with water clarity.

Dikes, embankments, and hydraulic control structures should be inspected regularly and immediately after any unusual flow event. Wetlands also should be checked after periods of rapid ice break-up. Any damage, erosion, or blockage should be corrected as soon as possible.

Unlike wet or dry stormwater ponds, sediment is rarely removed from constructed treatment wetlands. Sediment removal disturbs stable vegetation cover and disrupts flow paths through the wetland. The embankment height of constructed treatment wetlands should be designed to accommodate the gradual accumulation of sediment over the lifetime of the facility. Likewise, outlets should be designed to compensate for sediment accumulation by allowing the normal pool elevation to be adjusted to higher levels.

CONSIDERATIONS: As Figure 3 shows, wetlands are effective sedimentation devices and provide conditions that facilitate the chemical and biological processes that cleanse water. Pollutants are taken up and transformed by plants and microbes, buried in sediment, or released in the wetland's discharge.

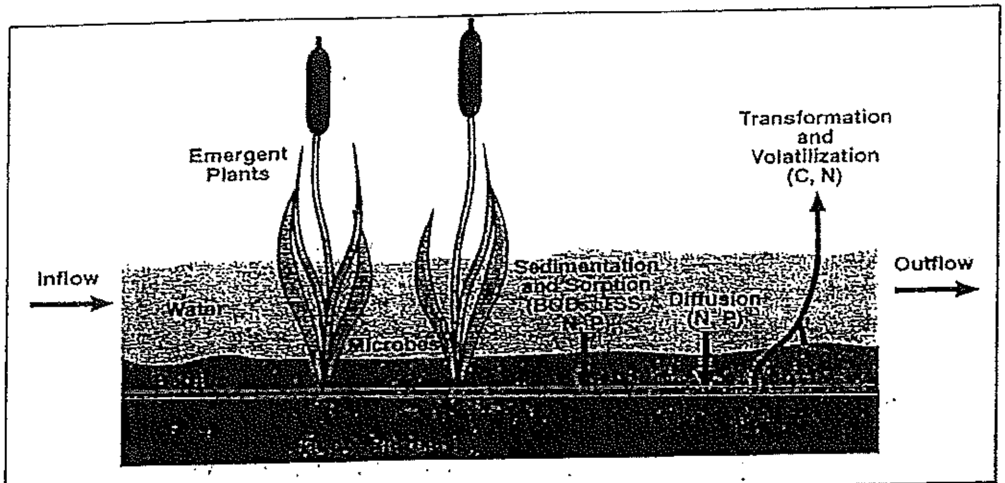


Figure 3. Wetland microbes, plants, and soil transform and take up pollutants in the wastewater.

Plants improve water quality by slowing water flow, settling solids, taking up wastewater pollutants, and supplying reduced carbon and attachment area for microbes (bacteria and fungi). Of these functions, the most important are physical; dense stands of vegetation create the quiescent conditions that facilitate the physical, chemical, and biological processes that cleanse water. Most herbaceous wetland plants die annually. Because the dead plant material requires months to years to decompose, a dense layer of plant litter accumulates. Like the living vegetation, the litter creates a substrate that supports bacterial growth and physically traps solids.

The most important microbial processes are decomposition of organic compounds, ammonification (conversion of organic nitrogen to ammonia), nitrification (conversion of ammonia to nitrite and nitrate), and denitrification (release of nitrogen to the atmosphere).

Microorganisms, adhering to vegetation, roots, and sediment in the wetland can convert significant quantities of nitrate directly to nitrogen gas. Large amounts of nitrogen and phosphorus also can be incorporated in new soil and in the extra biomass of the wetland vegetation. For these reasons, maintaining the health of the vegetative community is critical.

Long-term data from wetland treatment systems indicate that treatment performance for parameters such as 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), and total nitrogen (TN) typically does not deteriorate with age. However, the dissolved oxygen (DO) concentration in wetland effluent may be below 1.0 mg/L. Higher DO concentrations can be achieved in effluent by incorporating turbulent or cascading discharge zones.

Site conditions that may increase the cost of constructed treatment wetlands included high land costs, sloping topography, highly permeable soil, and low depth to bedrock. A liner may be required in some constructed treatment wetlands to reduce percolation and conserve water. Wetland topsoil must be suitable for healthy plant growth. Where the existing site soil is unsuitable for growth (such as clayey or rocky soil), it is beneficial to apply a rooting zone of about 12 inches of loamy or sandy soil. Embankments must be designed with adequate freeboard to accommodate the accretion of sediment over the design life of the facility.

REFERENCES:

Nursery Information and Referral Assistance

Pennsylvania Landscape Nurseryman's Association, 1707 S. Cameron St., Harrisburg, Pa. 17104 [800-898-3411]

Morris Arboretum, 9414 Meadowbrook Ave., Philadelphia, Pa. [215-247-5777]

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SPECIFICATIONS AND METHODOLOGY:

First-Order, Area-Based Constructed Wetland Sizing Model for Conceptual Design

(Based on Kadlec and Knight, 1996)

General Model:

$$J = k(C - C^*) \text{; where} \quad k = k_{20}\,\theta_k^{(T-20)}, \quad C^* = C^*_{20}\,\theta_c^{(T-20)}$$

where:
- J = removal rate ($g/m^2/yr$)
- k = first-order, area-based rate constant (m/yr)
- k_{20} = rate constant at 20°C (m/yr)
- C = pollutant concentration (mg/L)
- C^* = irreducible background concentration (mg/L)
- C^*_{20} = irreducible background concentration at 20°C (mg/L)
- T = temperature, °C
- θ_c = temperature coefficient for background concentration
- θ_k = temperature coefficient for rate constant

Wetland Area (based on modified plug-flow hydraulics):

$$A = Q / HLR = -\frac{Q}{k}\left[\ln\left(\frac{C_2 - C^*}{C_1 - C^*}\right)\right]$$

where:
- HLR = hydraulic loading rate (m/yr)
- A = wetland area at normal pool elevation (m^2), excluding habitat islands
- Q = design inflow rate (m^3/yr)
- C_1 = inflow concentration (mg/L)
- C_2 = outflow concentration (mg/L)

Model Parameter Values (at 20°C):

	BOD	TSS	NH_4-N	NO_3+NO_2-N	TN	TP
k_{20}, m/yr	35	1,000	18	35	22	12
θ_k	1.00	1.00	1.04	1.09	1.05	1.00
C^*_{20}, mg/L	6	$5.1+0.16C_1$	0.0	0.0	1.5	0.02
θ_c	—	1.065	—	—	—	1.00

Outlet Design

The outlet for the wetland should be designed to achieve two objectives:

1. Enable adjusting the normal operating level of the wetland manually
2. Detain stormwater

Wetlands should have both low-level and high-level outlets. High-level outlets such as weir boxes or broadcrested spillways should be sized to pass the 100-year 24-hour storm event (or larger maximum design storm event). The low-level outlet should be readily adjustable to change the normal pool elevation. In many instances, the wetland also will be designed to achieve a specific runoff peak attenuation. Flow routing using the methods described in the WET POND BMP should be used for the design. If forebays or detention ponds are used for equalizing flow, a multipond routing approach will be required.

The outlet device in Figure 4 incorporates the following design features:

- High-level weir box overflow
- Mid-depth opening to exclude floating plant material or bottom debris
- Adjustable V-notch weir
- Easy accessibility for inspection and maintenance

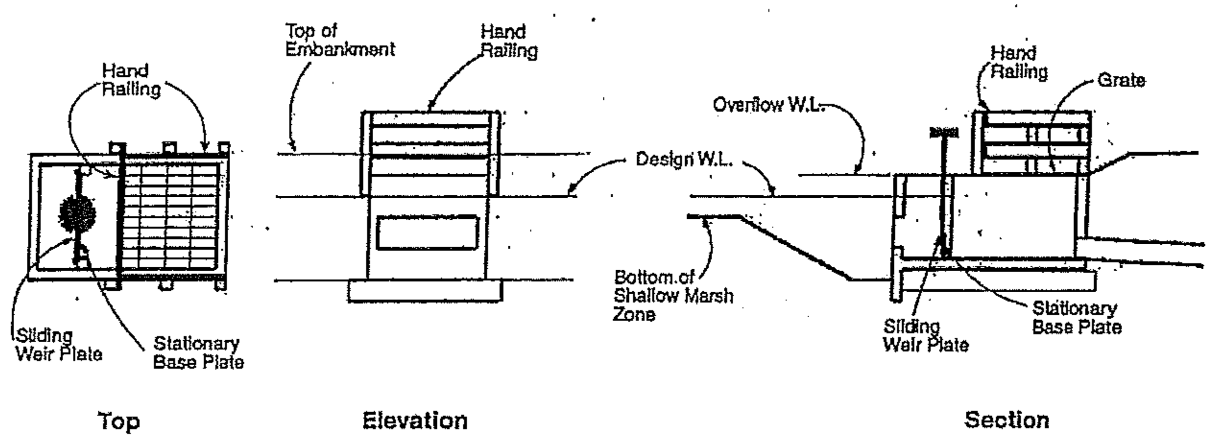


Figure 4. Design of typical outlet control structure.

Infiltration Design and Water Balance

The rate of infiltration through the base of the wetland can be estimated by using Darcy's law. For most wetlands, the rate of infiltration is relatively constant. Wetlands act as storage reservoirs, retaining water during precipitation events and releasing it slowly as outlet flow and infiltration. During summer months when evapotranspiration losses are large, pool levels commonly drop episodically below the design operating level and outflow ceases. However, water infiltrated in the wetland will continue to replenish the water table and will help stabilize base flow to adjacent drainages.

Ideally, wetlands should not completely dewater under conditions of normal precipitation. To identify potential problems, a monthly water balance should be constructed for the wetland. The pool level at the end of each month can be estimated as follows:

$$PL = PL0 + [BF + (PR \times AW) + (PR \times AD \times RO) - (ET \times AW) - (I \times A)]/A$$

Where:

PL	=	Pool depth at the end of month (feet)
$PL0$	=	Pool depth from the previous month (feet)
BF	=	Total monthly flow into the wetland (acre-feet)
PR	=	Total monthly precipitation (feet)
AW	=	Area of wetland (acres)
AD	=	Area of tributary drainage (acres)
RO	=	Runoff coefficient
ET	=	Monthly potential evapotranspiration (feet)
A	=	Area inundated at depth PL0 (acres)
I	=	Monthly infiltration (feet)

If PL is greater than the normal pool depth established at the outlet, then outflow will occur during that month. The quantity is not important. In months with a net outflow, the beginning pool depth for the next month will equal the normal pool depth.

Tables or equations for estimating potential evapotranspiration are available from many sources, including Kadlec and Knight (1996). However, for a conceptual design, wetland evapotranspiration can be estimated as 80 percent of the pan evaporation rate.

In most wetlands, the area that is inundated varies with depth. The normal operating pool depth also may be adjusted seasonally to accommodate changes in the water budget. These factors should be accounted for in the calculation.

If the water balance predicts that the wetland will dewater, design modifications can be considered, including:

- Reducing the infiltration rate by adding a clay layer or synthetic liner
- Increasing the drainage area that is tributary to the wetland
- Increasing the normal operating pool level

Limitations on increasing the normal pool level will be imposed by the need for shallow water habitat to support emergent plant vegetation.

Short periods during which the wetland becomes dry may be tolerated in some instances. However, the selection of plants must be tailored to accommodate these adverse conditions and special considerations will be required for the maintenance of the wetland during dry periods.

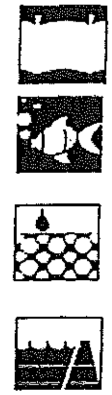
NAME: Bioretention

DEFINITION: Two general types of bioretention facilities exist: off-line areas and on-line areas. Off-line bioretention areas consist of sand and soil mixtures planted with native plants, which receive runoff from overland flow or from a diversion structure in a traditional drainage system. On-line bioretention areas have the same composition as off-line areas, but are located in grass swales or other conveyance systems that have been modified to enhance pollutant removal by quiescent settling and biofiltration.

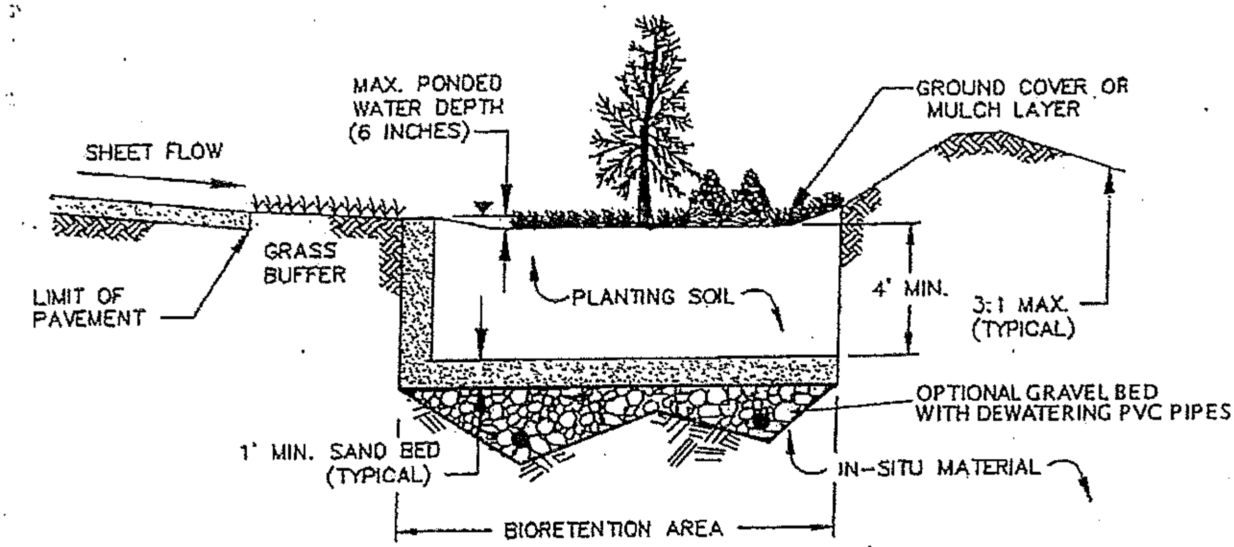
PERMANENT

COMPANION BMPS:
- GRASS SWALE
- FILTER STRIP
- PERMANENT VEGETATIVE STABILIZATION

ALTERNATIVE BMPS:
- INFILTRATION TRENCH AND DRY WELL
- WET POND
- CONSTRUCTED TREATMENT WETLAND



PURPOSE: Bioretention is an efficient method for removing a wide variety of pollutants, such as suspended solids and nutrients. It can also be an effective means of reducing peak runoff rates and recharging groundwater by infiltrating runoff. However, not all bioretention facilities will necessarily be optimized for all of these functions.



