Guidelines For Permanent Pool Detention Basin Design
For Piedmont Areas Using Driscoll's Model

OBJECTIVE

To examine possible permanent pool detention basin designs which would capture runoff from impervious areas resulting from the first 1/2-inch or 1-inch of rainfall. Basins were designed using Driscoll's model (USEPA, 1986a).

MODEL

1) Inputs: Long-term rainfall event statistically derived from hourly rainfall records for Piedmont stations (USEPA, 1986b)

2) Settling Models: Dynamic settling (during storm event) and quiescent settling (between storm events)

3) Design Parameters: Depth of pond, pond surface area/drainage area, and percent impervious surface in the drainage basin

4) Outputs: Percent total pollutant removal (Total suspended solids -TSS)

MANAGEMENT TOOLS

1) From the RDU and Greensboro historical rainfall records, approximately 62% and 85% of the storms had less than 1/2-inch and 1-inch of rain respectively.

2) Pollutant removal targets were set to coincide with the above frequency for rainfall events. TSS pollutant removal targets of 62% and 85% were chosen to represent the capture of the first 1/2-inch and 1-inch of rainfall respectively.

CHARTS

The following flow charts are provided for use in designing wet detention basins for these unavoidable situations. Chart 1 is to be utilized for North Carolina piedmont areas inside the critical area while Chart 2 is to be utilized outside the critical area.

NOTES

- These figures represent preliminary results and are subject to change as more data specific to North Carolina (particularly the Piedmont) become available.
- All ponds should have an average permanent water quality depth of 3 to 6 ft.
- Additional depth should be designed for flood, temporary water quality and sediment storage.
- Pond length:effective width ratio should be at least 2:1.
- Ponds should be properly designed for their distinct drainage area.
- Upstream of these basins other sediment/pollutant trapping practices should be utilized where feasible (e.g. buffer strips, infiltration ditches, etc.).
- A forebay should be included for initial settling. This enables one to drain only a portion of the basin to excavate accumulated sediment. The forebay should equal about 20% of the basin volume.
- Stormwater should be routed via grassed waterways or pipes to the upper part of the basin to maximize detention time and settling efficiency.

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CHART 1

FOR NORTH CAROLINA PIEDMONT AREAS

INSIDE CRITICAL AREA

Impervious %
≤ 6% ?

no

ONLY TO BE USED IN UNAVOIDABLE SITUATIONS

Wet Detention Basin

	SA/DA % for basin depths				
Impervious (%)	3.0 ft	3.5 ft	4.0 ft	5.0 ft	6.0 ft
7-29	1.8	1.5	1.4	1.1	1.0
30	2.4	2.1	1.8	1.5	1.3
50	4.0	3.5	3.0	2.5	2.1
70 (max)	5.7	4.8	4.3	3.5	2.9

(controls 1-inch rainfall)

