Maryland's Urban Stormwater Best Management Practices by Era Proposal

October 30, 2009

Introduction

The Maryland Department of Environment (MDE) is proposing to change how it reports on the implementation of stormwater management to the Chesapeake Bay Program (CBP). This effort has been initiated because urban best management practice (BMP) information throughout Maryland is limited due to inadequate reporting, which underestimates the total number of BMPs that have been implemented. Using Chesapeake Bay Program (CBP) developed acres since 1985, there should be approximately 457,429 acres of urban land controlled by stormwater management in Maryland, but as of 2009, the reporting has only shown approximately 200,000 acres. To better reflect actual implementation, MDE proposes a change in the reporting to the CBP from individual urban BMPs to four BMP categories defined by Maryland's predominate stormwater management eras. MDE has already begun to use the stormwater management by era analysis for showing progress toward Tributary Strategy and BayStat Milestones and believes that it will also be appropriate for the CBP model and Total Maximum Daily Load (TMDL) analysis. The major stormwater management eras for this analysis are described below and depicted in Figure 1.

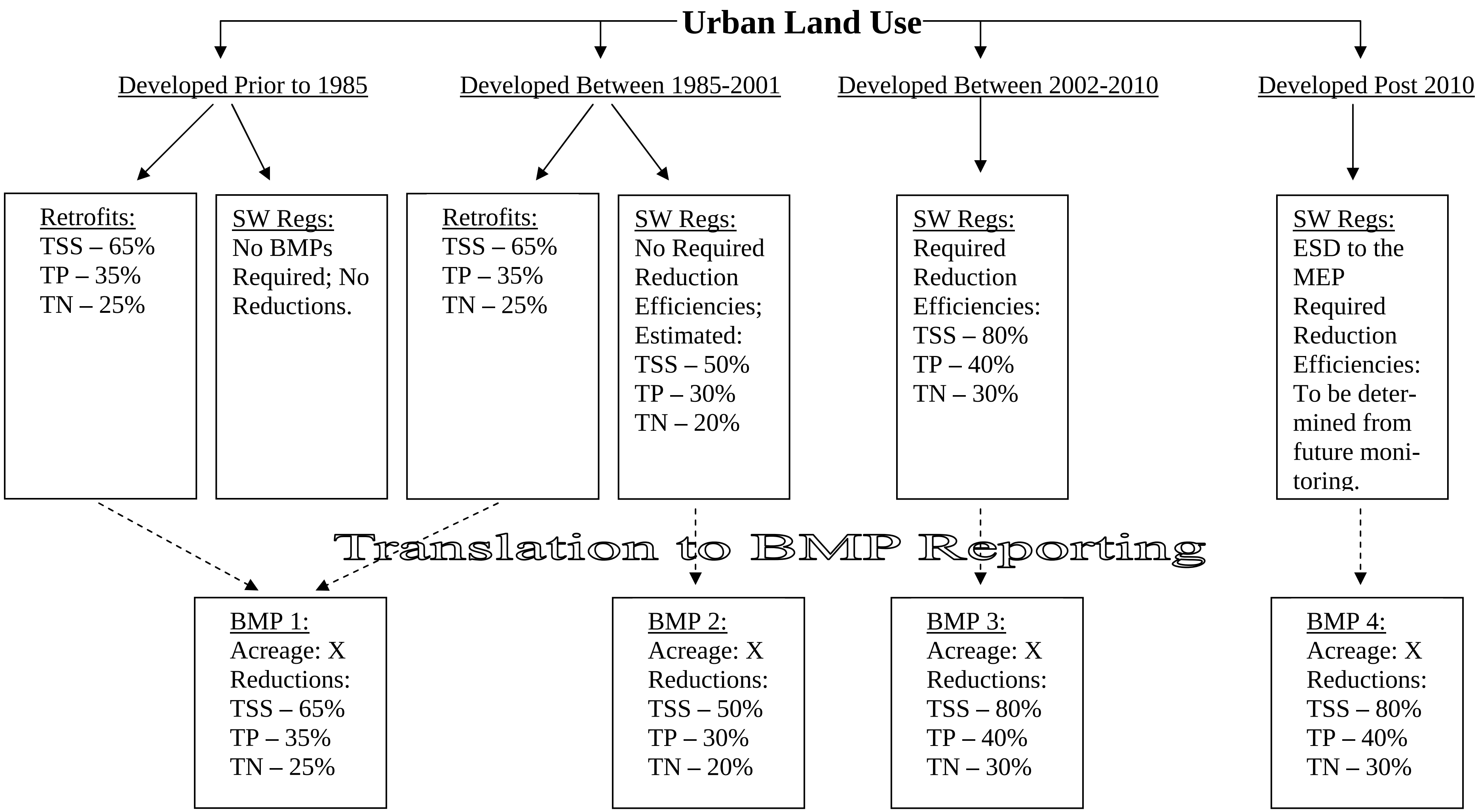
Major Stormwater Management Eras

Prior to any stormwater management in the State, urban runoff was directed into nearby waterways with little thought of either volume control or water quality treatment. In 1982, the Maryland General Assembly passed the State's first Stormwater Management law. While this law focused primarily on flood control, a preferred order of BMP implementation was established for treating water quality. Local ordinances and programs necessary to address the requirements of the new stormwater management law were completed by 1985. Because stormwater management programs did not occur statewide until this time, MDE proposes that urban land developed before 1985 be recorded with no pollutant load reductions.

Local programs, criteria, and associated BMPs to address the 1982 Stormwater Management law were implemented in Maryland from 1985 through 2001. Pollutant removal efficiencies for the BMPs implemented during this era are based upon CBP guidance.[1] Additionally, an analysis of MDE's Urban Best Management Practice database and a survey of Maryland Counties were used to determine the proportional coverage of each BMP type.[2] Based upon these data and analysis, MDE proposes that CBP urban land data between 1985 and 2001 be recorded with pollutant removal efficiencies of 50% for total suspended solids, 30% for total phosphorus, and 20% for total nitrogen.

Figure 1.