(Adapted from Prince George's County, 1993)

APPLICATION: Bioretention areas, consisting of sand and soil mixtures planted with native plants, which filter urban runoff, can be used in residential and nonresidential developments. Sources of runoff can be overland flow from impervious areas or discharge diverted from a drainage pipe. Also, on-line bioretention facilities use check dams or other barriers to retain flow in grass swales.

Bioretention facilities are most effective if they receive runoff as close as possible to the source. A site designer needs to look for opportunities to incorporate bioretention facilities throughout the site and minimize the use of inlets, pipes, and downstream controls. Prince George's County, Maryland, which initially developed the bioretention concept, reports saving as much as 50 percent on drainage infrastructure costs in developments that incorporate bioretention facilities.

Bioretention should not be used in areas with the following characteristics:

- The water table is within 6 feet of the land surface (the use of collector pipes may reduce this limitation).
- Mature trees would be removed for constructing the bioretention area.
- Slopes are 20 percent or greater.
- An unstable soil stratum is in the proximity.

Off-Line

Off-line bioretention facilities can be applied to most development situations. They are particularly applicable in urban areas where the opportunities and the land available for controlling stormwater reliably are scarce. Bioretention facilities may be installed in median strips, parking lot islands, or lawn areas of commercial developments. They also can be used in residential subdivisions with open drainage systems or in easements located around lots. Figure 1 shows a bioretention area receiving runoff diverted from a storm sewer.

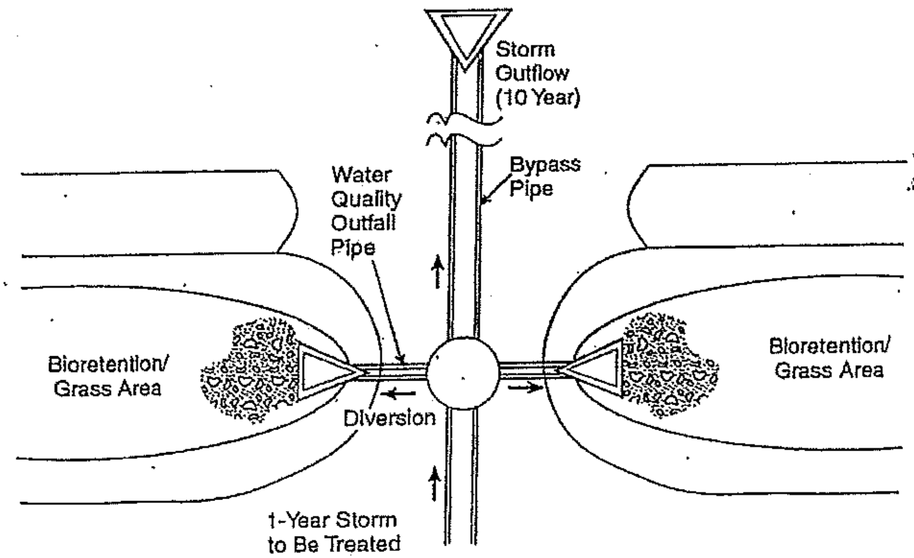


Figure 1. Storm sewer diversion into bioretention area

On-Line

On-line bioretention facilities use check dams to "collect" the water in the bioretention area, as shown in Figure 2. Adding a bioretention area behind the check dam allows filtering and sedimentation to occur. Check dams should only be used in small open channels or in filter strips that drain 5 acres or less. Runoff from storms larger than the water quality design storm should safely flow over or bypass the bioretention area.

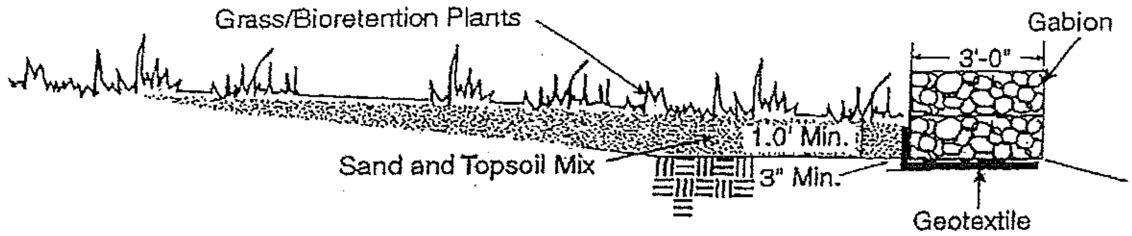


Figure 2. Bioretention cross section; bioretention facility incorporated in a grass swale with flat to mild slope.

RECOMMENDED DESIGN CRITERIA:

Requirements for Regulatory Compliance

(none specified)

Performance-Based Guidelines

Bioretention facilities should be optimized to treat the runoff generated by the water quality design storm. The peak discharge from larger storms should be bypassed, if possible.

For off-line bioretention systems, the Prince George's County's design manual recommends using planting soil ranging from 10 to 25 percent clay along with sandy loam, loamy sand, or loam texture. The soil pH should range between 5.5 and 6.5. The soil should be placed in lifts less than 18 inches and lightly compacted by tamping with a bucket from a bulldozer or a backhoe. A desirable planting soil would:

- Be permeable to allow infiltration of runoff
- Adsorb organic nitrogen and phosphorus

In areas where clay contents are higher and the soil is not conducive to infiltration, the bioretention facility can be modified with a collector pipe system installed beneath the basin to form a bioretention filter. The City of Alexandria has developed design guidelines for bioretention filters (City of Alexandria, 1995) and collector pipes for areas of clay soil.

Bioretention areas can be used successfully in a wide range of drainage areas. Median strips, ramp loops, and parking lot islands are examples of small drainage areas (less than 1 acre). In large drainage areas (less than 10 acres), diversion structures and energy dissipation devices need to be incorporated into the design to preserve the integrity of the bioretention area.

The Prince George's County's design manual recommends that the size of the bioretention area be 5 percent to 7 percent of the drainage area multiplied by the *c* coefficient of the rational formula. Smaller and larger ranges are being constructed in Virginia. Ongoing monitoring data will provide better guidance on the design of these facilities. The land required for bioretention facilities can be reduced by partially substituting vertical-extended detention storage for horizontal storage.

Check dams, as shown in Figure 2, reduce the velocity of concentrated stormwater flows, promoting sedimentation behind the dam. If properly anchored, railroad ties, gabions, or rock filter berms may be used as check dams. The use of railroad ties is shown in Figure 3. The use of gabions as a drop structure is shown in Figure 4. These types of structures can be used in swales with moderate slopes.

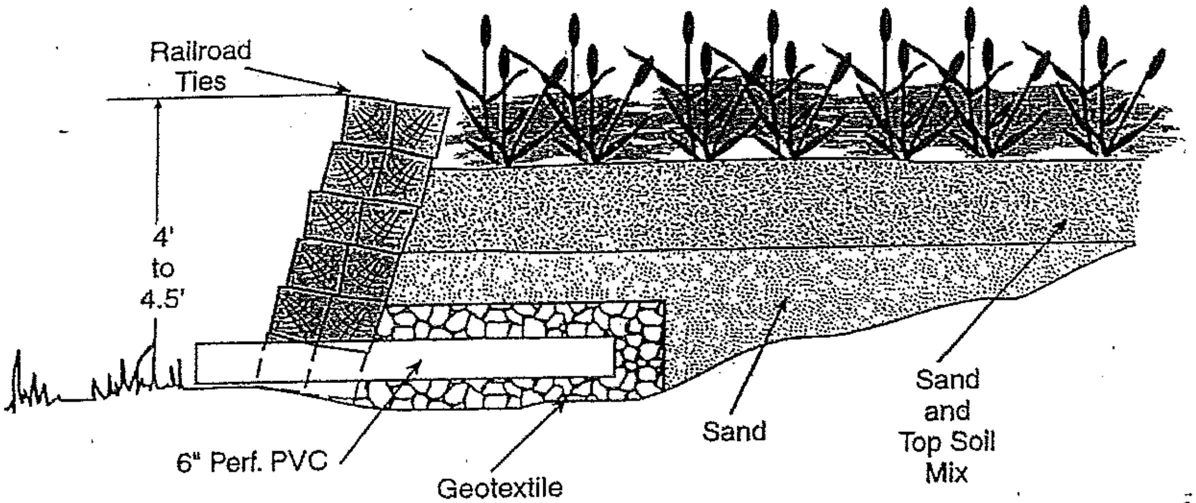


Figure 3. Bioretention cross section; bioretention facility incorporated in a grass swale with mild to moderate slope.

Check dams must be sized and constructed correctly and maintained properly, or they will be either washed out or contribute to flooding. The relationship between ponding depth and discharge rate can be computed by using the critical-depth formula, which accounts for a generalized weir profile. The relevant equation is:

$$Q = ((A^3 \times g) / T)^{1/2}$$

Where:
- Q = discharge rate
- A = area subtended by top of check dam and ponding elevation
- T = width of check dam
- g = gravitational constant

Check dams can be constructed of either rock or logs. The use of other natural materials available on the site that can withstand the stormwater flow velocities is acceptable. Check dams should not be constructed from straw bales or silt fences, because concentrated flows quickly wash out these materials.

Maximum velocity reduction is achieved if the toe of the upstream check dam is at the same elevation as the top of the downstream dam. The center section of the dam should be lower than the edge sections to minimize the potential for erosion of the abutments during frequently occurring storm events.

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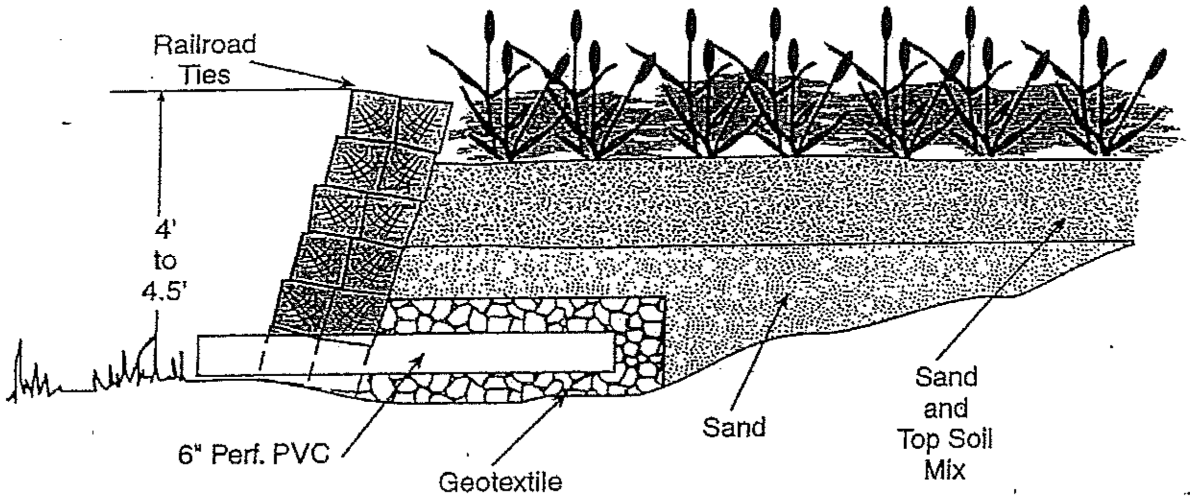

Figure 3. Bioretention cross section; bioretention facility incorporated in a grass swale with mild to moderate slope.

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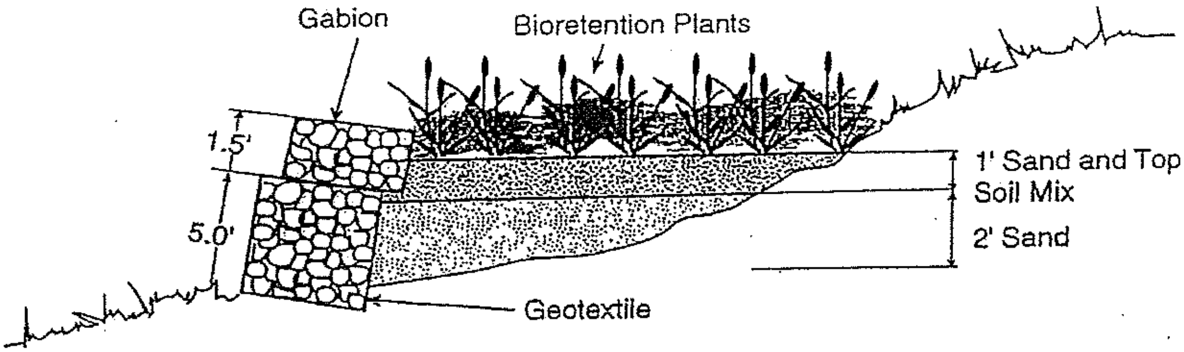


Figure 4. Bioretention cross section; bioretention facility incorporated in a grass swale with mild to moderate slope.

Bioretention facilities can be incorporated in an overall site plan for capturing runoff and recharging groundwater. Comparatively small, frequently occurring storms are most appropriate for establishing design criteria where ground recharge occurs (see Appendix F, *Runoff Capture Design*). The appropriate design criterion is the maintenance of the total annual runoff volume below a fixed value (usually the predevelopment runoff volume). Additional information on how to use this criterion for designing bioremediation facilities is in "Specifications and Methodology."

OPERATION AND MAINTENANCE: Monthly inspections are recommended until the plants are established. Annual inspections should then be adequate. Accumulated sediment behind check dams should be removed when it reaches one-half the sump depth.

CONSIDERATIONS: Collector pipe systems, if used, in bioretention areas can become clogged by underlying clay soil. Pipe cleanouts are recommended to facilitate unclogging of the pipes without disturbing the bioretention areas.