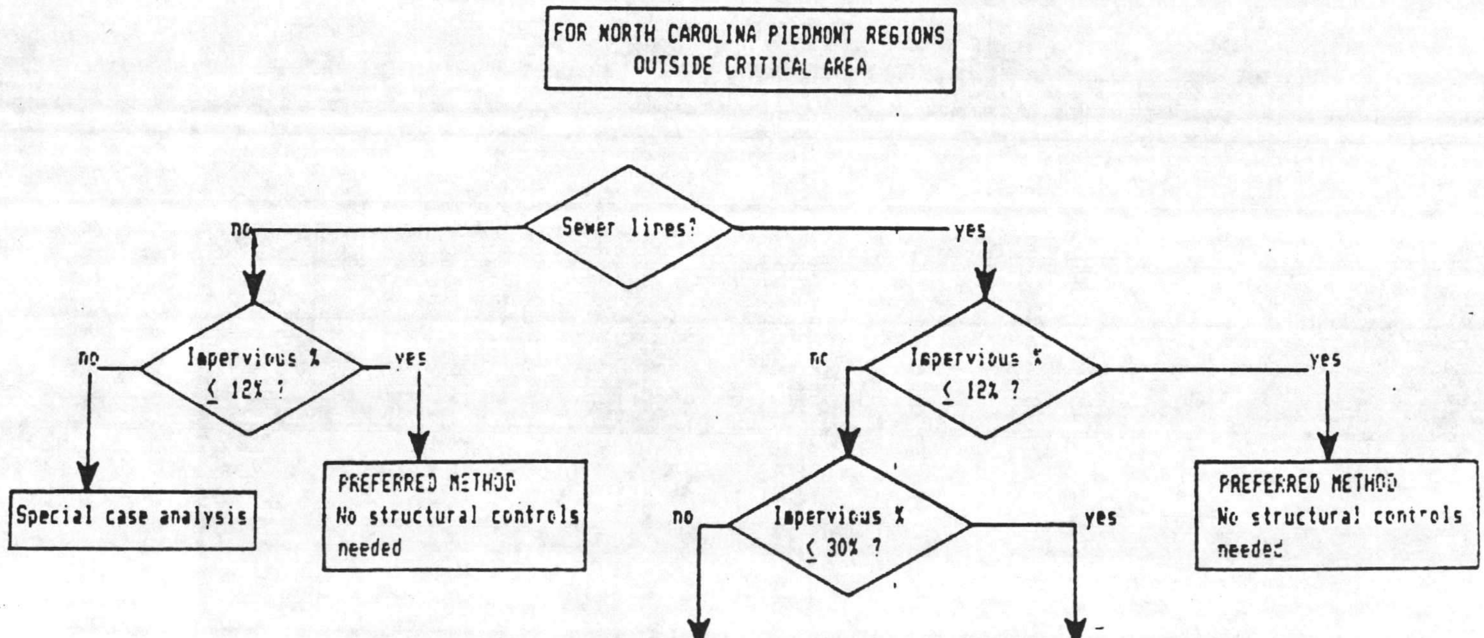
Interpolate intermediate values

* Surface area basin/drainage area * 100

yes

PREFERRED METHOD.
No structural controls neede

CHART 2



ONLY TO BE USED IN UNAVOIDABLE SITUATIONS
Wet Detention Basins

Impervious %	SA/DA % for basin depths 3.0 ft	3.5 ft	4.0 ft	5.0 ft	6.0 ft
31	2.4	2.1	1.8	1.5	1.3
50	4.0	3.5	3.0	2.5	2.1
70	5.7	4.8	4.3	3.5	2.9

(controls 1-inch runoff)

Interpolate intermediate values

* Surface area basin/drainage area * 100

ACCEPTABLE METHOD
Wet Detention Basins

Impervious %	SA/DA for basin depths 3.0 ft	3.5 ft	4.0 ft	5.0 ft	6.0 ft
13-30	1.0	0.9	0.8	0.7	0.5

(controls 1/2-inch rainfall)

*Surface area/drainage area * 100

CHART 3

NORTH CAROLINA COASTAL REGIONS

SA/DA PERCENTAGES FOR WET DETENTION BASINS
DESIGNED TO REMOVE 85% TSS (1" STORM)

Impervious %	SA/DA % For Basin Depths			
	3 Ft	3.5 Ft	4 Ft	5 Ft
30	2.5	2.2	1.9	1.6
40	3.4	3.0	2.6	2.1
50	4.2	3.7	3.3	2.7
60	5.0	4.5	3.8	3.2
70	6.0	5.2	4.5	3.7
80	6.8	6.0	5.2	4.2
90	7.5	6.5	5.8	4.8

CHART 4
SA/DA PERCENTAGES FOR WET DETENTION BASINS
DISCHARGING DIRECTLY TO A STREAM
(HENCE NO VEGETATIVE FILTER, POST-DEVELOPMENT DISCHARGE
RATE ≤ PRE-DEVELOPMENT RATE FOR 10 YEAR STORM)

Impervious %	SA/DA % For Basin Depths				
	3.5 Ft	3.5 Ft	4 Ft	5 Ft	6 Ft
30	3.5	3	2.7	2.2	1.6
40	4.5	4	3.5	2.8	2.1
50	5.6	5	4.3	3.5	2.7
60	7.0	6	5.3	4.3	3.4
70	8.1	7	6.0	5.0	3.9
80	9.4	8	7.0	5.7	4.6
90	10.7	9	7.9	6.5	5.2

Interpolate intermediate values
SA/DA % = surface area basin/drainage area to basin × 100

3D

AN OVERVIEW OF WET DETENTION BASIN DESIGN

Control of nonpoint source pollution is a stated goal of the 1987 Water Quality Act. An important source of these pollutants is stormwater runoff from urban areas. This runoff has the potential to degrade water quality in all types of waters, including, among others, those classified as water supply watersheds, shellfish areas and nutrient sensitive waters. Land-use control (i.e. low density) is the preferred method of reducing pollution from urban areas. In cases where low density is not feasible, engineered stormwater controls are viable solutions to reducing pollution. However proper design of these engineered solutions is essential for adequate pollutant removal. In turn, dissemination of technical information to both engineers and local officials on the design and maintenance of engineered solutions is equally important. Wet detention basins used as an engineered solution for stormwater control are the subject of this DEM Technical paper.