Stormwater Management by Era

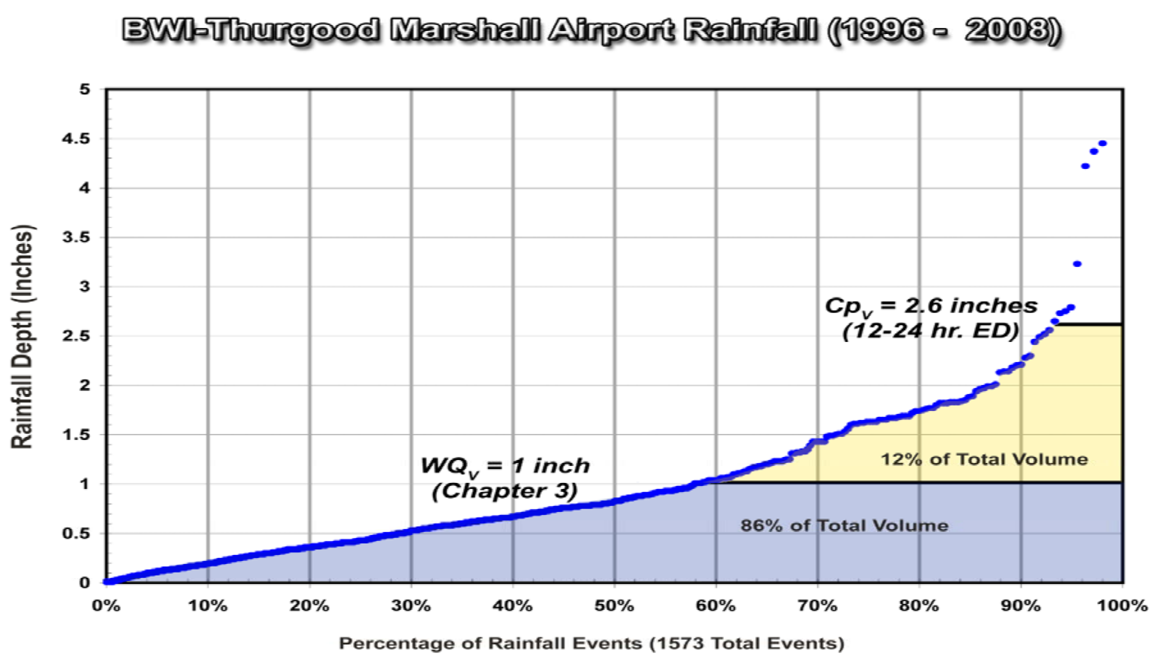


Significant changes to Maryland's Stormwater Management law occurred in 2000 with a focus on improving BMP water quality performance. The *2000 Maryland Stormwater Design Manual*, incorporated into the Code of Maryland Regulations as part of the 2000 update, stipulated volumetric criteria for groundwater recharge, water quality treatment, and channel protection. These criteria were based upon a *Technical Support Document for the State of Maryland Stormwater Design Manual Project*,[3] where all BMPs were required to meet an 80% reduction efficiency for total suspended solids, and a 40% reduction efficiency for total phosphorus.

Also, based on the typical BMPs implemented during this era and CBP guidance on pollutant removal efficiencies for these BMPs, a 30% reduction for total nitrogen is estimated. Counties and municipalities were implementing Maryland's *2000 Maryland Stormwater Design Manual* by 2002. MDE proposes that CBP land use data between 2002 and the present be recorded with pollutant removal efficiencies of 80% for total suspended solids, 40% for total phosphorus, and 30% for total nitrogen. An example of how the CBP's urban land use data and BMP efficiencies by Maryland's predominant stormwater management eras can be used to estimate pollutant loads and reductions is included in Appendix A.

Further changes to Maryland's Stormwater Management Law occurred in 2007 and promoted the use of environmental site design (ESD) to the maximum extent practicable (MEP). With a focus on stormwater planning during the conceptual stage of development and a reliance upon the use of vegetative non-structural practices, stormwater controls for new development will be designed to replicate forest runoff. Because ordinances are currently being updated and local program implementation has yet to begin, no changes to pollutant removal efficiencies are being proposed at this time.

Figure 2. Stormwater Volume Required by Maryland's 2007 Stormwater Management Act



Future monitoring of ESD to the MEP will be used to propose pollutant removal efficiencies to the CBP for BMPs implemented beyond 2010. It is anticipated that because 98% of the annual stormwater runoff volume (see Figure 2 above) will be captured through ESD to the MEP, pollutant removal rates will be even greater than 2000 BMP rates.[4]

Watershed restoration of older urban areas with little or no stormwater management is a primary target of Maryland's National Pollutant Discharge Elimination System (NPDES) municipal stormwater permits, and Maryland's Small Creeks and Estuaries and Stormwater Pollution Cost Share Programs. Because stormwater retrofits are a combination of newer BMPs as required by Maryland's 2000 stormwater management act and other BMP types similar to those implemented between 1985 - 2001, MDE has decided to pick the mean of these two stormwater management eras for reduction efficiencies. Thus pollutant removal efficiencies of 65% for total suspended solids, 35% for total phosphorus, and 25% for total nitrogen have been estimated. The land areas restored are a combination of pre-1985 development, where no stormwater management was required, and land developed between 1985 and 2002 where traditional flood control BMPs are often enhanced with water quality features. MDE proposes initially to evenly divide the data on acres restored between these two eras. As NPDES stormwater permittees begin to report data in a GIS format, restoration data and coverage will be more accurately defined and appropriated accordingly.

Bibliography

[1] Weammert, Sarah E. 2007. *The Mid-Atlantic Water Program (MAWP) reviewed BMP efficiencies implemented and reported by the Chesapeake Bay watershed jurisdictions prior to 2003.* University of Maryland, College Park, MD.

[2] A Survey by Baish, Alexander S. and Caliri, Marisa J., 2009. *Overall Average Stormwater Effluent Removal Efficiencies for TN, TP, and TSS in Maryland from 1984-2002.* Johns Hopkins University, School of Engineering, Baltimore, MD.

[3] Claytor, Rich, and Schueler, T.R., 1997. *Technical Support Document for the State of Maryland Stormwater Design Manual Project.* Water Management Administration, Maryland Department of the Environment, Baltimore, MD.

[4] 2000 Maryland Stormwater Design Manual, Supplement 1, 2008. Maryland Department of the Environment, Baltimore, Baltimore, MD.

Appendix A
Example of Applying Pollutant Removal Efficiencies by Stormwater Management Era

Maryland Stormwater Management by Program Era

Chesapeake Bay Program Urban Data			Total Nitrogen			Total Phosphorus			Total Suspended Solids		
Stormwater Program Era	Total Acres	Impervious Acres	Baseline Load (lbs/yr)	SWM Reduction	Reduced Load (lbs/yr)	Baseline Load (lbs/yr)	SWM Reduction	Reduced Load (lbs/yr)	Baseline Load (Tons/yr)	SWM Reduction	Reduced Load (Tons/yr)
Pre - 1985	1,009,014	188,340	3,758,087	0%	0	507,342	0%	0	75,162	0%	0
1985 - 2001	320,683	46,164	983,819	20%	196,764	132,816	30%	39,845	19,676	50%	9,838
2002 - 2009	91,410	28,576	517,504	30%	155,251	69,863	40%	27,945	10,350	80%	8,280
Restoration	65,784	13,292	260,591	25%	65,148	35,180	35%	12,313	5,212	65%	3,388
Total Loads:	1,486,891	276,372	5,520,001		417,163	745,200		80,103	110,400		21,506

Calculations:

1) Baseline load estimated using 0.226*((0.05+0.9*(30/100))*0.9*42)*emc*acres and assumes zero reduction
2) Load reduction attributed to SWM estimated using 0.226*((0.05+0.9*(30/100))*0.9*42)*emc*acres*reduction
3) Runoff EMC used for load estimates (TN = 2 mg/l, TP = 0.27 mg/l, TSS = 80 mg/l)
4) Restoration acres are evenly distributed between Pre-1985 and 1985-2001 land use data. For example, Total Acres 1985-2001 = (353,575-(65,784/2))

Reference Notes:

1) Total Urban Acres is derived from CBP 5.1 and 5.2
2) Pollutant Concentrations obtained from the CBP 5.2 and, Claytor, Rich, and Schueler, T.R., 1997. "Technical Support Document for the State of Maryland Stormwater Design Manual Project." Water Management Administration, Maryland Department of the Environment, Baltimore, MD.
3) Pollutant load calculations and reductions based upon the Simple Method, Schueler, T.R., 1987. "Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs." Metropolitan Washington Council of Governments, Wash., DC.
4) Pollutant Load Reductions for 2002 to Present from Claytor, Rich, and Schueler, T.R., 1997. Technical Support Document for the State of Maryland Stormwater Design Manual Project. Water Management Administration, Maryland Department of the Environment, Baltimore, MD.
5) Pollutant Load Reductions for 1985-2002 from Baldwin, Andrew H., Ph. D., and Weammert, Sarah E., and Simpson, Tom W., Ph. D., 2007. The Mid-Atlantic Water Program (MAWP) housed at the University Of Maryland (UMD) led a project during 2006-2007 to review and refine definition and effectiveness estimates for BMPs implemented and reported by the Chesapeake Bay watershed jurisdictions prior to 2003.
6) Pollutant Load Reductions also based upon Baish, Alexander S. and Caliri, Marisa J., 2009 "Overall Average Stormwater Effluent Removal Efficiencies for TN, TP, and TSS in Maryland from 1984-2002." Johns Hopkins University, Baltimore, MD.