REFERENCES:

Bitter, S.D. and J.K. Bowers. "Bioretention as a Water Quality Best Management Practice." *Watershed Protection Techniques.* Vol. 1, No. 3. 1994.

City of Alexandria (Virginia). *Alexandria Supplement to the Northern Virginia BMP Handbook,* Section XIII, Bioretention and Bioretention Filters. Department of Transportation and Environmental Services. Alexandria, VA. February 1994.

Pennsylvania State University. *The Agronomy Guide.* College of Agricultural Sciences (latest edition).

Prince George's County Government. *Design Manual for Use of Bioretention in Stormwater Management.* Prepared by Engineering Technologies Associates, Inc. and Biohabitats, Inc. 1993.

Reeves, E. "Performance and Condition of Biofilters in the Pacific Northwest." *Watershed Protection Techniques,* Vol. 1, No. 3. Fall 1994.

Schueler, T. R. "How to Design Urban Stormwater Best Management Practices," Seminar Notebook. 1995.

SPECIFICATIONS AND METHODOLOGY:

Planting Plan

The use of plants in bioretention areas is intended to replicate a terrestrial forest community ecosystem. The components of this community include tress, shrub layer, and a herbaceous layer. Native plants selected from Appendix H (tables H-2 and H-3) should be able to tolerate typical stormwater pollutant loads, variable soil moisture, and ponding fluctuations (Prince George's County, 1993). Designers are encouraged to check other sources, such as *The Agronomy Guide*, the *Field Office Technical Guide*, and local nurseries to identify plants that can adapt to specific site conditions.

The layout of the plant material should resemble a random and natural placement of plants rather than a standard landscaped approach with trees and shrubs in rows or other orderly fashion. The location of the plan material should provide optimal conditions for plant establishment and growth (Prince George's County, 1993).

Off-Line Bioretention Areas

There are six major components to the bioretention area:

- Grass buffer strip or energy dissipation area
- Ponding or treatment area
- Planting soil
- Sand bed (optional)
- Organic layer
- Plant material

The grass buffer strip or energy-dissipation area filters particles from the runoff and reduces its velocity. The sand bed further slows the velocity of the runoff, spreads the runoff over the basin, filters part of the water, provides positive drainage to prevent anaerobic conditions in the planting soil, and enhances exfiltration from the basin.

The ponding area functions as storage area for runoff awaiting treatment and as presettling basin for particulates that have not been filtered out by the grass buffer. The organic or mulch layer acts as a filter for pollutants, protects the soil from eroding, and is an environment for microorganisms to degrade petroleum-based compounds and other pollutants.

The planting soil layer nurtures the plants with stored water and nutrients. Clay particles in the soil adsorb heavy metals, nutrients, hydrocarbons, and other pollutants. The plant species are selected on the basis of their documented ability to cycle and assimilate nutrients, pollutants, and metals through the interaction among plants, soil, and organic layer (Bitter and Bowers, 1994). The minimum depth of the planting soil layer should be 3 to 4 feet.

The number of tree and shrub plantings may vary, especially in areas where aesthetics and visibility are vital to site development, and the density should be determined on an individual site basis. The minimum and maximum number of individual plants and spacing recommended by Prince George's County are shown in the following table. A minimum of three species of trees and three species of shrubs should be selected to ensure diversity.

Recommended Tree and Shrub Spacing			
	Tree Spacing (feet)	Shrub Spacing (feet)	Total Density (stems/acre)
Maximum	19	12	400
Average	12	8	1,000
Minimum	11	7	1,250
Source: Prince George's County, 1993			

As with any experimental BMP, sizing rules are continually changing. Although the site requirements will determine the actual dimensions, the following dimensions are recommended for bioretention areas:

- Minimum width is 10 to 15 feet.
- Minimum length is 30 to 40 feet.
- The ponded area should have a maximum depth of 6 inches. If collector pipes are used, the maximum pond depth can be increased to 12 inches.
- The planting soil should have a minimum depth of 4 feet.

Figures 5 and 6 show a profile and plan of a typical bioretention area. A curb diversion structure that can be installed to divert gutter flow to a bioretention area is shown in Figure 7.

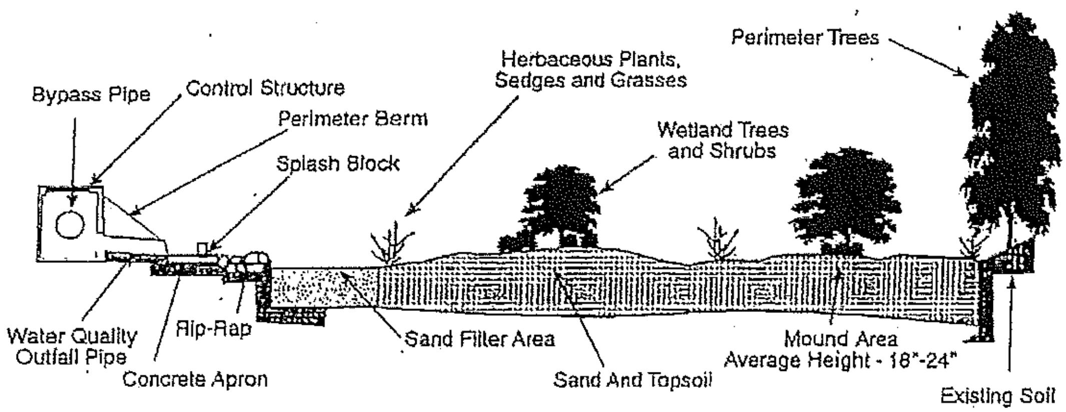


Figure 5. Bioretention cross section: Runoff from large storms (greater than a 1-year storm) is bypassed through the main drainage system. Runoff from small storms is diverted at the control structure (manhole). The energy of the stormwater flow is dissipated by the splash block or the rip rap. The stormwater is filtered through an open sand filter. Excess stormwater is treated in the bioretention area.

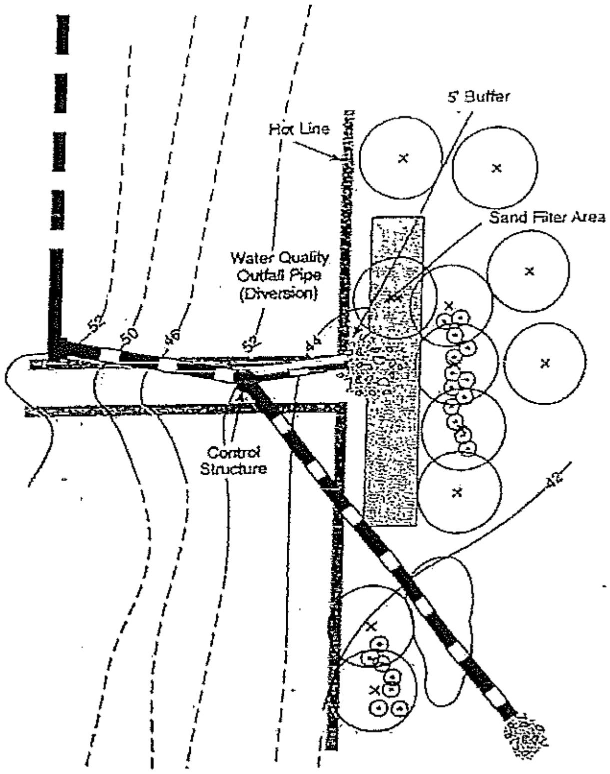


Figure 6. Bioretention plan view

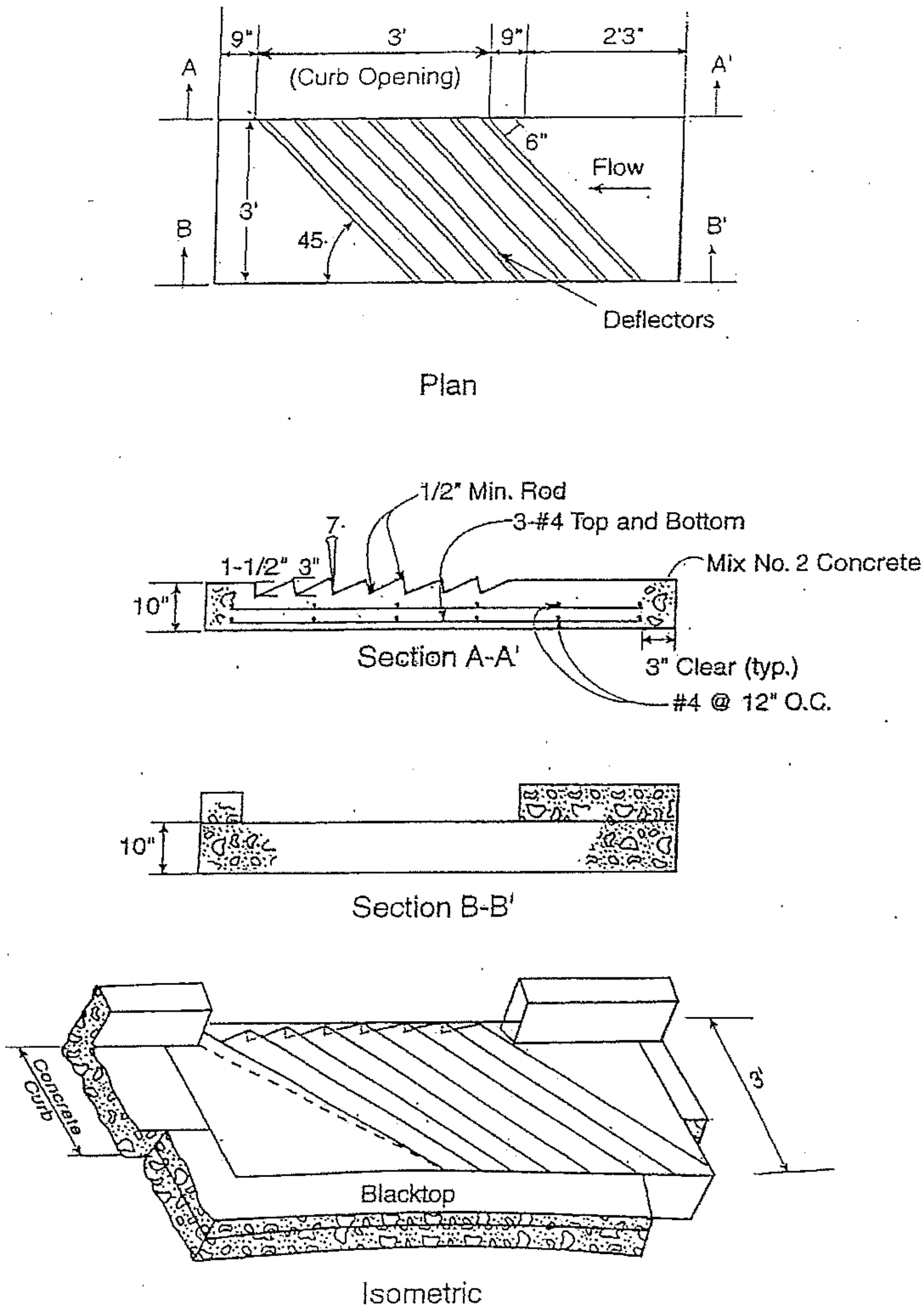


Figure 7. Plan and section views of a curb diversion structure (Prince George's County, 1993)

On-Line Bioretention Areas

A bioretention area upstream of a check dam is constructed with similar specifications as the off-line bioretention areas. The depth of the planting soil zone can be reduced (1 to 2 feet) if the drainage area is small (less than 2 acres).

Rock check dams usually are constructed of approximately 8- to 12-inch rock The rock is placed either by hand or mechanically, but never just dumped into the swale. The dam must completely span the ditch or swale to prevent being washed out. The rock used must be large enough to stay in place, given the expected design flow through the channel.

Log check dams usually are constructed of 4- to 6-inch-diameter logs and are illustrated in Figure 3. The logs should be embedded into the soil at least 18 inches. Gabion applications are illustrated in Figures 2 and 4.

Design Methodology for Controlling Runoff Volume

The runoff capture volume is the minimum volume of rainfall that must be retained and completely infiltrated on site during every storm. It is also equal to the rainfall quantity associated with the runoff capture design storm. Runoff capture criteria are discussed in Section 5.3 of the Handbook and in Appendix F, *Runoff Capture Design*.

The runoff capture volume is conveniently stated as a rainfall depth, in inches, over the area of the site. For example, to achieve a suitable level of groundwater recharge, the determination may be that a minimum of 0.75 inches of rainfall from every storm should be detained and infiltrated. In this example, all rainfall events with less than 0.75 inches of rainfall should be completely infiltrated.

Analysis of the site using the approach described in Appendix F will establish the total runoff capture storage that must be provided by infiltration BMPs at a particular site. In general, the retention volume of appropriately located bioretention areas can be applied to satisfy the runoff capture storage requirement for the site.

Bioretention facilities are effective measures for increasing the runoff capture capability of the site. Other methods that can be used to improve runoff capture and infiltration include:

- Installing permeable pavement
- Installing infiltration trenches or dry wells
- Modifying the site design to decrease imperviousness

Design Methodology for Runoff Peak Attenuation

Only bioretention facilities with large retention storage capacities will be effective in controlling runoff peak discharge rates. To predict a change in peak runoff, the Natural Resources (formerly Soil) Conservation Service's (NRCS) methodology (USDA, 1986) can be used. This methodology includes the so-called soil cover complex and nondimensionalized unit hydrograph techniques and is implemented in a variety of computer simulation packages. Alternative methodologies, including kinematic wave runoff routing and synthetic unit hydrograph generation, also are available in various computer software packages.

By retaining runoff during the initial stages of a storm, bioretention facilities can significantly reduce peak runoff rates. With these measures implemented, runoff from the site will be delayed until the storage capacity of the facilities is exceeded. When using the NRCS methodology, this effect can be accounted for as an increase in the initial abstraction, *Ia*, for the drainage subarea in which the facility is located. The relationship can be expressed as follows:

$$R = \frac{(V - Ia)^2}{(V - Ia) + S}$$

$$S = \frac{1{,}000}{CN} - 10$$

where:

V	=	Rainfall volume (inches, over the drainage area)
R	=	Runoff volume (inches, over the drainage area)
Ia	=	Initial abstraction (inches, over the drainage area)
S	=	Potential maximum retention after runoff begins (inches, over the drainage area)
CN	=	NRCS runoff curve number

Ia can be approximated as the combined runoff capture storage divided by the surface area of the drainage subarea. The effect will be more important for small runoff peak attenuation design storms.