Wet detention basins have proven to be effective in improving the quality of runoff from urban areas (Hartigan and Quaesbarth, 1985; Yousef et al., 1985; US EPA, 1983). Benefits of wet detention ponds over other stormwater devices are many. In contrast to wet detention basins, dry detention basins are inefficient in removing suspended solids and other pollutants (US EPA, 1983; Metropolitan Washington COG, 1983) and hold little aesthetic value (Maryland DNR, 1986). Wet detention basins are also appropriate in areas where infiltration is impractical due to low infiltration rates of the underlying soils. In addition to water quality benefits, wet detention ponds can reduce the peak runoff rate from a developed site and control downstream erosion.

DEM's approach to water quality control of stormwater in surface drinking water supply watersheds is based first on minimizing impervious surfaces and secondly on treating stormwater runoff from these surfaces. DEM guidelines (NCDNRCD, DEM, 8/5/87) on wet detention basins provide information on the appropriate volume storm to treat and the corresponding basin size.

The design of these wet detention basins is based on retaining the runoff from a storm for an extended length of time in order to settle out suspended solids and pollutants (such as heavy metals and nutrients). Biological treatment also occurs (US EPA, 1983; Metropolitan Washington COG 1983). Driscoll's model (US EPA, 1986) was chosen for the permanent pool water quality component of the design. As its storm input, the model uses a long-term average storm statistically calculated from the historical storm record. By using this storm and the appropriate watershed characteristics (e.g., impervious cover), a permanent water quality pool is sized to detain the storm long enough to attain the target TSS removal. The model incorporates settling that occurs during the storm (dynamic) and between storms (quiescent). The movement of the storm through the basin is

assumed to be via plug flow. In general, to obtain a 62% and 85% TSS removal in basins designed for the long-term average piedmont storm, runoff will be detained ten days and two weeks respectively (NCDNRCD, DEM, 8/5/87). This detention time relates to treating runoff from impervious surfaces that results from the first 1/2-inch and 1-inch of rainfall.