Maryland Department of the Environment, 2009

Average
Nutrient and Sediment Effluent
Removal Efficiencies for
Stormwater Best Management Practices
Implemented in Maryland
1984-2002

Alexander S. Baish
and
Marisa J. Caliri, Students

Department of
Geology and Environmental Engineering
Johns Hopkins University
Baltimore, MD 21218

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I. Introduction

The Maryland Department of the Environment (MDE), Sediment, Stormwater, and Dam Safety Program (SSDS), in charting the progress of stormwater management found it necessary to determine valid pollutant reduction rates for common Chesapeake Bay pollutants for the three predominant stormwater management eras in Maryland. Before 1984, there was little reduction in stormwater pollutants because best management practices (BMPs) were not required statewide. Since 2002, Maryland's stormwater management program has required that the BMPs implemented reduce total phosphorus (TP) by 40% and total suspended sediments (TSS) by 80%. However, there is a major knowledge gap regarding the reduction rates for the stormwater management practices that were built between 1984 and 2002, or the middle era.

The Johns Hopkins University (JHU) team focused on this middle era to determine what stormwater BMPs were employed in Maryland and how they functioned. These BMPs were organized by category, rate of implementation, and degree of land coverage. A literature review of the BMPs used in Maryland during this era was conducted by the JHU team to determine pollutant reduction capabilities. Finally, the team used these data to estimate average pollutant reduction rates for TN, TP, and TSS that can be reasonably expected from the implementation of Maryland's stormwater management program between the years 1984-2002.

II. Literature Review of BMP Removal Efficiency

The JHU team performed an exhaustive literature review of BMP pollutant removal efficiencies used by local regulatory agencies and found in published studies. The recommended pollutant removal efficiencies put forth in this paper are often based upon the raw data presented within these studies rather than on the final determination made in the studies. Often, the final reduction rates in these studies reflected a great deal of policy rather than science. The work groups and regulatory bodies tended to use the raw data as a scientifically based starting point, but adapted the numbers either to promote the use of certain BMPs or to reflect other benefits separate from stormwater treatment, for example, the creation of ecologically important habitat. The JHU team was tasked with determining an average pollutant removal percentage for Maryland's middle era of stormwater management based on published data regardless of policy ramifications.

The number of studies reviewed, range of pollutant removal values, and widely different methods used, all contribute to a great deal of variability when examining BMPs and efficiency rates. A guiding principle for the JHU team came from the discussions of the Chesapeake Bay Program (CBP) as it considered adjusting its model to fit new BMP data, "It is very important that…modeling activities be conservative, rather than optimistic." When available data did not follow statistical patterns or converge upon an easily discernable value for average removal efficiency, the JHU team erred on the side of "realistic conservatism," operating under the assumption that when making decisions about widely ranging values, they should be within the realm of reason, but lean toward underestimating true BMP removal efficiencies rather than overestimating them.

One particular local study was used extensively by the JHU team. In support of the CBP, a professional review of available literature, studies, and expert assessments, was performed by the Mid-Atlantic Water Program (MAWP) and Dr. Andy Baldwin. A premise of the review was to get data from actual BMPs as opposed to laboratory or controlled tests of perfectly maintained BMPs. The results, while heavily qualified, formed the basis of the removal efficiencies used in the CBP's 5.0 Watershed Model. The robust nature of the review and statistical analysis used to determine these initial numbers for the CBP made it a good basis for the JHU team's research into BMPs implemented in Maryland between 1984-2002 and their efficiencies. The JHU review of pollutant removal efficiencies for stormwater BMPs is provided below.

Dry Detention Ponds

Removal Rates: TN 10%, TP 30%, TSS 50%

Dry detention ponds (DPs) was one of the most common BMPs implemented during the middle era of stormwater management in Maryland. These were also one of the most difficult BMPs to assess for average removal efficiencies for reasons the CBP discovered in 2006-2007. DPs were primarily designed to dampen the "first flush" of runoff from impervious acreage, slow channel erosion and decrease peak floods to streams. They were not designed specifically for nutrient and sediment removal. It is generally accepted that DPs have some of the lowest removal efficiencies among pond-like stormwater management structures. Few reliable studies have been performed on the removal efficiencies of DPs, and among these studies, removal rates, especially for TN, are widely variable.

In Dr. Baldwin's statistical assessments, average removal efficiencies for DPs were 10% for TN, 40% for TP, and 50% for TSS. The report found that there was considerable evidence of skewing for TSS toward low removal efficiencies, skewing of TP toward higher efficiencies, and so few data points for TN that, in terms of skewing estimates, "meaningful inference cannot be made." The report also made note of "considerable variability in removal efficiency, as reflected by high standard deviations" among the multiple studies examined.

A review of the statistical histograms of various studies shows a negative skewing of the TSS average primarily because of four studies where an increase in TSS occurred from the DPs discharge. These studies were most likely accurate reflections of DPs that had been improperly maintained (filling with organic matter that was being flushed out by each storm event, flooding rather than draining and causing large quantities of stormwater to bypass the BMP altogether, etc). For reasons of conservatism, the JHU team was inclined to accept the MAWP's recommendation of TSS removal efficiency of 50% for DPs.

The statistical histograms also show a positive skewing of the suggested TP removal average by three of the 15 studies. These three studies concluded TP removal efficiency for DPs was in the 80-90% range. The remaining 12 studies in the histograms display an almost bell-like curve of predicted efficiencies around 30-40%. For reasons of conservatism, the JHU team felt that the MAWP suggested average of 35% was close to adequate, but that a marginal drop to 30% would ensure that the removal efficiencies of TP for DPs would not be overestimated.

On the issue of TN removal, only six relevant studies were deemed accurate and rigorous enough to be considered by Dr. Baldwin and the MAWP. Although there was a high standard of deviation among these studies, and no clear pattern in the histograms, the average of the findings was simply accepted as a baseline for CBP use. Due to the robust nature of the literature review performed by the MAWP, the JHU team was unable to uncover additional DP studies done with a similar level of accuracy. Because biological activity and plant uptake in DPs would provide at least some level of nitrogen removal, the JHU team believes that a 10% removal rate as recommended by MAWP is a conservative reflection of this biological activity and appropriate for the purposes of this study.

<u>Extended Detention Structure/Dry</u>

Removal Rates: TN 20%, TP 20%, TSS 60%

The MAWP recommendations to the CBP were 20% for TN, 20% for TP, and 60% for TSS. These removal rates were based upon several recent multiple site studies that showed consistent results. The data indicate that a 60% removal efficiency for TSS is reasonable. Also, evidence from the most recent studies shows that a TN removal rate in the 15-30% range is possible, however, much closer to the 15% than 30%. These efficiencies make sense in terms of comparison to DPs, as the longer stormwater is detained, the higher TSS and TN removal rates should be.