Some bioretention facilities may also include peak attenuation storage. The effectiveness of these facilities in attenuating runoff peak rates must be evaluated according to procedures described in DRY POND. In addition, the impacts of large flows and velocities on the plant material need to be carefully evaluated before using bioretention facilities as peak attenuation facilities. Bioretention facilities with small drainage areas (i.e., less than 0.25 acres) may be effective for peak attenuation if they are installed throughout a subdivision or nonresidential development.

NAME: Pond, Wet

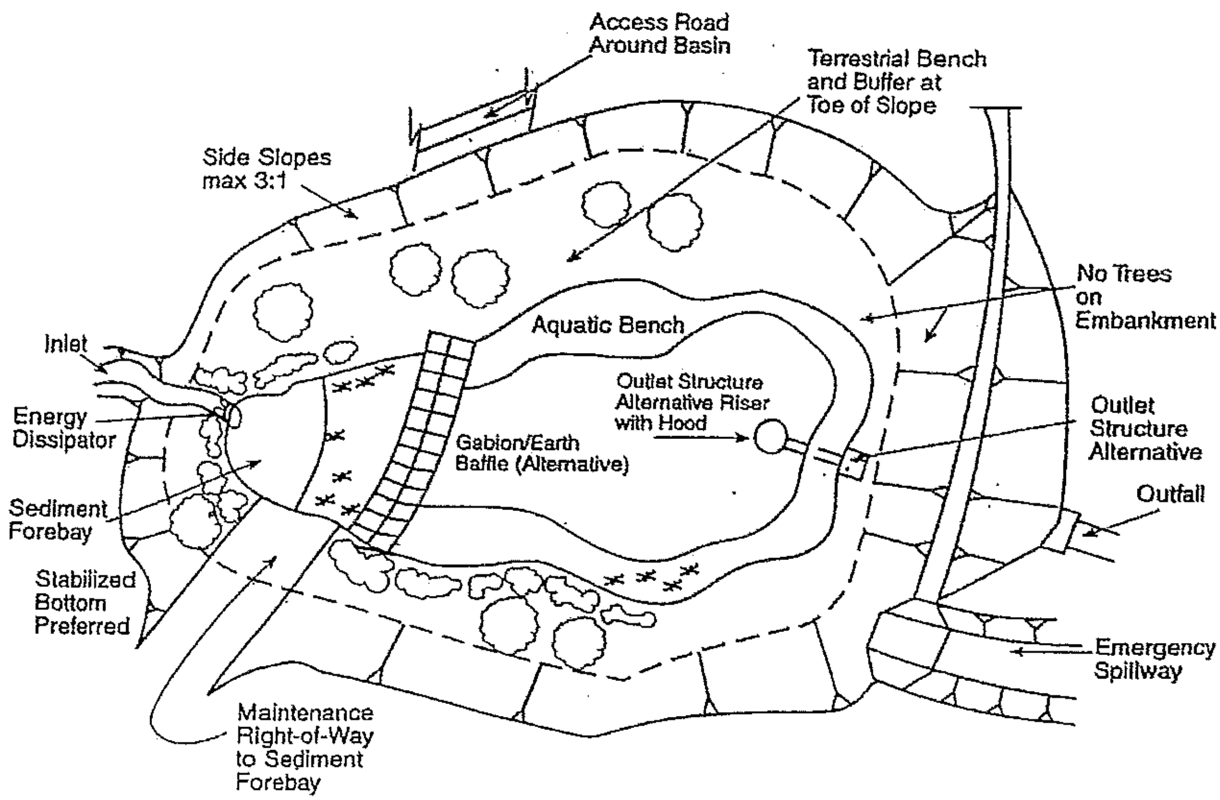
PERMANENT

COMPANION BMPS:
- OUTLET STABILIZATION STRUCTURE
- GRASS SWALE
- FILTER STRIP
- PERMANENT VEGETATIVE STABILIZATION

ALTERNATIVE BMPS:
- DRY POND
- CONSTRUCTED TREATMENT WETLAND
- BIORETENTION

DEFINITION: A wet pond is a stormwater management facility, which includes: a) a permanent pool of water for enhancing water quality and b) additional capacity above the permanent pool for detaining stormwater runoff.

PURPOSE: Wet ponds fill with stormwater and release most of it over a period of a few days, slowly returning the pond to its normal depth. Wet ponds improve water quality by two mechanisms. Water contained in the permanent pool mixes with and dilutes the initial runoff from storm events. Runoff generated during the early phases of a storm usually has the highest concentrations of sediment and dissolved pollutants. Therefore, the concentration of pollutants in runoff released to downstream drainages is reduced. Following storm events, pollutants are removed from water retained in the pond. Several mechanisms that remove pollutants in wet ponds include settling of suspended particulates and biological uptake, or consumption of pollutants by plants, algae, and bacteria in the water. Therefore, the total mass of pollutants released to downstream areas also can be substantially reduced by using wet ponds.



APPLICATION: Wet ponds are most applicable in low-density residential or commercial developments where a reliable source of water for maintaining the permanent pool exists. Because of design requirements, which incorporate large storage volumes to achieve extended detention times, wet ponds require larger land areas than many other BMPs. Locations for ponds that will serve more than one development site are best selected in the context of regional or watershed-wide site planning. Wet ponds generally are not appropriate for drainage areas smaller than 5 acres.

The effectiveness of wet ponds can be improved by combining them with other BMPs that attenuate peak stormwater discharges or reduce runoff volume. These BMPs include PERMEABLE PAVING SYSTEM, ROOFTOP RUNOFF MANAGEMENT, INFILTRATION TRENCH AND DRY WELL, and FILTER STRIP. Through a comprehensive approach for managing runoff in a drainage area, the size of wet ponds can be substantially reduced.

Wet ponds are not reliable methods for recharging groundwater. Fine-grained sediment, which accumulates in the ponds, tends to clog soil pores and reduce infiltration capacity over time.

Where site conditions permit, BIORETENTION facilities can be used to achieve similar performance objectives. In general, a group of smaller bioretention facilities can be used to replace the function of one wet pond. Maintenance of bioretention facilities frequently is less involved and less costly than wet ponds.

Although similar in some respects to CONSTRUCTED TREATMENT WETLAND, wet ponds generally require less space and are more resilient when faced with rapidly varying runoff flow rates. However, constructed treatment wetlands may be preferable in areas where water quality degradation would have a significant effect downstream.

Most conventionally designed SEDIMENT BASIN cannot readily be converted for use as wet ponds. This is because sediment basins generally are designed to be compact structures and are typified by comparatively steep side slopes and high embankments. However, in many instances it may be advantageous to construct a sediment basin using an outlet design and embankment geometry that will make conversion to a permanent wet pond more convenient.

RECOMMENDED DESIGN CRITERIA:

Requirements for Regulatory Compliance

Wet ponds should comply with all criteria implemented in municipal ordinances or specified in a watershed plan developed under the auspices of the Pennsylvania Act 167 stormwater management planning grants program.

Ponds that 1) will have a contributing drainage area exceeding 100 acres, 2) will have embankments higher than 15 feet, measured from the downstream toe, or 3) will impound more than 50 acre-feet of runoff during the high-water condition may be regulated as dams PADEP. The designer should consult 25 Pennsylvania Chapter 105 to determine which provisions may apply to a specific project.

Large wet ponds that include a wetland fringe, and which are abandoned in place without first being drained and regraded, may subsequently be regulated as wetlands under the provisions of Sections 401 and 404 of the Clean Water Act.

The 25 Pennsylvania Chapter 102 does not regulate the design of wet ponds. However, the Pennsylvania *Erosion and Sediment Pollution Control Program Manual* contains design requirements for sediment basins, which are used during construction and can be converted into a wet pond after the construction is finished. Regulations covering sediment basins are discussed in the BMP description, SEDIMENT BASIN.

Performance-Based Guidelines

Quality Control

Two primary mechanisms remove pollutants from stormwater in wet ponds: sedimentation and biological uptake. Extended detention times allow many of the sediment-bound pollutants to settle. The permanent pool and vegetated banks promote the necessary conditions for the pollutants to be taken up biologically.

Because of the great range in potential site conditions and pond configurations, providing numerical estimates of wet pond treatment efficiencies is not possible. Pond designs should be tailored to the specific site requirements. However, the general effectiveness of wet ponds as water quality measures can be characterized as follows.

Efficiency of Wet Ponds in Removing Pollutants

Pollutant	Estimated Removal Efficiency
Sediment as total suspended solids	High [1]
Nutrients	
Total phosphorus	Low
Total nitrogen	Low
Metals	
Lead	Moderate to High
Zinc	Moderate
Organic matter as biochemical and chemical oxygen demand	Moderate
Oil and grease	Low
Bacteria	High

1 To achieve high overall efficiency, measures must be taken to minimize re-suspension of sediment during subsequent storms.

(Compiled from Schueler 1987; Schueler, *et al.* 1992; US EPA 1990; Phillips 1992; Birch, *et al.* 1992 and others.)

The following sections describe the methodology for designing a wet pond, including the physical features required for successfully controlling water quantity and quality. Also discussed are design modifications and alternatives that can be implemented to change the operational functions of the pond, if desired.

Quantity Control

Design Storms

Unless local hydraulic conditions dictate otherwise, wet ponds should be designed to completely control runoff generated by the water quality design storm within the water quality storage (see Section 5.3 of the Handbook). The water quality storage is that part of the pond that lies between the crest of the high-level outlet and the permanent pool level. To promote quiescent settling of particulates, the water quality volume should be released over a period of not less than 24 hours.

Depending on the requirements of local ordinances or regional stormwater plans, high-level outlets should be incorporated to achieve runoff peak attenuation for less frequently occurring storms, including the 2-year, 5-year, 10-year and 25-year storms. An emergency spillway capable of passing the spillway design flood (SDF) also must be integrated into the design (see Section 5.3 of the Handbook). This is usually equal to the 100-year return frequency storm.

Hydrograph Calculations

Inflow and discharge hydrographs should be calculated for each selected design storm. The entire hydrograph must be calculated, not just the peak runoff rate, because the detention storage characteristics of the pond must be evaluated. Provided that no conflict will exist with local ordinances or watershed plans, hydrographs should be based on a 24-hour rainfall event. Shorter rainfall distributions may not adequately account for partial filling of pond storage prior to the occurrence of the peak storm runoff. The Natural Resources (formerly Soil) Conservation Service's (NRCS) 24-hour type II rainfall distribution for the specific locality is recommended.

The predevelopment and post-development hydrographs for the drainage area can be calculated by using the NRCS methodology described in the NRCS *National Engineering Handbook,* Section 4. This methodology includes the so-called soil cover complex and nondimensionalized unit hydrograph techniques and is implemented in a variety of computer simulation packages. Alternative methodologies, including kinematic wave runoff routing and synthetic unit hydrograph generation, also are available in various computer software packages.

The predevelopment hydrograph calculations should be based on the assumption that the land area, before it developed, exhibited hydrologic conditions (land use, slope, vegetative cover) typical for that type of area. The post-development hydrograph calculations should be based on the specific development scenario. In cases where the pond is intended to serve as a regional facility and the drainage area may be developed over a period of several years, reasonable predictions of the future pattern of development in upgradient areas must be made.

The predicted post-development hydrographs for the drainage areas are the inflow hydrographs for the wet pond. The peak runoff rates of the predevelopment hydrographs typically provide the maximum permissible discharge for each selected design storm (e.g., 2-, 5-, 10-, and 25-year storm).

Pond Outlet Design

To accommodate the design storm requirements, the inflow hydrographs must be hydraulically routed through the pond. A multistage outlet structure typically must be part of the design. The outlet system typically will have three elements:

1. Low-flow or smallest-storm release outlet. This outlet controls the extended detention function of the pond and will be responsible for discharging the water quality design storm.

2. High-level or principal outlet that will attenuate the peak discharge of less frequent storm events.

3. Emergency overflow spillway.

More information on outlet configurations and performance is in Appendix I, *Common Design Elements*.

The inflow hydrographs can be routed hydraulically through the basin by manual or computerized procedures. One of the manual processes widely used is the Storage/Indication method (also known as the Modified Puls method, Chow, 1964). The Modified Puls method is discussed in the DRY POND BMP description. Numerous commercially available computer programs, which enable relatively quick analyses of alternatives, are available. Whatever method is used, it must be able to accurately simulate a reservoir with multiple outlets.

The primary data required for an analysis are:

- Depth-storage information that is developed on the basis of the proposed size and shape of the pond, and computations of the volume of stormwater stored for each increment of pond depth
- Depth-discharge information that relates the outlet capacity to the depth of water in the pond

When routing wet ponds, the volume of the permanent pool should not be included in the depth-storage relationship. Likewise, the outlet capacity of the low-flow outlet should not be included in the depth-discharge relationship (see Appendix I, *Common Design Elements*).

Pond Configuration

A sediment forebay can be constructed near the inlet to trap coarse sediment. Because the forebay acts like a sediment basin or trap, the sediment will need to be removed periodically. To create the forebay, a baffle can be introduced to restrict hydraulic communication between the inlet and the remainder of the pond. Baffles can be constructed from stone, rip rap, gabions, or similar materials.

Short-circuiting of the stormwater should be minimized. The most direct way of minimizing short-circuiting stormwater is to maximize the distance between the inlet and the outlet. A minimum length-to-width ratio of 3:1 is recommended for a wet pond design. Wet ponds with long, narrow, and irregular shapes also have reduced surface area exposed to wind and, therefore, a reduced tendency to resuspend previously settled material. Irregularly shaped ponds also appear more natural, or less "engineered." If local site conditions inhibit constructing a relatively long, narrow facility, baffles constructed from gabions or other materials should be placed in the pond to "lengthen" the stormwater flow path as much as possible.