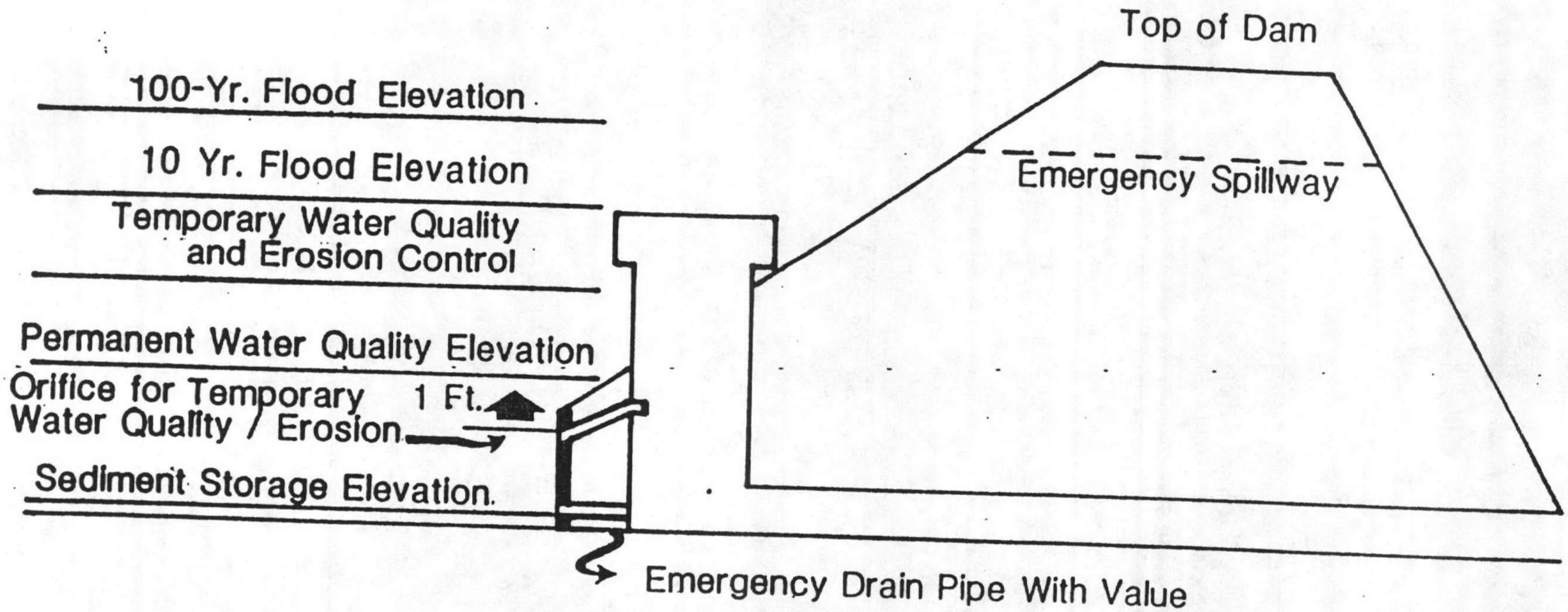
In addition to the permanent water quality pool, the basin should have a temporary water quality pool for extended detention. This temporary water quality storage, located above the permanent pool, is necessary for periods when runoff entering the basin is significantly warmer than the permanent water quality pool. During these periods, a thermocline is established, plug flow does not occur and runoff exits the basin without being detained long enough to achieve maximum settling. To counteract this lack of detention time and settling, the runoff (from the 1-inch storm) should be slowly released through a negatively sloped pipe (Figure 1).

Once the minimum volume of the basin (that needed to achieve the stated water quality goals) is determined, the principal outlet and emergency spillway may be sized for flood or erosion control. The storage allocated to flood control is located on top of both water quality pools, while the storage for erosion control occupies the same storage as the temporary water quality pool (Figure 1).

Each locality should decide whether a policy based solely on flood control (i.e., peak flow reduction) or on erosion control (i.e., bed-material load reduction or velocity control, both of which may also control flooding) is appropriate. An example of a flood control goal might be to reduce the 10-yr post-development peak discharge to the 10-yr pre-development peak discharge and safely pass the 100-yr storm. However research has shown that detention practices which control the after-development peak discharge of large storms are not effective in reducing downstream erosion. This peak flow reduction does not control bed-material loadings or reduce the duration during which the discharge velocity exceeds the critical velocity of the receiving channel (McCuen and Moglen, 1987; Schueler, 1987).

Smaller more frequent storms (those that produce a bankfull flood) are responsible for the majority of streambank erosion (McCuen, 1987; Andersen, 1970; Leopold et al., 1964). In a natural watershed this bankfull flood is caused by a storm which occurs on average every 1.5 to 2 years. However as the watershed develops and stormwater volumes and peaks increase, bankfull floods occur more frequently and channel erosion is more probable. Therefore designs based on detaining runoff from a small storm, such as a 1-inch storm, for 24-40 hours should reduce the probability of downstream erosion (Schueler, 1987). A stormwater routing technique should be executed to assure that each outlet (principal and emergency) performs satisfactorily for its design storm.

FIGURE 1. WET DETENTION BASIN



4

The wetted perimeter of the basin should be planted with aquatic vegetation (Maryland DNR, 1987; Schueler, 1987; Florida DER, 1986). This vegetation not only enhances pollutant removal but provides wildlife and waterfowl habitat, and protects the shoreline from erosion.

If a detention basin is constructed adjacent to impervious surfaces and only collects runoff from these surfaces, then the basin can be sized just for the impervious area. However, if the basin receives runoff from surfaces in addition to impervious surfaces, then the basin should be sized for the entire contributing area. Basins must be sized to account for any offsite drainage that flows into the reservoir. In general, instream impoundments should not be installed in order to avoid sizing the storage for the entire upstream watershed. If a development encompasses the entire upper part of a drainage area, then the location of the basin in the streambed should not cause an increase in required storage. However, if the development has offsite drainage flowing onto the site, then the basin either should be sized for the entire contributing watershed or several basins should be located out of the streambed and sized for smaller drainage areas in the development.