The average TP removal rate for the three multiple site studies was exactly 20%. The single site studies documented a significantly higher efficiency for TP; however, the 20% seems a more reasonable assessment. Although more TP may precipitate out in extended detention as compared to DPs, the anaerobic conditions in the bottom of EDs created by an extended 24 hour effluent discharge time results in phosphate release from the soil. This should result in a lower TP removal rate for EDs than for DPs.

Wet Ponds/Wetlands

Removal Rates: TN 20%, TP 45%, TSS 60%

The MAWP recommendations to the CBP were 20% for TN, 45% for TP, and 60% for TSS. There were many more single site studies available for WPs than multiple site studies. While the removal rates for the single site studies tended to be lower, the data were still well within the range of efficiencies found in the multiple site studies. Also, the median and means for both groups of studies were close and the statistical histograms showed a low degree of skewing. The JHU team was satisfied by the analysis of the MAWP and its removal efficiencies for WPs. The analysis of studies seemed statistically sound and the efficiencies themselves reasonable, i.e., as good as or better than ED removal efficiencies.

Oil/Grit Separators

Removal Rates: TN 0%, TP 0%, TSS 0%

Studies by MDE and the Metropolitan Washington Council of Governments showed that oil/grit separators (OGSs) have extremely small storage volumes compared to the impervious surface areas they drain, very short detention times, and a high tendency to leave much sediment in suspension. Total sediment volumes in OGSs remained the same or decreased overtime, indicating high rates of resuspension and flushing of TSS in effluent. A comprehensive Federal Highway Administration report on BMPs supported OGSs inability to eliminate TSS but also TN and TP from stormwater. Due to their short detention times, even particulate forms of nitrogen and phosphorous are not removed. The JHU team decided that based on these reviews, OGSs were assigned removal rates of 0% for TN, TP, and TSS.

Underground Storage Vault

Removal Rates: TN 0%, TP 0%, TSS 0%

Underground storage structures (UGS) are designed primarily for flood control in much the same manner as a DP. When it comes to pollutants, UGSs are much less efficient because they are constructed of cement instead of earth, soil, and vegetation. Removal rates indicated in the literature for these structures are minimal for TN, 20% for TP, and 60% for TSS. These removal rates however are based upon a Northern Virginia Study that required weekly cleaning and maintenance of its test facility to maintain these efficiencies. To be conservative, the JHU team relied upon previously mentioned research regarding similar structures such as OGSs where maintenance is infrequent at best. In these situations, UGSs can loose efficiency and even become sediment sources. For this reason, the JHU team decided to view these structures conservatively and apply zero reduction rates for TN, TP, and TSS.

<u>Infiltration Trench/Basin and Dry Well with/without Exfiltration</u>

Removal Rates: TN 60%, TP 60%, TSS 90%

The United States Environmental Protection Agency (EPA) carried out a literature review in 1999 similar to the MAWP. This literature review cited several studies from Maryland. Both EPA's report and the California Stormwater BMP Handbook (2003), stated that because there is no effluent flow from infiltration trenches and basins, all stormwater infiltrates into the surrounding soil and a 100% reduction in the load discharged to surface waters. However, numerous studies also state that effluent from such trenches and basins, if not allowed to infiltrate would be less efficient and estimate reduction rates of 60% for TN, 60% for TP, and 90% for TSS.

Among MDE's Urban BMP database, some infiltration trenches (IT, ITCE), all infiltration basins (IB), and all dry wells (DW) have no effluent because all inflow is designed to infiltrate into the surrounding soil. The JHU team came across several studies in Maryland that showed large failure rates for infiltration BMPs within two years of implementation. The most common reasons for failure are due to clogging, poor maintenance, or the siting of these BMPs in areas of poor soil permeability. For these reason, the JHU team believes that few of these BMPs will be capable of 100% infiltration and a more conservative decision is to use the removal efficiencies of 60% for TN, 60% for TP, and 90% for TSS.

Several infiltration BMPs are not designed for infiltrating the entire amount of runoff and are know as Water Quality Exfiltration Trenches (ITWQE), which process only the first flush of water from impervious surfaces during a storm event, and a Partial Exfiltration Trench (ITPE), which has an under drain in the trench so not all runoff infiltrates into the surrounding soil. Based upon EPA's literature review of BMPs with these characteristics, the JHU team assigned effluent removal efficiency rates of 60% for TN, 60% for TP, and 90% for TSS.

<u>Bioretention</u>

Removal Rates: TN 35%, TP 80%, TSS 90%

Although there was a great deal of literature describing Bioretention (BIO, BR) as a BMP, there were comparatively very few studies completed on its removal efficiencies. Most of the studies were completed by Dr. Davis at the University of Maryland or in a few locations in Prince George’s County, where the practice was developed. However, most of these studies were either performed in a laboratory or in well maintained sample BMPs.

Most studies showed that BIOs are remarkably efficient at TSS removal, ranging from 86-99% removal with more studies toward the upper end of that range. As noted above, because few of these studies tended to be from actual field conditions, the JHU team felt it could not assign the BIO a higher than 90% TSS removal efficiency.

Davis and other studies tended to distribute TP removal findings evenly about 71-90%. The JHU team felt comfortable assigning a realistic and conservative removal efficiency of 80% to TP. The TN removal efficiency ranged more widely and some BIOs actually produce TN by promoting nitrification between precipitation events. Other structures effectively infiltrated or promoted the organism uptake of TN, causing this wide range of removal efficiencies. The JHU team recognized a general range of 25-45% TN removal efficiency for most studies, and settled on the middle of this range.

Porous Pavement

Removal Rates: TN 80%, TP 65%, TSS 90%

Although there are limited studies on Porous Pavement (PP) due to its relative status as a new technology, several of the long-term studies were performed in Maryland and Virginia. An EPA document from 1999 estimated removal efficiencies of 82-95% TSS, 65% TP, and 80-85% TN based on these studies which were located in Rockville, MD and Prince William, VA. An article in Government Engineering in 2005 cited this EPA document, and highlighted the consistency of its results compared to three other studies. Averages of these studies came to 91% TSS removal, 66% TP removal, and 72% TN removal. The JHU team, choosing to weight the local, long-term studies slightly heavier than the studies of unknown location, generally agrees with the EPA removal efficiencies.

Sand Filter

Removal Rates: TN 0%, TP 55%, TSS 80%

Sand filters (SF) implemented in Maryland between 1984-2002 were likely modeled after the Delaware/DC or the Austin models. Both are constructed below grade and tend to be smaller scale structure than an open at-grade structure. Based on a Federal Highway Administration Database of BMPs as well as the California Stormwater BMP Handbook, SFs, depending on the media used within them, could have an average TSS removal efficiency of 80%. This rate is more heavily weighted toward the lower FHWA database numbers, for conservatism. A TP removal efficiency rate of 55% was chosen which is well within the range of all literature.

There is discrepancy for the TN removal efficiencies. The California Handbook and the FHWA database, which includes data from the Delaware/DC SF, indicated highly variable results for TN removal. The Austin SF has been show to actually be a source of TN due to nitrification in the sand beds between precipitation events. For these reasons, the JHU team has conservatively decided that sand filters have a negligible TN removal rate.