Aquatic benches can be introduced to provide a shallow-water environment for emergent wetland vegetation. Vegetated aquatic benches can:

- Enhance biological pollutant removal
- Provide a habitat for wildlife and waterfowl
- Protect the shoreline from erosion
- Improve sediment trap efficiency

In some designs, that portion of the pond devoted to peak attenuation storage will incorporate a nearly level terrestrial bench. Unlike the aquatic bench that is submerged at all times, this bench is inundated during large storms, only. It can be planted with shrubs and trees that will shade the pool and help reducing warming effects. The terrestrial bench also introduces the following benefits:

- Enhances wildlife habitat
- Leaf litter provides an additional carbon source for aquatic macro-invertebrates
- Contributes to aesthetic value of the BMP
- Improves safety, by providing a buffer that separates the pond edge from the permanent pool.

- Reduces currents during large storms, thereby minimizing the potential for the resuspension of sediment

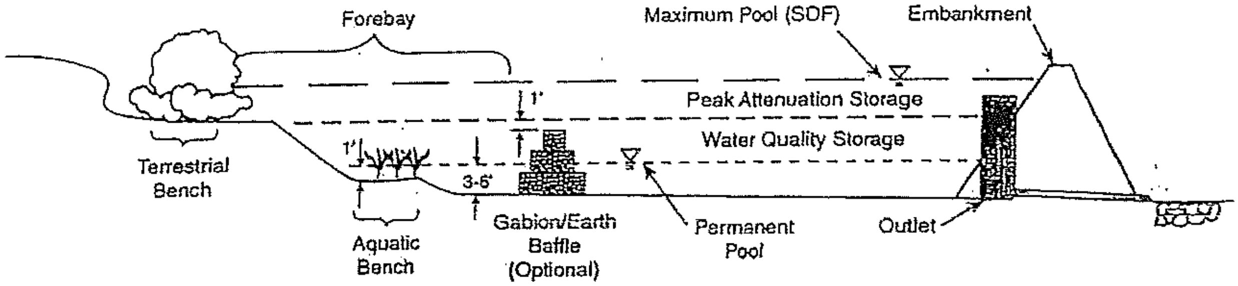


Figure 1. Depth relationships.

OPERATION AND MAINTENANCE: The maintenance requirements for wet ponds are intensive compared to most BMPs. Normal maintenance costs can range from 3 to 5 percent of the construction costs annually (Schueler, 1992). Areas of concern include excessive weed growth, maintaining adequate vegetative cover, sedimentation, bank erosion, insect control, outlet stoppages, algal growth, embankment failures, and seepage. An active program of preventive maintenance is required to ensure that the facility remains operational and safe at all times. The following items should be part of preventive maintenance procedures:

- Grass maintenance
- Control of noxious weeds and invasive plants
- Maintenance of wetland vegetation
- Removal and disposal of trash and debris
- Removal and disposal of sediment
- Maintenance of mechanical components
- Elimination of mosquito-breeding habitats
- Maintenance of pond
- Inspection of pond and reporting of results

Typically, sediment is removed once every 5 to 15 years. A rule-of-thumb is to increase the storage volume by 25 percent for sediment accumulation, but detailed calculations that are based on watershed sediment yields and pond trap efficiency will more accurately reflect the volume requirements and expected frequency of sediment removal. All wet ponds should have a drain so that the pond can be completely emptied for maintenance, repairs, and sediment removal. The bottom of the pond must be accessible for maintenance during periodic draining. The access way should be a minimum of 10 feet wide (widths of 15 feet are common), have a maximum slope of 5H:1V, and not cross the emergency spillway. Measures must be employed during sediment removal to minimize the potential for resuspension and release of sediment to downstream areas. Appropriate controls are discussed in BMPs PORTABLE SEDIMENT TANK, STRAW BALE BARRIER, SILT FENCE, and FILTER BAG.

The most effective mosquito-control program is one that eliminates potential breeding habitats. Almost any stagnant pool of water can be attractive to mosquitoes and the source of a large mosquito population. To minimize the potential for stagnation, wet ponds should be situated where they will receive base flow during dry periods. Ponded water in open cans and bottles are ideal locations for mosquitoes to breed. Through fish stocking practices, a balanced "micro-habitat" can be fostered in which natural mosquito predators help maintain mosquito populations in check. As required, the pond can be drained periodically to suppress mosquito breeding.

A program of monitoring the aquatic environment of a permanent pond should be established. Although the complex environment of a healthy aquatic ecosystem will require little maintenance, water quality, aeration, vegetative growth, and animal populations should be monitored regularly. The timely correction of an imbalance in the ecosystem can prevent more serious problems from occurring. Because the ecosystem of a pond is complex, the recommendation is that agencies such as the U.S. Fish and Wildlife Service be consulted for corrective maintenance procedures.

The stability of embankments and side slopes can be impaired by large roots and animal burrows. Trees and brush with extensive woody root systems should be completely removed from embankments to prevent the embankments from destabilizing and seepage routes from being created. Roots also should be completely removed to prevent them from decomposing in the embankment. Root voids and burrows should be plugged by filling them with material similar to the surrounding materials, and capped just below grade with stone, concrete, or other material. If plugging the burrows does not discourage the animals from returning, further measures should be taken to either remove the animal population or to make critical areas of the facility unattractive to them.

Accumulations of snow and ice can threaten the functioning of a facility, particularly at inlets, outlets, and emergency spillways. Providing the equipment, materials, and personnel to monitor and remove snow and ice from the critical areas is necessary to ensure the continued functioning of the facility during the winter months.

The facility should be inspected quarterly and after major storms. Detailed inspections by a qualified inspector should occurring at least annually to ensure that the facility is operating as designed and to schedule maintenance that the facility may require. If possible, inspections should be made during wet weather to ensure that the facility is maintaining desirable retention times. In addition to regularly scheduled inspections, deficiencies should be noted during any visits by maintenance personnel. An important purpose of inspections is to ascertain the operational condition and safety of the facility, particularly the condition of embankments, outlet structures, and other safety-related aspects.

Recommended Minimum Inspection Requirements
• Embankment settling, woody growth, and signs of piping • Signs of seepage on the downstream face of the embankment • Condition of grass cover on the embankment, pond floor, and perimeter of the pond • Rip rap displacement or failure • Principal and emergency spillway meet design plans for operation • Outlet controls, debris racks, and mechanical and electrical equipment • Outlet channel conditions • Safety features of the facility • Access for maintenance equipment

CONSIDERATIONS: Because wet ponds can be aesthetically pleasing, they can be sited in both low- and high-visibility areas. Quite often, residents feel that a permanent pool of water enhances property values as well as the aesthetic value of the area. Wet ponds have been used to provide wildlife habitat and a focal point for a recreation area.

Aesthetic maintenance, although not required for keeping a wet pond operational, will maintain the visual appeal of a facility and will benefit everyone in the local community. Visual appeal is particularly beneficial for ponds that also are used by members of the community for recreation. Aesthetic maintenance also can reduce the amount of preventative and corrective maintenance.

Although a regular grass maintenance program will keep weed intrusion to a minimum, some weeds invariably will appear. Periodic weeding will not only help to maintain a healthy turf, but also will keep grassed areas looking attractive. Applying chemicals to control weeds needs to be carefully considered and monitored. Careful, meticulous, and frequent attention to maintenance such as removing debris and cutting grass will result in a facility that is both functional and attractive. When properly maintained, wet ponds are one of the most effective and reliable devices for removing pollutants from stormwater.

One disadvantage of wet ponds is that they may contribute to thermal pollution and cause downstream warming. Because wet ponds can cause downstream warming, their use in areas where sensitive aquatic species live may be precluded.

Wet ponds may sometimes create problems such as nuisance odors, algae blooms, and rotting debris when not properly maintained. Wetland plants may need to be harvested or removed periodically to prevent releasing plant nutrients into the water when the plants die.

The permanent pool of water presents an attractive play area to children; hence, wet ponds may create safety problems. Design features that discourage child access are recommended. Trash racks and other debris-control structures should be sized to prevent entry by children. Bar spacing on debris-control structures should be no greater than 12 inches in any direction and the preferred spacing is 5.5 inches. Other safety considerations include using fences around the spillway structure, embankment, and pond slopes; using shallow safety benches around the pond; and posting warning signs.

Because a wet pond typically is included with the site utilities and often is used as a sediment basin during the construction of the upstream development, a wet pond frequently is one of the first facilities planned and constructed on the site. However, a wet pond is most vulnerable to damage caused by extreme rainfall events during its construction. Therefore, temporary drainage or erosion control measures generally are required to minimize the potential for damage to the wet pond before the site is stabilized. The control measures may include stabilizing the surface with erosion mats, sediment traps, and diversions. Vegetative cover and the emergency spillway also should be completed as quickly as possible during the construction phase.

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SPECIFICATIONS AND METHODOLOGY: The following topics are covered in this section:

- Pond Depth
- Sediment Forebay
- Permanent Pool Volume
- Embankments
- Vegetation
- Inlets and Outlets
- Provisions for Draining

Pond Depth

Pond depth is an important design criteria because most of the pollutants are removed through settling. Very shallow ponds may be prone to currents that can resuspend materials and deep ponds can be thermally stratified and release pollutants back into the water. Therefore, an average depth of 3 to 6 feet for the permanent pool is recommended for most ponds. In colder areas, deeper pools may be required to minimize the potential for "winter kill" of beneficial pond fauna and flora.

A 10-foot-wide shelf, or aquatic bench, with a gentle slope (5H:1V or flatter) is recommended around the perimeter of pond. If aquatic plants or a wetland fringe is installed on the bench, the depth of the permanent pool should be about 1 foot higher than the bench. The design of the bench should take into account slope stability to minimize the potential for sloughing.

Sediment Forebay

A forebay is an extra storage area near an inlet of a BMP to trap incoming sediment. With heavy, coarse sediment confined to the forebay area, maintenance is made simpler and less costly and the life of the BMP is extended. Forebays are recommended for use on all stormwater pond BMPs as part of the overall pond design.

When installed in wet ponds, forebays will be permanently submerged. In general, it is not practical to vegetate forebays in wet ponds and other methods are required to stabilize these areas. Rip rap or gabions can be used. However, sediment removal may be made more convenient if the forebay is surfaced with cement or bituminous concrete. Design criteria for forebays are listed below.

- The minimum recommended forebay length is 10 feet.
- Sufficient storage volume should be provided to trap sediment between clean-out intervals (typically ranging between 5- and 15-year).
- The height of the berm or baffle that separates the forebay from the remainder of the pond should be 1 foot below the ponding depth associated with the water quality design storm.
- The forebay should be accessible and stabilized to accommodate equipment used in removing accumulated sediment.
- Non-erodible material should be used to construct the forebay berm. Armoring, such as rip rap or gabions, is generally preferred to stabilize the upgradient face of the berm.

Permanent Pool Volume

Although larger ponds typically are more successful, a threshold size seems to exist, above which further improvement of water quality by sedimentation is negligible. At a minimum, the volume of the permanent pool should equal the water quality volume (see Section 5.3 in the Handbook). The upper limit for the volume of the permanent pool may be dictated by the dry-period base flow to the pond. Large ponds with inadequate inflow rates may become stagnant.

The volume in the permanent pool needs to be sustained by low flows, either generated by groundwater or rainfall. To reduce losses due to percolation, it may be necessary in some instances to line wet ponds. Natural clay or bentonite linings generally are preferable over synthetic liners.

Large seasonal fluctuations in the groundwater table may directly influence the depth of the permanent pool. Fluctuations that are too large may interfere with the growth of vegetation in the wetland fringe of some wet ponds.

Embankments

A maximum slope of 3H:1V should be used to allow maintenance equipment to enter the pond and to maintain ground cover. Steeper slopes should be avoided. If site conditions require steeper slopes on one side of the pond, bioengineering methods should be used to ensure long-term stability of the slope. The pond's freeboard should be a minimum of 1 foot above the elevation of the SDF. Embankment design should incorporate the following considerations:

- Foundation preparation and treatment
- Control of seepage
- Embankment stability
- Construction considerations

Guidelines for the design and construction of earth embankments are provided in Appendix I, *Common Design Elements*.

Vegetation

In general, wet ponds will incorporate a variety of emergent wetland vegetation, especially where a shallow-water bench is included in the design. A wide range of potential plant species is available for this purpose. For more information on the maintenance of wetland vegetation, see Appendix H, *Plant Lists for Wetland Management* and the BMP description for CONSTRUCTED TREATMENT WETLAND.

On the tops of berms and on the exterior slopes of containment berms, maintaining turf grass is advisable. This will stabilize the embankment, enhance access to the facility, and make maintenance and inspection much easier.

Inlets and Outlets

The release time for the water quality volume should not exceed 48 hours because:

- Longer detention times typically will not improve settling efficiency.
- Prolonged periods of inundation will adversely affect wetland vegetation, which is integral to the water quality function of the wet pond.
- Persistently high pond water levels will interfere with the attenuation of peak flows.

In addition to being designed to achieve specific hydraulic requirements for runoff detention and peak attenuation, outlets also must be functionally simple and easy to maintain. Durable materials, such as reinforced concrete or plastic, are preferable to corrugated metal in most instances. The riser should be placed in or at the face of the embankment. By placing the riser close to the embankment, maintenance is facilitated and flotation problems prevented. Outlets are described in greater detail in Appendix I, *Common Design Elements*.

Erosion protection measures should be used in front of a stream inflow structure, downstream of an inflow "spillway" of any length, and at the pond discharge point. The inflow-control structure must be constructed so that it distributes the flow evenly into the pond or the sediment forebay, if one is used, to prevent short-circuiting of flow.

The low-flow stormwater outlet drain pipe should be negatively sloped (i.e., sloped in the direction of the pond). The negative slope minimizes the loss of fine-grained sediment.

Provisions for Draining

Wet ponds should be designed with provisions for draining the permanent pool. This will facilitate maintenance and sediment removal. The draining mechanism usually will consist of some type of valve or gate attached to the spillway structure. Some guidelines for designing pond drains are given below:

1. Pond drains should be designed with sufficient capacity so that maintenance (e.g., sediment removal) can be carried out without fear of inundation from relatively common or frequent rainfall events. Therefore, pond drains should be designed to pass a flood having a 1-year recurrence interval with limited ponding in the reservoir area. In most cases, the pond drain system should be no smaller than 8 inches in diameter.