In addition to proper design, the basin must be routinely maintained if one is to satisfy long-term water quality and flood control goals. The basins may be maintained either by the private owner/homeowners associations or by a local government/municipality. Like gas, electricity, and sanitary sewers, stormwater management may be designated as a public "utility". Under this approach property owners within a jurisdiction are assessed a monthly user-fee which covers capital and operation and maintenance costs for the stormwater management program (Hartigan, 1986). Regardless of the approach a key to any maintenance program is the allocation of adequate funding and the designation of the responsible party.

In newly developing areas, a regional detention basin may be an option for the locality to consider. According to James, et al., (1987) possible benefits of regional detention basins over onsite basins are less land area designated to the basins and their easements and reduced maintenance. Other benefits may include lower construction, operation, and maintenance costs; enhanced aquatic life, aesthetic and recreational values; and a comprehensive regional approach, rather than a piecemeal approach, to stormwater management (Hartigan, 1986). Regional basins would probably involve compensation and joint maintenance contracts between upstream and downstream property owners.

The following material consists of an outline of steps to take in designing a wet detention basin (with references) and an example of a wet detention basin design. Copies of most of the references cited are also attached.

DESIGN OF PERMANENT POOL DETENTION BASINS

A. Design For Water Quality Control

a) For the permanent water quality pool, use basin surface area/drainage area (SA/DA) ratios for given levels of impervious cover and basin depths (NCDNRCD, DEM, 8/28/87).

b) Average permanent water quality pool depths should be between 3 to 6 feet.

c) Use impervious levels expected in the final stages of development

d) Locate the temporary water quality pool for extended detention above the permanent water quality pool. The orifice of the negatively sloped pipe should be sized to release runoff from the first 1-inch rainfall over a 48 hour period (Schueler, 1987, pp. 3.4-3.5).

e) Basin shape should minimize dead storage areas: average length of flow to effective width > 2.0 (Barfield, <u>et al</u>., 1981, pp. 426-429; Florida DER, 1982 draft, pg. 6-289).

f) A forebay (may be established by a weir) should be included to encourage early settling. This allows drainage of only a portion of the basin in order to excavate accumulated sediment. The forebay volume should equal about 20% of the basin volume (Figure 2).

g) Check area ratios to make sure that the watershed will support a wet basin on existing soils (NCDNRCD, DEM, 8/28/87 attached, and Harrington, 1986).

h) If the basin is used as a sediment trap during construction, make sure that all sediment deposited during construction is removed before normal operation begins.

i) While not required at this time, sand filters or other treatment may be necessary on the effluent from the water quality basins especially in the Piedmont. The UNC WRRI has funded a study by Dr. Wu at UNC-Charlotte, to evaluate the removal efficiency and sediment size distribution of inflow and outflow samples and other aspects of detention basins. Results are expected in the near future. Basin designs should ensure that the flood flow does not pass through the sand filters (Urbonas and Ruzzo, 1986, pp. 739-760).

j) Aquatic vegetation should be included for a wetland type detention basin (Maryland DNR, March 1987; Schueler, 1987, Chapter 4 and 9). A minimum 10 foot wide, one foot deep shelf is required around the edge of the basin for safety and to provide appropriate conditions for aquatic vegetation establishment (Schueler, 1987). This shelf should be sloped 6:1 or flatter and extend out to a point 2 to 2.5 feet below the surface (Florida DER, 1986). A list of suitable wetland species and propagation techniques are provided in Schueler (1987) and Maryland DNR (1987).

k) An emergency drain (with a pipe sized to drain the pond in less than 24 hours) should be installed in all ponds to allow access for riser repairs and sediment removal (Schueler, 1987).