Filter Strip

Removal Rates: TN 10%, TP 30%, TSS 70%

Literature reviews show an almost unanimous agreement to the efficiency of Filter Strips (FS) as a BMP. The 2004 Stormwater BMP Design Guide, Barfield et al., provided graphical and chart descriptions of the most widely agreed upon removal efficiencies. The JHU team recognized that FSs efficiencies vary with length. However, upon reaching a length of 30 meters, a relatively short distance reached by many FSs, most removal efficiencies plateau.

Vegetated Buffers, Natural Area Conservation, and Landscaping Practices

Removal Rates:

Efficiency Recommendation	TN	TP	TSS
Riparian Forest Buffers			
Inner Coastal Plain	65	42	56
Outer Coastal Plain Well Drained	31	45	60
Outer Coastal Plain Poorly Drained	56	39	52
Tidal Influenced	19	45	60
Piedmont Scnist/Gneiss	46	36	48
Piedmont Sandstone	56	42	56
Valley and Ridge - Marble/Limestone	34	30	40
Valley and Ridge - Sandstone/Shale	46	39	52
Appalachian Plateau	54	42	56
Riparian Grass Buffers			
Inner Coastal Plain	46	42	56
Outer Coastal Plain Well Drained	21	45	60
Outer Coastal Plain Poorly Drained	39	39	52
Tidal Influenced	13	45	60
Piedmont Scnist/Gneiss	32	36	48
Piedmont Sandstone	39	42	56
Valley and Ridge - Marble/Limestone	24	30	40
Valley and Ridge - Sandstone/Shale	32	39	52
Appalachian Plateau	38	42	56
Forest harvesting	50	60	60

The JHU team looked to the MAWP's literature analysis of riparian forest buffer practices for direction in choosing BMP removal efficiencies for vegetated buffer (VB), natural area conservation (NAC) and landscaping practices (LANDSCAPE). There are many variables to consider when assigning removal efficiencies to these kinds of BMPs; hydro-geological conditions, slope, planted/buffer width, plant type and species (herbaceous vs. woody and native vs. non-native), among many others. The JHU team strongly states that although conservatism has been used in removal efficiencies, these practices were by far the most difficult to assign rates with confidence. It should be noted that these BMPs were used with extreme infrequency during the "middle era" of stormwater management in Maryland.

The MAWP tried to take hydro-geological conditions into consideration for riparian forest buffers by applying baseline percent removals for TN and TP in the most permeable of soils and subtracting value from these baseline rates as soils and groundwater conditions became progressively less conducive to infiltration of stormwater and uptake of nutrients. The JHU team examined Maryland hydro-geological maps to determine the dominant hydro-geological regime in each county.

It has always been a convention to have TP removal values be 75% of TSS removal values, so the TSS removal rates were calculated up from the nutrient rates. Also as a convention, it is assumed that grass buffers are 70% as efficient at reducing TN as riparian forest buffers. The MAWP calculated down these TN values for grass buffers, but kept TP and TSS values the same as for forest buffers.

NACs include a wide variety of vegetation types, but are “natural areas that help maintain predevelopment hydrology” in general. The JHU team recognized that these areas could be almost any habitat, from forest retention to non-tidal wetlands, but understood the concept behind this BMP was to preserve the natural riparian vegetation adjacent to streams and runs. Considering this, the JHU team assigned the riparian forest buffer removal rates to NACs. These riparian forest buffers are supposed to be designed to mimic removal rates of natural, native riparian vegetation and floodplain ecosystems. The JHU team felt that the conservative removal rates of these artificially planted BMPs would be a conservative estimate for the removal rates of the natural habitats they are meant to mimic.

Grass Swales

Removal Rates: TN 0%, TP 35%, TSS 65%

Grass Swales, abbreviated SW in the MDE list of BMPs, are simply gently sloping grass channels meant to slow water, promote sediment drop, and soak up nutrients. Federal Highway Administration, the Idaho Department of Environmental Quality (IDEQ), and StormwaterQuality.org all provided percent removal study syntheses for TSS, TP, and TN.

The TSS removal efficiency numbers had a small range of variation, inside a range of 65-68% removal. The JHU team agreed to use the lower bound of this range in its calculations. The TP removal efficiency numbers ranged from 29-43%, with one value for the IDEQ as low as 15%. Considering that the IDEQ gives maintenance officials two maintenance schedules for their grass swales, one to promote nutrient removal and one not to promote nutrient removal, the JHU team took Idaho’s estimate of 15% removal as a conservative estimate by the IDEQ, and agreed to focus on the studies in the 29-43% range. The TN removal efficiencies were of mixed results, but often grass swales proved to be nitrogen producers, as natural organic buildup of clippings and leaves tended to break down and promote nitrification between storm events.

III. Removal Efficiencies by Stormwater Management Era (1984 -2002)

MDE's Urban Stormwater BMP Database was developed initially as a pilot program for only a few counties within the Patuxent watershed. As a result, there are unequal amounts of data provided for each county. Additionally, although it was required, many of the counties were reluctant to provide MDE with information creating a number of gaps within the given data. Because this database is the only source of BMP prevalence in Maryland, it is presumed to be the most accurate data available. This database was queried for the years 1984-2002 and the frequency of use of each BMP was calculated by percentage.

In order to further verify the accuracy of the information provided in MDE's database, the JHU team issued a survey to all local stormwater contacts. The survey provided a list BMPs commonly implemented between and 1984-2002 and asked local administrators to report on the frequency based on local data. These values were then compared to the frequency of use value generated from MDE's database. For 21 of the 23 counties that responded, the results ranged from general concurrence with MDE's database to very precise. This proved satisfactory to the JHU team in establishing a pattern of general accuracy of MDE's database.

The JHU team next used a method of "relative abundance" to determine the coverage of BMPs by County. The technique worked by summing the acreage of land drained by a specific BMP within each county and then dividing it by the acreage of land drained by all stormwater BMPs for that county. A weighted BMP removal efficiency was then developed by multiplying the relative abundance of each BMP by the pollutant removal efficiencies determined in Part II. Literature Review of BMP Removal Efficiency. An example of these calculations is shown in Example 1 below for a Dry Pond (DP).

Example 1: Weighted BMP Removal Efficiencies

Structure	TN Removal Efficiencies	TP Removal Efficiencies	TSS Removal Efficiencies	Drain Area (by percent of total)
DP	10%	30%	50%	30.52%

TN Percent Removal = (0.10)*(0.3052) = 0.03052 = 3.052%
TP Percent Removal = (0.30)* (0.3052) = 0.09156 = 9.156%
TSS Percent Removal = (0.50)* (0.3052) = 0.1526 = 15.26%

These calculations were performed for each BMP and then summed with all other BMPs used in the County to determine a cumulative percent removal rate. The JHU team believes that these calculations effectively estimate an overall BMP removal rate for each county for Maryland's Stormwater Management Program between the years 1984-2002. Statewide removal efficiencies were calculated as well. Table 1 below shows removal rates for TN, TP, and TSS by county and by State.