2. In most cases, sluice gates are preferred over "inline" type valves such as those used in water distribution systems (e.g., eccentric plug valves, knife gate valves, and gate valves). Sluice gates generally are more appropriate for passing debris-laden flow, less prone to clogging, and easier to maintain.

3. The design of a pond drain system should include operating instructions regarding draining the impoundment. In general, drawdown rates should not exceed 6 inches per day. For embankments or shoreline slopes of clay or silt, drawdown rates as slow as 1 foot per week may be required to ensure slope stability. An uncontrolled or rapid drawdown could induce problems such as slides or sloughing of the saturated upstream slope of the embankment or shoreline area.

4. Instances where wet ponds cannot be drained by gravity are common. In particular, the permanent pool may be constructed by excavating below the adjacent grade. In many instances, the bottoms of ponds extend below the groundwater table. In these cases, it will be necessary to dewater the pond using pumps. The pump discharge must be filtered prior to discharge to the receiving downstream watercourse. Measures that may be useful include PORTABLE SEDIMENT TANK, FILTER BAG, and STRAW BALE BARRIER.

NAME: Pond, Dry

DEFINITION: A dry pond is a permanent stormwater management facility that temporarily stores incoming stormwater. The pond typically is dry between storm events. To qualify as a BMP, dry ponds should incorporate extended detention of runoff derived from small rainfall events.

PURPOSE: The primary purpose of dry ponds is to attenuate and delay stormwater runoff peaks. The benefits are a reduced potential for flooding and for stream bank scour and erosion in downstream areas. Dry ponds are not suitable as infiltration or groundwater recharge measures.

PERMANENT

COMPANION BMPS:
- OUTLET STABILIZATION STRUCTURE
- PERMEABLE PAVING SYSTEM
- INFILTRATION TRENCH AND DRY WELL
- PERMANENT VEGETATIVE STABILIZATION

ALTERNATIVE BMPS:
- WET POND
- CONSTRUCTED TREATMENT WETLAND
- ROOFTOP RUNOFF MANAGEMENT

Extended detention dry pond with shallow marsh.

APPLICATION: Dry ponds are used appropriately where water quality issues are ancillary to managing peak runoff. If improving water quality is an important design objective, other BMPs should be considered, including WET PONDS, BIORETENTION, and CONSTRUCTED TREATMENT WETLANDS.

Dry ponds are most applicable in low-density residential, industrial, and commercial developments where enough space exists to locate the pond out of plain view. Dry ponds can be designed to control runoff from an individual development site, multiple development sites, or entire drainage areas. However, regional dry detention ponds need large land areas, pose safety risks, and can be very expensive to construct and maintain. Locations for ponds that will serve more than one development site should be selected in the context of a regional site planning program.

The effectiveness of dry ponds can be improved by combining them with other BMPs that attenuate stormwater peak discharges or reduce runoff volume. These include PERMEABLE PAVING SYSTEMS, ROOFTOP RUNOFF MANAGEMENT, INFILTRATION TRENCHES AND DRY WELLS, and FILTER STRIPS. By taking a comprehensive approach to managing runoff in a drainage area, the size of dry ponds can be substantially reduced. Frequently, the need for a dry detention pond can be eliminated entirely.

The overall pollutant removal capability of conventional dry ponds is low. By incorporating extended detention of runoff from small rainfall events, the capacity of the ponds to trap suspended solids can be significantly improved. However, dry ponds should not be relied upon to mitigate existing water quality problems on a watershed. In extended detention dry ponds, a low-flow outlet is used, which will slowly release water retained below the primary outlet device over a period of days.

Sites where the water table is less than 2 feet below the bottom of the pond are not suitable for dry ponds. Ponds in these areas are vulnerable to developing ephemeral pools of standing water during wet-weather periods. If high water table conditions are anticipated, then the design of a WET POND or BIORETENTION facility should be considered.

RECOMMENDED DESIGN CRITERIA:

Requirements for Regulatory Compliance

Dry ponds should comply with all criteria implemented in municipal ordinances or specified in a watershed plan developed under the auspices of the Pennsylvania Act 167 stormwater management planning grants program.

Ponds that 1) will have a contributing drainage area exceeding 100 acres, 2) will have embankments higher than 15 feet, measured from the downstream toe, or 3) will impound more than 50 acre-feet of runoff during the high-water condition, may be regulated as dams by PADEP. The designer should consult 25 Pennsylvania Chapter 105 to determine which provisions may apply to a specific project.

The 25 Pennsylvania Chapter 102 does not regulate the design of dry ponds. However, the Pennsylvania *Erosion and Sediment Pollution Control Program Manual* contains design requirements for sediment basins, which are used during construction and can be converted into dry detention ponds after the construction is completed. Regulations covering sediment basins are discussed in the BMP description, SEDIMENT BASIN, and guidelines for converting a sediment basin to a dry detention pond are in the "Specification and Methodology" section below.

Performance-Based Guidelines

Stormwater control in dry ponds is a function of watershed hydrology and pond hydraulics. The inflow and discharge hydrographs must be computed and the outlet structure hydraulics must be evaluated to design the dry pond for controlling stormwater quantity.

Design Storms

Dry ponds typically are designed to control runoff peak rates for rainfall events with return frequencies of 2 years, 5 years, 10 years, and 25 years. Local ordinances also may require peak controls for less frequent storms, including the 50-year or 100-year storms. An emergency outlet or spillway capable of passing the spillway design flood (SDF) also must be integrated into the design. The SDF usually is equal to the 100-year return frequency storm (see Section 5.3 of the Handbook).

Unless local hydraulic conditions dictate otherwise, dry ponds should be designed to completely control runoff generated by the water quality design storm within the water quality storage (see Section 5.3 of the Handbook). The water quality storage is that part of the pond that lies below the crest of the primary outlet. To promote quiescent settling of particulates, the water quality volume should be released over a period of not less than 24 hours.

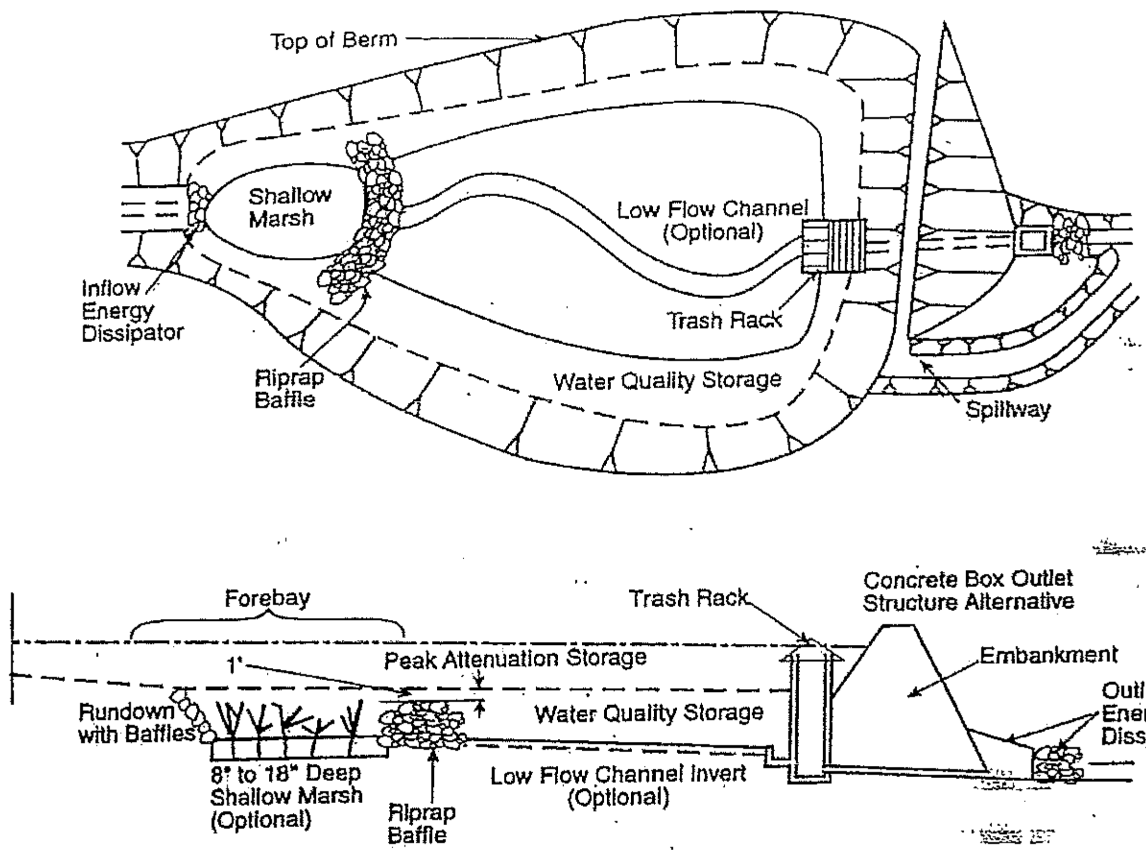
Hydrograph Calculations

Inflow and discharge hydrographs should be calculated for each selected design storm. The entire hydrograph must be calculated, not just the peak runoff rate, since the detention storage characteristics of the pond must be evaluated. Provided that no conflict will exist with local ordinances or watershed plans, hydrographs should be based on a 24-hour rainfall event. Shorter rainfall distributions may not adequately account for partial filling of pond storage prior to the occurrence of the peak storm runoff. The Natural Resources (formerly Soil) Conservation Service's (NRCS) 24-hour type II rainfall distribution for the specific locality is recommended.

The predevelopment and post-development hydrographs for the drainage area can be calculated by using the NRCS methodology described in the NRCS *National Engineering Handbook,* Section 4. This methodology includes the so-called soil cover complex and nondimensionalized unit hydrograph techniques and is implemented in a variety of computer simulation packages. Alternative methodologies, including kinematic wave runoff routing and synthetic unit hydrograph generation, are also available in various computer software packages.

The predevelopment hydrograph calculations should be based on the assumption that the land area before it developed exhibited hydrologic conditions (land use, slope, vegetative cover) typical for that type of area. The post-development hydrograph calculations should be based on the specific development scenario. In cases where the pond is intended to serve as a regional facility and the drainage area may be developed over a period of several years, the future pattern of development in upgradient areas must be reasonably predicted.

The predicted post-development hydrographs for the drainage areas are the inflow hydrographs for the dry pond. The peak runoff rates of the predevelopment hydrographs typically are used to predict the maximum permissible discharge for each selected design storm.



(Adapted from *Dam Design and Construction Standards*, Fairfax County, Virginia, 1991)

Pond Outlet Design

To accommodate the design storm requirements, the inflow hydrographs should be hydraulically routed through the pond, and a multistage outlet structure typically must be part of the design. The outlet system typically will have three elements:

1. Low-flow or smallest-storm release outlet. This outlet controls the extended detention function of the pond and will be responsible for discharging the water quality design storm.

2. High-level or primary outlet that will attenuate the peak of less frequent storm events.

3. Emergency overflow outlet.

The primary outlet structure can incorporate weirs, orifices, pipes, or a combination of these to control runoff peaks for two or more design storms. More information on outlet configurations and performance is in Appendix I, *Common Design Elements*.

The inflow hydrographs can be routed hydraulically though the pond by manual or computerized procedures. One of the manual processes widely used is the Storage/Indication method (also known as the Modified Puls method, Chow, 1964). The Modified Puls method is discussed in the "Specifications and Methodology" section. Numerous commercially available computer programs, which enable relatively quick analyses of alternatives, are available. Regardless of the method used, it must accurately simulate a reservoir with multiple outlets.

The primary data required for an analysis are:

- Depth-storage information that is developed on the basis of the proposed size and shape of the pond, and computations of the volume of stormwater stored for each increment of pond depth
- Depth-discharge information, which relates the outlet capacity to the depth of water in the pond

To maximize hydraulic efficiency and minimize pond size, the primary outlet extends to the bottom of the pond in conventionally designed dry ponds. However, in extended detention dry ponds, the water quality storage is provided below the primary outlet. When routing ponds that incorporate the extended detention function, the outlet capacity of the low-flow outlet should not be included in the depth-discharge relationship.

Pond Configuration

By causing turbulence and eddies in the flow, short-circuiting of stormwater flow can interfere with the functioning of the pond outlet system and should, therefore, be minimized. The most direct way of minimizing short-circuiting stormwater is to maximize the distance between the riser and the outlet. A minimum length-to-width ratio of 2:1 is recommended for a dry pond design. Larger aspect ratios should be provided if sedimentation of particulates during low flows is desirable. Irregularly shaped ponds appear more natural, or less "engineered." If local site conditions inhibit constructing a relatively long, narrow facility, baffles constructed from gabions or other materials can be placed in the pond to "lengthen" the stormwater flow path.

A serpentine low-flow channel should be constructed through the pond to transport dry-weather flows and minor storm flows. Preferably the channel would be grass-lined and sloped at approximately 2 percent to promote drainage of the pond between storms. The entire bottom of the pond should drain toward the low-flow channel.

Unlike wet ponds, depth is not an important factor in dry pond design. Frequently, the depth of the pond and design of the embankments will be determined by criteria used for designing a sediment basin, which is the predecessor to the extended detention dry pond. Effective multiple outlet systems generally can be tailored to most pond configurations

A forebay is an extra storage area near an inlet of a BMP to trap incoming sediment. With heavy, coarse sediment confined to the forebay area, maintenance is made simpler and less costly and the life of the BMP is extended. Forebays are recommended for use on all stormwater pond BMPs as part of the overall pond design. Baffles constructed from stone, rip rap, gabions, or similar materials can be used to create a separate forebay compartment in the pond.

Below-grade Detention Facilities

As an alternative to conventional dry detention ponds, runoff peak attenuation can be provided by below-grade facilities. Although more costly than above-grade ponds, below-grade detention facilities can preserve land area for alternative uses, including:

- Patios
- Tennis courts
- Parking areas

To support the weight of overlying land uses, below-grade detention facilities can be filled with uniform gravel or aggregate fill. The calculation of detention volume for below-grade facilities must be adjusted to reflect the pore space of the fill. Otherwise, the design process is similar. Below-grade detention facilities should not be used in environments where runoff contains significant amounts of suspended sediment. Below-grade facilities cannot easily incorporate water quality functions. Therefore, it is common to combine below-grade detention facilities with water quality BMPs, such as grass FILTER STRIP or SAND FILTER. BMPs that have a tendency to shed organic matter during large rainfall events, including grass swales, should be used with caution, because they can result in clogging.