B. Design For Water Quantity

a) Design storm

1) The primary outlet will most likely be designed for a 10-yr storm. SCS suggests using the 24-hr storm (USDA, SCS, 1986, pg. 1-1; NCDNRCD, Land Quality, 7/29/86, pg. 9-22).
2) The emergency spillway should be designed for the 100-yr storm. The Dam Safety Act gives guidance on design storms for spillways in larger basins (NCDNRCD, 11/1/85, pg. 2K-11).
3) Note that storms of other durations should be checked for overtopping (Malcom and New, 1975, pp. 3-13 to 3-14).

b) Peak Runoff Flow

1) Use the SCS method (USDA, SCS, 1986, TR-55; NCDNRCD, Land Quality, 7/29/86, pg. 9-22), or
2) Use the Rational method, especially for watersheds less than 25 acres (NCDNRCD, Land Quality, 7/29/86, pg. 3-8).
*Note: care should be taken with either method to accurately calculate the Curve Number or Rational C.

c) Volume of Runoff, Hydrograph Shape and Storage Required

1) Follow procedures in Malcom, et al., 1986, pp. 61-65, or
2) Use SCS methods (USDA, SCS, 1986, TR-55; NCDNRCD, Land Resources, 12/86).
3) Be sure to include a sediment storage pool in addition to the water quality and flood pools. Unfortunately there is only limited data on sediment yields from urban areas. A method outlined in Schueler (1987, pp. 1.9-1.20) may be used for predicting those sediment yields. See example 1-2 on page 1.19. In Piedmont areas, (P) = 42 inches per year and (Pj) = 0.9 (estimated). This calculation is for stabilized areas. The designer should keep in mind that this average sediment yield is at best an estimate of the actual sediment yield which is extremely dependent on such factors as soil type, slope and vegetative and stabilization practices. The designer would be prudent to overestimate sediment yield since more conservative (i.e., higher) sediment yield estimates will result in a larger allocated sediment storage and less frequent clean outs.

d) Stage-Storage Function for basin

See Malcom and New, 1975, pp. 106-109.

e) Stage Discharge

1) See appropriate equations for outflow structures and when each equation is the limiting factor (Barfield, et al., 1981, pp. 227-236; Malcom and New, 1975, pp. 3-9 to 3-11), or
2) Use methods in Land Quality's Sediment Basin handout (NCDNRCD, Land Quality, 12/86, pg. 5).

f) Emergency Spillway and Dam Height

1) Use SCS methods for emergency spillway design (USDA, SCS, 1986, Chapter 11; NCDNRCD, Land Quality, 12/86).
2) Include calculation for wave height and wind setup for a detailed freeboard analysis (Lindsley and Franzini, 1972, pp. 179-183).
3) Dams 15 feet or higher with an impoundment capacity of 10-ac-feet or greater at the top of the dam must obtain a Dam Safety permit from NCDNRCD, Land Quality.

g) Storm Routing

1) Use either Storage Indication Method (Viessman, et al., 1977, pp. 240-244; Malcom and New, 1975, pp. 113-115; USDA, SCS, National Engineering Handbook, Sec. 4, Chapter 17), or
2) Use HRM (H.R. Malcom) method of routing which is easy to execute and approximates the Storage-Indication Method (Malcom and New, 1975, pp. 3-2 to 3-6, 110-113), or
3) Use SCS TR-20 method of routing.
4) The TR-55 routing method may be used for preliminary design (USDA, SCS, 1986, TR-55, pp. 7-6 to 7-13).

h) Downstream Protection

1) As required in the Sedimentation Control Plan (NCDNRCD, 8/1/85, Title 15, NCAC 4B.0009). The post-construction velocity of the 10-yr storm runoff shall not exceed the greater of:
   a) the maximum permissible velocity for the given channel lining,
   b) the 10-yr pre-development velocity.
2) Use methods in N.C. Division of Land Quality's Energy Dissipater handout (no date).
3) As mentioned in A(c) above, release the runoff from the first one-inch of rainfall over a 48 hour period for temporary water quality control. McCuen and Moglen's research (1987) as well as research reviewed by Schueler (1987) suggest that smaller storms are the key to controlling downstream streambank erosion. Schueler (1987) suggests that runoff from the first one-inch of rainfall released over 24-40 hours can reduce downstream erosion. Therefore the design and storage pool for erosion control shall be the same as that for

the temporary water quality pool.

i) Construction of basin and dam

1) See SCS Technical Guideline #378-1, Ponds.
2) See guidelines in Dam Safety Act (NCDNRCD, 11/1/85) and SCS handbook (USDA, SCS, 1986, Chapters 11 and 17).
3) See estimated construction costs from the NURP project in Washington, D.C. (Metropolitan Washington COG, 1983, Chapter 3).