Table 1. Weighted BMP Removal Rate by County and State

County	TN Percentage	TP Percentage	TSS Percentage
Anne Arundel County	33%	45%	64%
Baltimore City	18%	27%	55%
Baltimore County	16%	31%	54%
Calvert County	54%	59%	74%
Caroline County	37%	48%	68%
Carroll County	25%	42%	60%
Cecil County	16%	35%	55%
Charles County	46%	56%	67%
Dorchester County	27%	45%	58%
Frederick County	22%	36%	61%
Garrett County	32%	45%	61%
Hartford County	15%	31%	53%
Howard County	20%	20%	60%
Kent County	18%	29%	60%
Montgomery County	18%	39%	61%
Prince George's County	22%	42%	61%
Queen Anne County	25%	47%	61%
Somerset County	22%	45%	60%
St. Mary's County	23%	31%	60%
Talbot County	20%	38%	61%
Washington County	14%	33%	52%
Wicomico County	26%	48%	63%
Worcester County	15%	36%	53%
Maryland	**25%**	**40%**	**60%**

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Storm Water Best Management Practice Categories and Pollutant Removal Efficiencies

Background:
The Urban Storm Water Workgroup developed a list of BMP categories with associated pollutant removal efficiencies and hydrologic effects. The workgroup developed this information so that the Chesapeake Bay Program can better model the urban pollutant load reductions of TN, TP, and TSS from storm water BMPs in the watershed.

Phase 4.3 of the Chesapeake Bay watershed model does not account for differences in pollutant removal efficiencies among different categories of urban storm water BMPs. Currently, all BMPs are lumped into one category called “storm water management” and are given one efficiency for TN, TP, and TSS. For example, a wet pond will have the same pollutant removal efficiency as a dry pond, an infiltration trench, and an oil/grit separator. Additionally, Phase 4.3 does not account for reductions in pollutant loads that may result from hydrologic effects of the urban storm water BMPs. In reality, many urban storm water BMPs reduce peak runoff flows and volumes and increase time of concentration. When peak runoff flows are reduced, stream flow velocities are reduced, which may result in reduced stream bank erosion. Currently, the model does not account for reductions in sediment loads from reduced stream bank erosion that may result from urban storm water BMP implementation.

It is important to note that these pollutant removal efficiencies apply to reductions of loads to surface waters only. Also, these efficiencies are meant for modeling purposes and not for the design and construction of BMPs.

Approach:
The Urban Storm Water Workgroup compiled data on the pollutant removal efficiencies of commonly employed urban storm water management BMPs. Based on the BMP pollutant removal efficiencies and general hydrologic effects these BMPs were grouped into categories. Each category contains a number of BMP types that have similar pollutant removal efficiencies and hydrologic effects.

<u>Confidence Limits</u>
It’s important to note the studies on BMP pollutant removal efficiencies are variable and oftentimes scarce. Additionally, many factors affect performance of BMPs such as the design, frequency of inspection and maintenance, seasonality, and the life span and age of the BMP. Given these uncertainties, the Workgroup rounded its estimates to the nearest 5%.

<u>Maintenance</u>
The Workgroup did not fully account for changes in pollutant removal efficiencies based on the level of BMP maintenance and the life span of the BMPs. Due to lack of data on storm water maintenance programs in the watershed, the group was unable to use a “multiplier” to account for reductions in efficiencies due to insufficient maintenance. However, the workgroup did not neglect maintenance altogether. Many of the studies evaluated for this effort were focused on BMPs that were not regularly maintained. Therefore, the efficiencies, in part, may reflect some lower reduction of pollutant loads due to insufficient maintenance. However, the BMPs are fairly “young” and, therefore, probably do not fully account for reductions in pollutant removal

efficiencies due to aging BMPs.

Low Impact Development/Environmental Site Design
The Workgroup decided not to include Low Impact Development (LID) or Environmental Site Design as a BMP Category because no jurisdiction is reporting the number of acres under LID. Jurisdictions are reporting number of acres under certain BMP practices that can be considered a component of LID, such as bioretention or rooftop disconnection. These practices are already accounted for in the BMP categories. In the future, if more and more jurisdictions use LID and start to report the number of acres under LID, then a separate category.

Treatment Trains
Treatment trains are a number of BMPs that are connected in series to treat the same volume of runoff. The Workgroup has concluded that there is not enough hard data to account for pollutant removal efficiencies for "treatment trains". Funding opportunities to obtain literature and field data are currently being pursued.

The following table summarizes the BMP categories and the pollutant removal efficiencies. See the Support Document for a complete list of BMP types, BMP definitions, pollutant removal efficiencies, and references that were used in this analysis.

Category	% Pollutant Removal Efficiency			Comments
	TN	TP	TSS	
Category A: Wet Ponds and Wetlands	30	50	80	This category includes practices such as wet ponds, wet extended detention ponds, retention ponds, pond/wetland systems, shallow wetlands, and constructed wetlands.
Category B: Dry Detention Ponds and Hydrodynamic Structures	5	10	10	Hydrodynamic structures are not considered a stand alone BMP. It acts similar to a dry detention pond and therefore it is included in this group.
Category C: Dry Extended Detention Ponds	30	20	60	This category includes practices such as dry extended detention ponds and extended detention basins.
Category D: Infiltration Practices	50*	70*	90*	This category includes practices such as infiltration trenches, infiltration basins, and porous pavement that reduce or eliminate the runoff. *These efficiencies are based on limited studies.
Category E: Filtering Practices	40	60	85	This category includes swales (dry, wet, infiltration, and water quality), open channel practices, and bioretention that transmit runoff through a filter medium. Grass swales were excluded because they have minimal water quality benefits.

Category	% Pollutant Removal Efficiency			Comments
	TN	TP	TSS	
Category F: Roadway Systems	TBD	TBD	TBD	We acknowledge that roadways make up a large portion of the urban acreage in the watershed and that there are practices that are on the ground today that result in some water quality benefit. Due to lack of data, the workgroup has not assigned pollutant removal efficiencies to this category. Your data will help the workgroup to develop an approach for crediting these BMPs
Category G: Impervious Surface Reduction	Model Generated	Model Generated	Model Generated	This category includes a number of practices that essentially turn impervious surfaces into pervious surfaces. Examples of these practices are green roofs, disconnected roofs, rain barrels, removal of impervious surfaces. Pollutant load reductions will be modeled based on the conversion of impervious surfaces to pervious urban surfaces.
Category H: Street Sweeping and Catch Basin Inserts	TBD	TBD	TBD	This category includes municipal efforts such as street sweeping, catch basins cleaning that prevent pollutant loads from entering the Bay. Pollutant load reduction efficiencies will be determined based on the number of pounds of TN, TP, and/or TSS removed through these practices.

Category	% Pollutant Removal Efficiency			Comments
	TN	TP	TSS	
Category I: Stream Restoration	0.02 lb/linear ft	0.0035 lb/linear ft	2.55 lb/linear ft	These numbers are based on a study conducted on Spring Branch Stream, an urban watershed in Baltimore County. The Urban Storm Water Workgroup will work with other stream restoration experts to refine these efficiencies, as data become available and to develop criteria for what constitutes water quality-based stream restoration. Please provide details on the types of stream restorations activities you undertook.

THIRD REVIEW DRAFT

Technical Support Document for the State of Maryland Stormwater Design Manual Project

Prepared for:

Water Management Administration
Maryland Department of the Environment
2500 Broening Highway
Baltimore, MD 21224

Prepared by:

Tom Schueler and Rich Claytor
Center for Watershed Protection
Suite L-105
8737 Colesville Road
Silver Spring, MD 20910

February, 1997

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Technical Support Document

Preface

Preface

This Technical Support Document was prepared for the Water Management Administration under a cooperative agreement between that agency and the Maryland Department of Natural Resources pursuant to National Oceanic and Atmospheric Administration Grant No. NA67OZ0302.