OPERATION AND MAINTENANCE: The maintenance requirements for dry detention ponds are intensive and potentially costly. General objectives of maintenance are to prevent clogging of the outlets, prevent standing water, and prevent the growth of weeds and noxious plants. Normal maintenance costs can be expected to range from 3 to 5 percent of the construction costs annually (Schueler, 1987).

Maintaining turf grass on the tops of berms and on the exterior slopes of embankments is advisable. This will enhance access to the facility and make maintenance and inspection of the embankment condition much easier. The stability of dams, embankments, and side slopes can be impaired by trees and brush with extensive woody root systems. Any seedlings or planting should be removed at the earliest opportunity and the disturbed areas properly stabilized. Control of woody vegetation will require periodic mowing and a policy of not allowing plantings on these facilities. The frequency of mowing may need to be greater if the facility is in an area of high visibility. However, if possible, the facility should be managed as an upland meadow with grass no shorter than 6 to 8 inches. Keeping grass much shorter than this can cause areas of the turf to die off or require a much higher level of maintenance.

Root voids and animal burrows should be plugged by filling them with material similar to the surrounding materials, and capped just below grade with stone, concrete, or other material. If plugging the burrows does not discourage borrowing animals from returning, further measures should be taken to either remove the animal population or to make critical areas of the facility unattractive to them.

Extended detention dry ponds should have enough volume to account for sediment accumulation over time. Cleaning out sediment will be necessary, on average, every 2 to 10 years. Cleaning involves digging out the accumulated sediment, mud, sand, and debris with earth-moving equipment and disposing appropriately. Once the sediment is removed, the disturbed areas need to be immediately stabilized and revegetated, or the facility will mobilize sediment to downstream areas. Freshly seeded areas should be protected with erosion mat that has been securely staked in place to prevent flotation. In many cases, sodding offers the best approach to stabilization after sediment removal.

The bottom of the pond must be accessible for maintenance. The access way should be a minimum of 10 feet wide (widths of 15 feet are common), have a maximum slope of 5H:1V, and not cross the emergency spillway. Steeper slopes may result in rutting and require more access road maintenance.

The facility should be inspected quarterly and after major storms. Detailed inspections by a qualified inspector should occurring at least annually to ensure that the facility is operating as designed and to schedule maintenance that the facility may require. If possible, inspections should be made during wet weather to ensure that the facility is maintaining desirable retention times. In addition to regularly scheduled inspections, deficiencies should be noted during any visits by maintenance personnel. An important purpose of inspections is to ascertain the operational condition and safety of the facility, particularly the condition of embankments, outlet structures, and other safety-related aspects.

Recommended Minimum Inspection Requirements
• Dam settling, woody growth, and signs of piping
• Signs of seepage on the downstream face of the embankment
• Condition of grass cover on the embankment, pond floor, and perimeter of the pond
• Rip rap displacement or failure
• Principal and emergency spillway meet design plans for operation
• Outlet controls, debris racks, and mechanical and electrical equipment
• Outlet channel conditions
• Safety features of the facility
• Access for maintenance equipment

Perhaps the largest single expense in maintaining BMPs is the eventual repair or replacement of the parts of the facility; therefore, high-quality materials with a long service life should be used. Structural use of corrugated metal pipe or plastic products is discouraged.

CONSIDERATIONS: Dry ponds can effectively control peak runoff discharge rates from both small and large drainage areas. The main problem for extended detention dry ponds is a tendency to develop a soggy bottom, which hinders facility maintenance and the growth of effective vegetative cover.

Dry ponds should be located where they are not easily seen or where they can be concealed with landscaping. Ponds can be unsightly, especially if floating and other debris accumulate in them. If inadequately drained, standing water can become a nuisance and an eyesore to residents. Ponds with fouled outlets can overflow during large rainfall events, and result in erosion and flooding in downstream areas. The poor or nonexistent maintenance of dry detention ponds is a common problem in developments throughout the state.

Long-term provisions for the routine inspection, maintenance, and repair of ponds should be included in any proposal for a new installation. The appearance of some dry ponds has been improved by planting hardy wildflowers in the bottom. Residents' acceptance of a "wildflower pond" is much higher than their acceptance of an unadorned open pond.

Dry ponds are costly in terms of the space that they require. Because they take up large areas, dry ponds generally are not best suited for high-density residential developments. Other BMPs that require less space or that can more readily be incorporated into the landscape generally are preferred in densely developed areas. Alternatively, runoff peak attenuation facilities can be concealed below grade.

Ponds present attractive play areas to children; hence, ponds may create safety problems. Design features that discourage child access are recommended. Trash racks and other debris-control structures should be sized to prevent entry by children. Bar spacing on debris-control structures should be no greater than 12 inches in any direction and the preferred spacing is 5.5 inches. Barriers should not be installed at the outfall end of pipes. Other safety considerations include using fences around the spillway structure, embankment, and pond slopes; using shallow safety benches around the pond; and posting warning signs.

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World Wide Web. Home page code: http://h2osparc.wq.ncsu.edu/descprob/industri.html. 1997.

SPECIFICATIONS AND METHODOLOGY: The following topics are covered in this section:

- Forebays
- Embankments
- Outlet design

Additional design criteria pertaining to the outlet configurations is discussed in the Appendix I, *Common Design Elements*.

Forebays

When installed in dry ponds, forebays generally are vegetated to improve filtering of runoff, provide velocity control, and stabilize soil against erosion. Forebays are frequently constructed as shallow marshes and may incorporate the ephemeral ponding of runoff to a depth of 2 feet or less. Design criteria for forebays are listed below.

- The minimum recommended forebay length is 10 feet.
- Sufficient storage should be provided to trap sediment over a 2- to 10-year period.
- The height of the berm or baffle that separates the forebay from the remainder of the pond should be 1 foot below the ponding depth associated with the water quality design storm (i.e., the elevation associated with the water quality storage).

Embankments

A maximum slope of 3H:1V should be used so that the facility can be properly maintained. If steeper slopes are required, they should be paved. The pond's freeboard should be a minimum of 1 foot above the elevation of the SDF. Embankment design should incorporate the following considerations:

- Foundation preparation and treatment
- Control of seepage
- Embankment stability
- Construction

Guidelines for the design and construction of earth embankments are provided in Appendix I, *Common Design Elements.*

Outlet Design

In addition to being designed to achieve specific hydraulic requirements for runoff detention and peak attenuation, outlets also must be functionally simple and easy to maintain. Durable materials, such as reinforced concrete or plastic are preferable to corrugated metal in most instances. The riser should be placed in or at the face of the embankment. By placing the riser close to the embankment, maintenance is facilitated and flotation problems prevented. Outlets are described in greater detail in Appendix I, *Common Design Elements.* Erosion protection measures should be used at the pond discharge point.

The effect of detention is to reduce the maximum discharge rate and delay the occurrence of the runoff peak. The total volume of water that is discharged remains unchanged. Figure 1 graphically represents the relationship between unattentuated inflow and attenuated outflow hydrographs.

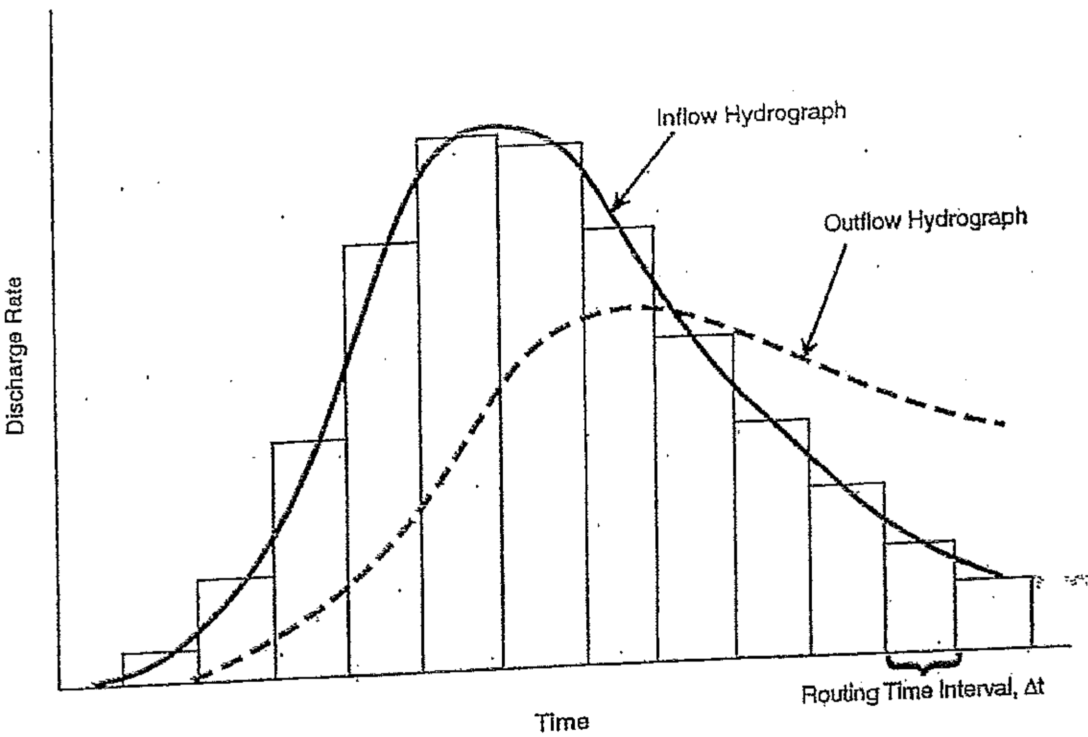

Figure 1. Detention curve.

The procedure for designing dry pond outlets applies equally well to designing many other stormwater detention measures, including WET PONDS, CONSTRUCTED TREATMENT WETLANDS, DRY WELLS, WATER QUALITY INLETS, SEDIMENT BASINS, BIORETENTION, and ROOFTOP RUNOFF MANAGEMENT devices. All of the measures have:

1. Storage devices that have a unique relationship between storage volume and depth
2. Outlet control devices that have a unique relationship between discharge rate and depth

Knowledge of the two relationships plus the design input hydrograph will enable the designer to compute the outflow hydrograph. Figure 2 graphically illustrates the stage-discharge and stage-storage functions for a hypothetical dry pond. In this example, water quality storage occupying the part of the pond below the primary outlet has been assumed. For the routing analysis, no discharge is assumed to be associated with the low-flow outlet, which controls the water quality storage part of the pond. The assumption will introduce no significant error because the discharge rate for low-flow outlets is intentionally much less than for primary outlets, which control the runoff peak attentuation function of the pond.

Storage Routing Relationships

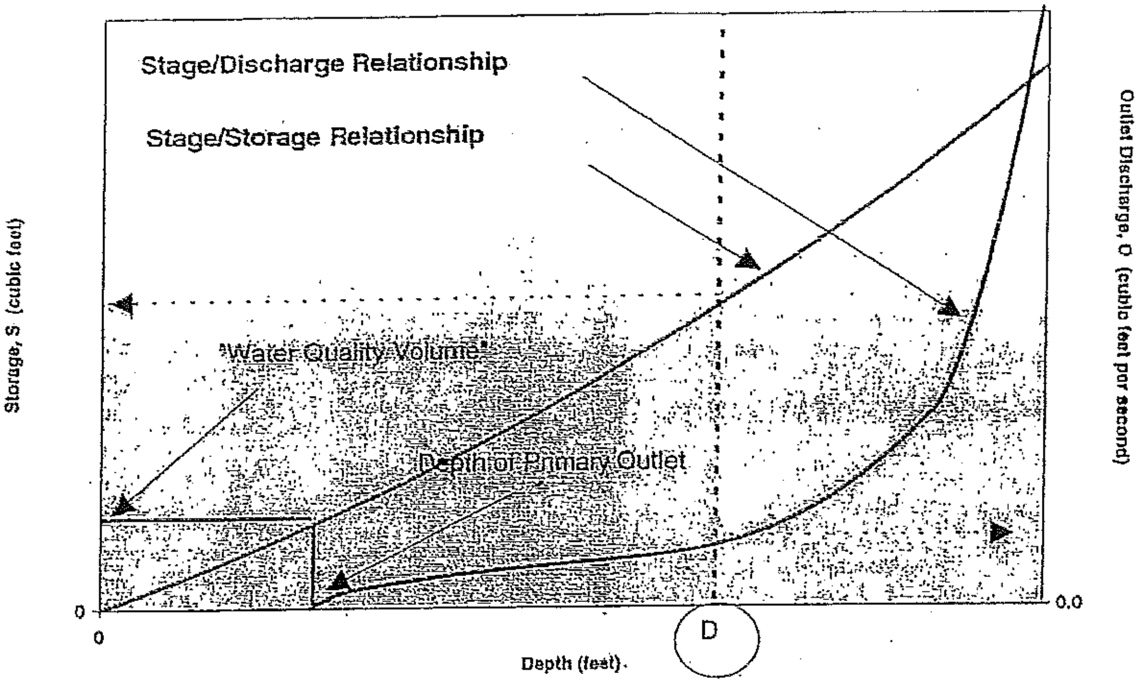

Figure 2. Example storage routing relationships

The design of all outlet systems involves the routing of a design storm hydrograph through the facility. The design storm hydrograph is frequently based on the 24-hour rainfall, distributed according to the NRCS Type II distribution. Total rainfall amounts are published for the various return frequencies (e.g., 2-year, 5-year, 10-year, and 25-year return frequency).

Runoff hydrographs can be generated from the design storm rainfalls by using a variety of hydrograph generation algorithms. The NRCS methods, which use a nondimensionalized unit hydrograph and predict runoff potential on the basis of the runoff curve number (CN), are widely accepted for stormwater management design. Once the hydrograph has been computed for a particular design storm, it can be routed manually or with the assistance of computer algorithm. Dozens of routing techniques have been published (see Maidment, 1993). In general, all of the algorithms, if appropriately applied, will give similar results. However, when using any method the assumptions on which the method is based and the limitations that apply to its use must be understood.