j) Other Design Considerations

1) A trash rack should be included to avoid pipe clogging (Florida DNR, 1984 draft, pg. 6-282).
2) To further avoid clogging, barrels should be no smaller than 6 inches, risers no smaller than 8 inches, and reinforced concrete/concrete block structures no smaller than 24 X 24 inches (USDA, SCS, 1986, pg. 11-16).
3) An antivortex structure should be included (Florida DNR, 1984 draft, pg. 6-282.)
4) Antiseep collar(s) may be necessary to prevent undermining of the dam around the barrel (Barfield, et al., 1981, pp. 456-458; Florida DNR, 1984 Draft, pg. 6-294).
5) The barrel should be anchored to avoid flotation (Florida DER, 1984 Draft, pg. 6-282).
6) Side slopes should be no greater than 2-1/2:1 (horizontal:vertical) for mowing with a riding lawnmower. Slopes of 3:1 or 4:1 make mowing easier and provide safety benefits (Maryland DNR, 1986, page 34).
7) Facilities with a large amount of oil and grease should use an oil and grease skimmer.
8) Stormwater should be routed via grassed waterways or pipes to the upper part of the basin to reduce short circuiting and obtain maximum detention time and settling.

C. Operation And Maintenance

a) Routine maintenance is vital to the proper operation of the wet basin (Schueler, 1987, pp. 4.13-4.17; Maryland DNR, 1986).
b) Adequate funding is the most important factor in a successful maintenance program (Maryland DNR, 1986).
c) Designation of a lead agency(ies) is important to assure proper inspection and maintenance. The Maryland DNR report (March 1987) surveyed different counties to find the strengths and weaknesses of various inspection and maintenance arrangements.
d) Estimated annual operation and maintenance (O&M) costs for wet basins of 5% of construction costs were found in a survey conducted by the State of Maryland on their wet

detention basins (Maryland DNR, 1986, pg. 37). In addition the NURP study in Washington, D.C. estimated O&M costs to be 5% of construction costs (Metropolitan Washington COG, 1983, Chapter 3).

e) A study of Maryland basins found that in general people had more favorable impressions of wet basins, were less likely to throw litter in them, and were more likely to clean and perform routine maintenance on these basins (Maryland DNR, 1986).

f) A permanent easement must be provided to assure easy access for maintenance. Care should be taken to secure all appropriate legal agreements for the easement.

g) A benchmark for sediment removal should be established to assure adequate storage for water quality and flood control functions.

D. Location

a) In order to avoid sizing the basin for the entire upstream drainage area, basins should be located out of the streambed and sized for smaller subbasins in the development. Particular care should be taken to modify storm drainage so that all developed areas drain to the basin especially if the site is intensively developed (e.g., condominium or commercial). This method will assure that all runoff from impervious areas will be treated, without the necessity of retreating upstream runoff.

b) In newly developing areas of the watershed, a regional detention basin may be an option for the local government and developers to consider. Compensation and joint maintenance contracts between upstream and downstream property owners would probably be necessary.

c) Buffers around the basin should be determined by the flood pool (usually the 100-yr storm).

E. Certification

All basins should be designed, stamped, and certified that they are built as designed by a N.C. registered professional engineer.

* Use the 1986 revised SCS TR-55.

F. Definitions

1) Forebay- The forebay is an excavated settling basin or a section separated by a low weir at the head of the primary impoundment. The forebay serves as a depository for a large portion of sediment and facilitates draining and excavating the basin.

2) Plug flow- Fluid particles pass through the basin and are discharged in the same sequence in which they enter. The particles remain in the tank for a time equal to the theoretical detention time. This type of flow is especially

appropriate for basins with high lengthy-to-width ratios (Metcalf and Eddy, Inc., 1979).

3) Primary outlet- The primary outlet is often constructed of a riser/barrel assembly and provides flood protection (i.e., for the 10-yr storm) or reduces the frequency of the operation of the emergency spillway.

4) Emergency spillway- The emergency spillway is a vegetated or nonvegetated spillway designed to discharge flow in excess of the principal spillway design discharge (i.e., safely pass the 100-yr storm).

5) Impervious surface- Surfaces providing negligible infiltration such as pavement, buildings, recreation facilities, etc.

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