This document provides technical support and documentation to resolve numerous technical and policy issues that may ultimately be incorporated into the Statewide Stormwater Manual. This draft is a working document, and has not yet received full review and approval by State and Local agencies. The proposed organization, methods, sizing criteria, performance standards and other technical guidance contained herein were developed by the Center, are subject to change, and do not necessarily reflect current or future State policy.

The Center has been contracted to produce a draft statewide stormwater design manual by mid-1997, after review and input by MDE, DNR and the Stormwater Regulations Committee.

The authors gratefully acknowledge the work of two subcontractors, Environmental Quality Resources, Inc. and Loiederman Associates, Inc. that contributed to this document, and extend personal thanks to Tim Schueler (EQR), Karen Carpenter and Josie Greenberg (LA) for their help.

Section 1.0 Draft Outline for Maryland Stormwater Design Manual

A detailed outline of the proposed Design Manual is provided on the following pages. The proposed organization is intended to keep the manual to a manageable size; construction specifications, design examples, designs tools and a landscaping guide will be appended (possibly in a separate volume).

Draft Outline
for
State of Maryland
Stormwater Design Manual

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List of Tables

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- Lakes and Reservoirs
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- Chesapeake Bay

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C. How to Use The Manual

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A Recharge Volume
B Pollutant Removal Volume
C Channel Protection Volume
D Overbank Flooding Volume
E Extreme Flood Volume
F Stormwater Hotspot Designation
G General Performance Criteria for BMPs
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Terrain Factors
Stormwater Treatment Suitability
Physical Feasibility
Community and Environmental Benefits
Locational/Permitting Considerations

Chapter 5: Minimum Design Criteria for BMP Groups

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D Filtering Systems
E Open Channel Systems

Chapter 6: Stormwater Credits

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B Disconnection of Rooftop Runoff
C Disconnection of Surface Impervious Cover
D Use of Stream Buffer
E Use of Open Channels
F Environmentally sensitive rural development
G Impervious Cover Reduction

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A-2 Infiltration trenches
A-3 Infiltration basins
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Part B. Step by Step Design Examples *

B-1 Pond Design
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B-4 Sand Filter
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B-6 Open Channel

* contingent upon timely approval of Chapter 2 criteria

Part C: Assorted Design Tools

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C-2 Geotechnical Methods for Karst Feasibility Testing
C-3 Filter Fabric Specifications
C-4 Curve Number Adjustments for Karst Regions
C-5 Curve Number Adjustments for Small Storm Hydrology
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C-7 Critical Area 10% Criteria
C-7 Industrial Categories for NPDES Stormwater Permit
C-8 General Requirements for Stormwater Pollution Prevention Plan

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D-2 Herbaceous Material and Ground Covers
D-3 Emergent Wetland Plants

Section 2.0 Unified Sizing Criteria for Stormwater BMP Systems

Section 2.1 Introduction

This section presents a unified approach for sizing stormwater BMP systems in the State of Maryland to meet recharge, pollutant removal, channel protection and flood control objectives at new development and redevelopment sites. The section is organized as follows:

2.1 Introduction
2.2 Recharge Requirement (Re_v)
2.3 Pollutant Removal Requirement (WQ_v)
2.4 Channel Protection Criteria (Cp_v)
2.5 Overbank Flood Protection (Q_{p2} and Q_{p10})
2.6 Extreme Flood Control (Q_{p100})
2.7 Stormwater Hotspot Designation
2.8 Comparison of Storage Volumes Required to Meet the Sizing Criteria
2.9 General Performance Standards for Stormwater Management

The purpose of this section is to provide a unified framework for sizing stormwater BMPs to maintain recharge, remove pollutants in stormwater, prevent channel erosion, reduce overbank flooding, and pass extreme floods. It utilizes the concept of the rainfall frequency spectrum, and includes rainfall analyses for seven Maryland stations that are representative of the entire state. Each of the succeeding sections outlines the options for sizing BMPs, along with a technical review of the advantages and disadvantages of each option. In addition, each section makes additional recommendations on the technical procedures and methods needed to apply individual sizing criteria. Guidance is also provided on stormwater hotspot designation, and the storage implications for the new sizing criteria. The section concludes with eight performance criteria that apply to all new development in Maryland.

It is anticipated that the manual will have a brief summary of the four recommended sizing criteria, along with a real world example using all of the four criteria on a typical development site. Table 2.1 summarizes our recommendations for unified sizing criteria for stormwater.

Section 2.2 **Recharge Requirement (Re_v)**

The intent of this sizing criteria is to maintain groundwater recharge rates at development sites so as to preserve existing water table elevations thereby providing baseflow to streams and wetlands. The amount of recharge that occurs on a site is a function of slope, soil type, vegetative cover, precipitation and evapo-transpiration. Sites with natural ground cover, such as forest and meadow, have higher recharge rates, less runoff and greater transpiration losses, under most conditions. Since development increases impervious surfaces, a net decrease in recharge rates is inevitable.

Table 2.1 *Summary of the Five Recommended Sizing Criteria for Stormwater in the State of Maryland*

Sizing Criteria	Recommended Statewide Sizing Criteria
Recharge	Re_v = fraction of WQv, depending on predevelopment soil hydrologic soil group
Water Quality Volume	WQ_v = 1.0 (Rv) (A) East of Frederick WQv = 0.9 (Rv) (A) West of Frederick
Channel Protection Criteria	Cp_v = 12 to 24 hours extended detention of one year, 24 hour storm event No requirement for Eastern Shore of Maryland
Overbank Flood Protection	If Cp_v provided, then control peak discharge rate from ten year storm event to predevelopment rate (Q_{p10}). No control of the two year storm event required (Q_{p2}) For Eastern Shore, provide peak discharge control for the 2 year storm events (Q_{p2}).
Extreme Storm	No control is needed if development is excluded from 100 year floodplain and downstream conveyance is adequate.

2.2.1 Options for Recharge Requirements

Currently, there are no State sizing criteria for stormwater recharge, although the infiltration preference of the State regulations clearly attempts to promote recharge through the selection of infiltration BMPs.

The Center has developed a sizing option to promote recharge. The approach is based on determining the average annual recharge rate based on the prevailing hydrologic soil group present at the site using USDA, NRCS Soil Surveys. Based on this information, the following predevelopment recharge volumes can be assigned to soil types.

NRCS Estimates of Predevelopment Annual Recharge Rate by Soil Type

Hydrologic Soil Group	Annual Recharge Volume
A	18 inches/year
B	12 inches/year
C	6 inches/year
D	3 inches/year

The next step is to determine the annual recharge volume produced by an infiltration facility sized to capture one half-inch of runoff. A conservative estimate, based on data from Horsley (1996), is that an infiltration facility creates about 24 inches of recharge each year (or about 33% more than the highest annual recharge rate for the most permeable hydrologic soil group).