A simple, but reliable procedure that can be implemented conveniently on a spreadsheet is the storage/indication method or Modified Puls algorithm. The routing procedure is based on the continuity equation, which states that the rate of change of water storage volume equals the inflow rate minus the outflow rate:

$$I - O = dS/dt$$

The finite-difference formulation for this expression can be rewritten as:

$$I^{o} + I^{oo} + (2S^{o}/t - O^{o}) = (2S^{oo}/t + O^{oo})$$

Where: I^{o} = Inflow rate occurring during the previous time interval
I^{oo} = Inflow rate volume occurring during the present time interval
S^{o} = Storage volume at the beginning of the time interval
S^{oo} = Storage volume at the end of the time interval
O^{o} = Outflow rate occurring during the previous time interval
O^{oo} = Outflow rate occurring during the present time interval
t = Length of the routing time interval

To route runoff through a detention facility, the hydrograph must be divided into discrete time intervals, t. At the beginning of each new time interval, all the terms on the left-hand side of the finite difference equation are known. Therefore, the value of the right-hand terms, collectively called the storage function, can be computed directly. By using the depth-storage and depth-discharge relationship that characterize the detention facility, the unique relationship between depth and the storage function can be constructed (Figure 3).

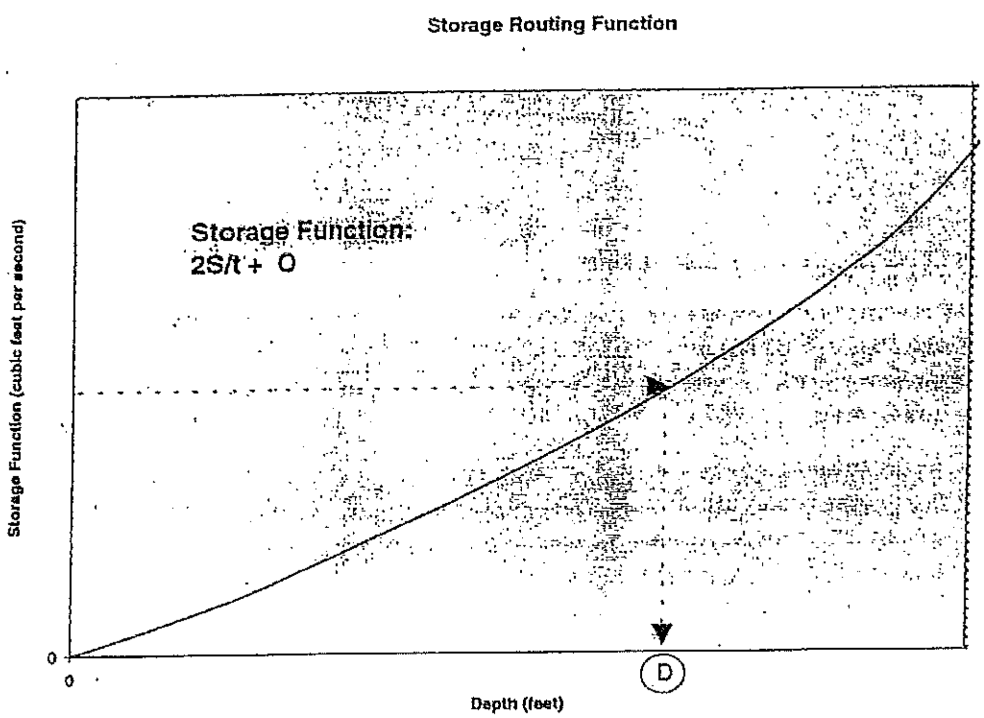

Figure 3. Example storage function.

By using this relationship, the average ponding depth during the new time interval can be determined. The procedure can be summarized as follows:

1. From known S^{o}, O^{o}, I^{o}, and I^{oo}, determine the value of the storage function for the new time interval.
2. Using the storage function, determine the ponding depth for the new time interval.

3. Using the depth-storage and depth-discharge relationships, determine S^{∞} and O^{∞}.
4. Repeat.

When routing storm runoff hydrographs, the maximum time interval should be 15 minutes. Near the peak where the inflow and outflow rates are varying rapidly, the time interval should be reduced to a maximum of 5 minutes.

Runoff "treatment trains" frequently incorporate multiple detention devices in series. For instance, a dry well connected to roof drains, may drain sequentially to a bioretention device. In these cases, each detention component must be routed separately and in sequence.

The design of outlets is discussed further in Appendix I, *Common Design Elements*.

Ordinance Appendix H
DEP Levee Data

Bureau Of Waterways Engineering
Rachel Carson State Office Building
P. O. Box 8460
Harrisburg, PA 17105-8460

FAX TRANSMITTAL SHEET

TO: Paul DeBarry

FAX NO. 610-837-5918

PHONE NO. 610-837-5917

FROM: Joseph G. Capasso

OFFICE PHONE NO. (717) 787-3411

FAX NO. 717-772-0409

NUMBER OF PAGES NOT INCLUDING COVER SHEET: 4

DATE: Thursday, August 28, 2003

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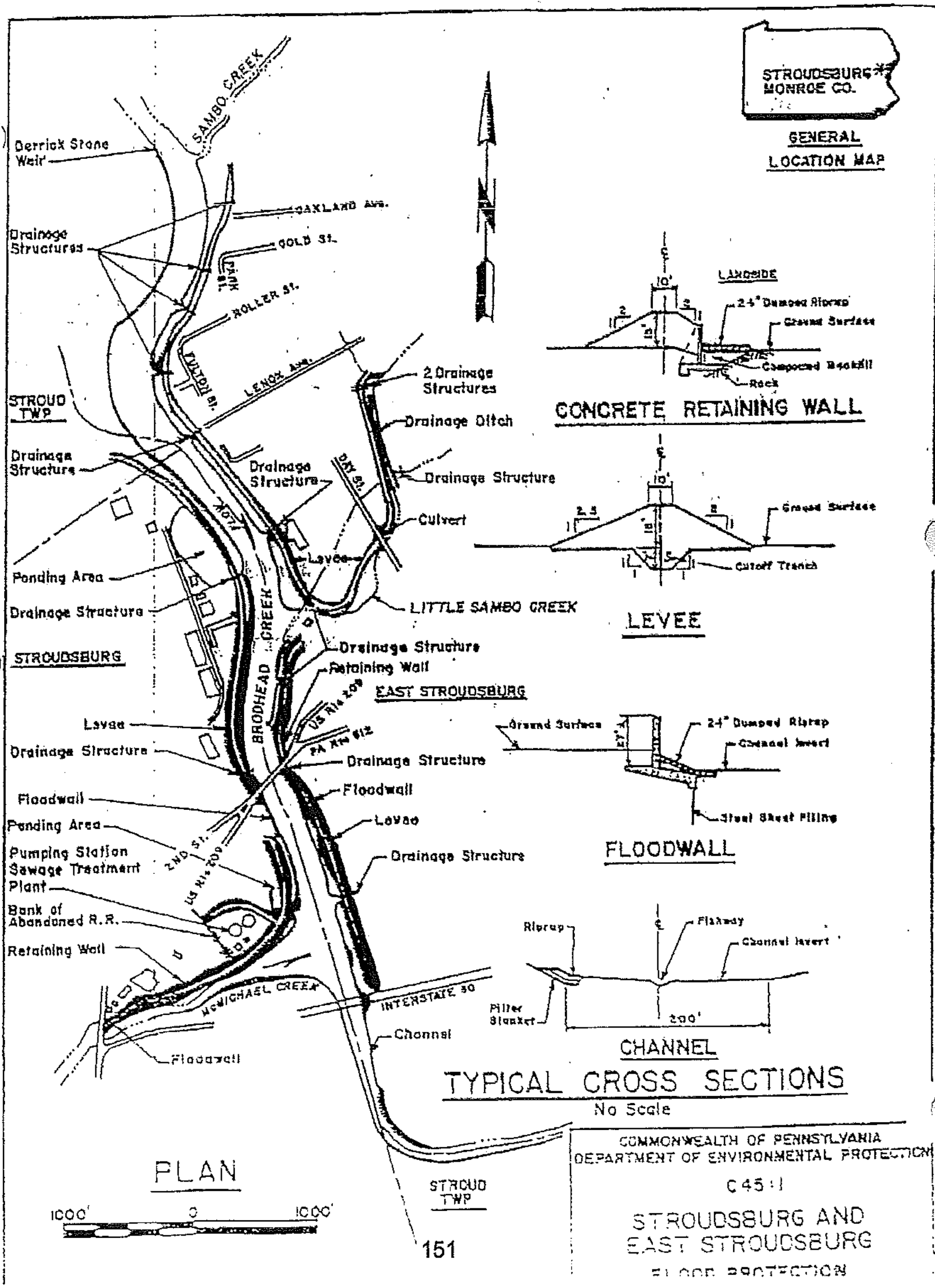
STROUDSBURG
MONROE CO.
GENERAL LOCATION MAP
SAMBO CREEK
Derrick Stone Weir
OAKLAND AVE.
GOLD ST.
PARK ST.
Drainage Structures
ROLLER ST.
FULTON ST.
LENOX AVE.
2 Drainage Structures
Drainage Ditch
STROUD TWP
Drainage Structure
Drainage Structure
Drainage Structure
Culvert
Levee
Ponding Area
Drainage Structure
LITTLE SAMBO CREEK
BRODHEAD CREEK
STROUDSBURG
Drainage Structure
Retaining Wall
EAST STROUDSBURG
US Rte 209
PA Rte 612
Levee
Drainage Structure
Drainage Structure
Floodwall
Floodwall
Levee
Ponding Area
2ND ST.
US Rte 209
Pumping Station
Sewage Treatment Plant
Drainage Structure
Bank of Abandoned R.R.
Retaining Wall
McMICHAEL CREEK
INTERSTATE 80
Channel
Floodwall
PLAN
1000'
0
1000'
STROUD TWP
LANDSIDE
10'
2
3
15'
24" Dumped Riprap
Ground Surface
Compacted Backfill
Rock
CONCRETE RETAINING WALL
10'
2.5
2
15'
5
Ground Surface
Cutoff Trench
LEVEE
Ground Surface
24" Dumped Riprap
Channel Invert
Steel Sheet Piling
FLOODWALL
Riprap
Flowway
Channel Invert
Filter Blanket
200'
CHANNEL
TYPICAL CROSS SECTIONS
No Scale
COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
C45:1
STROUDSBURG AND
EAST STROUDSBURG
FLOOD PROTECTION

STROUDSBURG AND EAST STROUDSBURG FLOOD PROTECTION, C45:1

LOCATION: Brodhead, McMichael and Little Sambo Creeks, Stroudsburg and East Stroudsburg Boroughs and Stroud Township, Monroe County

QUADRANGLE: Stroudsburg, Latitude: 40°59'00", Longitude: 75°11'30"

SPONSOR: Boroughs of Stroudsburg and East Stroudsburg

PROJECT DESCRIPTION: This project consisted of the improvement of 11,800 feet of earth channel, including widening, cleaning, and realignment; construction of 16,000 feet of earth levees, including 15 drainage structures equipped with emergency sluice gates; construction of 560 feet of reinforced concrete floodwall and 390 feet of concrete retaining wall; and construction of both a sanitary sewage and storm water pumping station. Channel slopes were protected with rock riprap at critical areas. Two ponding areas were provided to allow interior runoff to collect during high stream stages.

Improvements to the interior drainage system and installation of staff gauges were completed in 1964.

DESIGNER: Fridy, Gauker, Truscott and Fridy, Inc., Philadelphia, Pa.
CONTRACT NO.: C45:1 PERMIT NO.: 13627
BID OPENING: May 13, 1960 CONTRACT AWARD: May 31, 1960
LOW BIDDER: Elmhurst Contracting Co., Corona, N.Y
PROJECT COMPLETED: October 9, 1962 CONSTRUCTION COST: $1,591,233.77

DRAINAGE CRITERIA:	DRAINAGE AREA	FLOOD OF RECORD (August 19, 1955)	FIS 100-YEAR DISCHARGE
Brodhead Creek:			
Below McMichael Creek	258 SM	68,800 CFS	36,000 CFS
Above McMichael Creek	146 SM	----------	26,000 CFS
McMichael Creek:	107 SM	5,740 CFS	10,300 CFS

Maximum Channel Bottom Width: 220 FT
Levee Top Width: 10 FT
Land Slope 1V to 2H
Stream Slope 1V to 2.5H
Pumping Station:
Sewage - 2 Pumps at 100 gallons per minute (GPM) each
Storm Water - 2 Pumps at 800 gallons per minute (GPM) each

QUANTITIES:

902,375 C.Y.	Excavation (All Types)	16 EA.	Drainage Structures
506,770 C.Y.	Rolled Embankment	1 EA.	Sewage Pumping Station
39,230 S.Y.	Dumped Riprap	1 EA.	Storm Pumping Station
3,260 C.Y.	Concrete	38 AC.	Seeding

Project turned over to sponsor for operation and maintenance on October 17, 1962.

STROUDSBURG LEVEE STABILIZATION PROJECT, C45:1, DGS 180-27

PROJECT DESCRIPTION: Riprap was placed on the left bank levee from the Gold Street area upstream to Sambo Creek. Rock riprap was also placed from the bottom of the existing riprap down to a depth of 5 feet below the channel invert on the remaining length of levee. A control structure was installed across the channel invert to minimize future degradation of Brodhead Creek.

DESIGNER: Department

CONTRACT NO.: DGS 180-27.1 **PERMIT NO.:** Unknown

BID OPENING: May 14, 1980 **CONTRACT AWARD:** June 25, 1980

LOW BIDDER: Allegheny Mountain Construction Co., Galeton, Pa.

PROJECT COMPLETED: April 14, 1981 **CONSTRUCTION COST:** $923,000.00

DESIGN CRITERIA:

Same as Stroudsburg and East Stroudsburg Flood Protection.

QUANTITIES:

68,000	C.Y.	Excavation
21,500	S.Y.	18-Inch Riprap
10,000	S.Y.	20-Inch Riprap
25,000	C.Y.	Filter Blanket