Thus, the design objective is to mimic the average annual recharge rate for the prevailing hydrologic soil group(s) present at the development site. Thus, an annual recharge volume target is specified as follows:

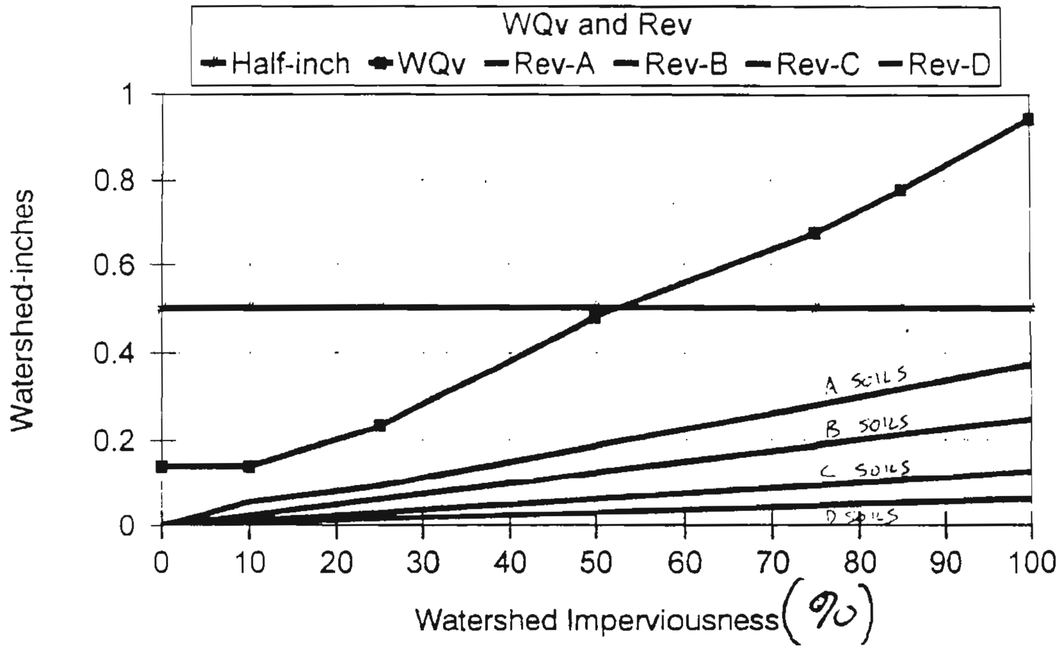
Hydrologic Soil Group	Recharge Volume Requirement
A	(0.40 inches)(I_s)
B	(0.25 inches)(I_s)
C	(0.10 inches)(I_s)
D	(0.05 inches)(I_s)

where (I_s) is the total impervious area at the site

The recharge volume requirement was derived by comparing the annual recharge rate provided by an infiltration facility (sized for a half-inch of runoff storage and assuming an average year of 40 inches of rainfall) with the annual recharge rate for a vegetated site for each soil type (Horsley, 1996). Two key points emerge from this comparison. First, the recharge rate from a standard infiltration facility exceeds the rate from a vegetated, pervious site (primarily because evapotranspiration losses from natural sites sharply reduce recharge rates during the entire growing season). Thus, a standard infiltration practice recharges groundwater at a higher net rate than undisturbed areas. Second, the annual recharge rate declines sharply as soils shift from A to D hydrologic soil groups. The practical implication is that a very modest volume of infiltration is needed to maintain recharge rates for B, C, and D soils, even if the site is highly impervious.

The recharge volume is considered a part of the total water quality volume (WQ_v) that must be provided at a site. The relationship between the Re_v and WQ_v is shown in graphical form in Figure 2.1.

Figure 2.1 Relationship Between Re_v and WQ_v as a Function of Site Impervious Cover



The benefits of the recharge volume requirement are that it:

- promotes greater effort to infiltrate runoff, but does not mandate a specific structural practice that has been problematic (e.g., infiltration).
- provides strong incentives for designers to utilize site designs and non-structural practices that utilize overland flow over vegetated surfaces (filter strips, grass channels, drywells, disconnection of rooftop runoff etc).
- since the Re_v is based on impervious cover, it provides a strong incentive to minimize the area of impervious cover produced by new development.

- acknowledges that recharge ability is strongly influenced by soil type, and still promotes some infiltration on soils that are not considered feasible for structural infiltration practices.

- encourages designers to allocate a greater fraction of WQ_v to pretreatment measures or combining infiltration with other structural practices (since Re_v is inclusive of WQ_v). This should help increase the longevity of the infiltration practices that are installed.

The Center recommends that recharge be provided to mimic the average annual recharge rate based on the prevailing hydrologic soil group present at the site using USDA, NRCS Soil Surveys, and the methodology outlined above. The recharge volume is inclusive of the WQv, and can be achieved by either infiltration, overland flow, disconnection of rooftop runoff, partial exfiltration through the soils of filtering systems, bioretention, filter strips, and other non-structural measures.

Section 2.3 Water Quality Volume (WQ_v)

2.3.1 Basic Options to Size BMPs for Pollutant Removal (WQ_v)

The two basic sizing options for defining the volume of runoff needed for stormwater quality treatment (denoted as the WQ_v) are:

half-inch rule: the half inch rule simply requires that one-half inch of runoff be treated from the total area of the site. It's origins are somewhat murky, but reflect modeling and monitoring data collected in the late 1970's that seemed to indicate that the first flush phenomena was very strong, and therefore, although some storms might not be captured, up to 90% of the annual stormwater pollutant load would be conveyed along with the first flush of runoff. A slight variant is the **half-inch impervious area rule.** This modification of the half-inch rule defines the WQ_v as one-half inch times the impervious drainage area. First proposed by Hartigan (1982), it generally results in an inadequate WQ_v for most sites.

90% capture rule. The 90% capture rule was first proposed by Schueler (1992) and is based on a regional analysis of the rainfall frequency spectrum. For this region of the country, it is equivalent to one inch multiplied by the runoff coefficient (Rv) and site area. Rv is defined as:

$Rv = 0.05 + 0.009(I)$, where I is percent impervious cover.

The 90% rule is essentially identical to Driscoll's (1983) VB/VR sizing approach, and subsequently modified by Harrington for Md WRA (1986). The technical basis for the 90%

capture rule is that the BMP is explicitly designed to capture 90% of the annual runoff volume generated by the site, making it available for treatment. As such, this sizing rule is not dependent on first flush assumptions, and results in an increasing WQ_v with greater site impervious cover.

2.3.2 Rainfall Analysis for Maryland

A rainfall frequency spectrum was compiled for seven weather stations in Maryland using ten years of daily rainfall record. Rainfall events less than 0.1 inch were deleted from the rainfall record, as they do not generate runoff. A rainfall frequency analysis was then performed for Cambridge, City of Baltimore, College Park, Cumberland, Frederick, Hagerstown, and Salisbury. An example of the rainfall frequency spectrum is provided in Figure 2 for the Frederick region. The figure shows the percentage of annual rain-days less than or equal to one-inch of rainfall. Subsequent calculations compute both the rain-days and rainfall volume that is captured by a BMP assuming that rain events above one-inch threshold are partially captured (i.e., up to one inch).

The rainfall records were further analyzed to (A) identify the rainfall depth that produces 90% of the annual runoff volume and, (B) the fraction of average annual runoff volume captured by a BMP sized based on the WQ_v (one inch of rainfall) using capture efficiency of a BMP for all storm events for the one-inch rainfall event. The runoff capture statistics assumed full capture of all rainfall events less than one-inch, and partial capture of rainfall events greater than one inch (i.e., rainfall up to the one-inch threshold are still captured by these larger storm events). The results for the seven Maryland stations are shown in Table 2.2.

Some of the key findings from this analysis include:

- Each variable decreases slightly from the Eastern portion of the State to Western portion of the State.

- the "straight" 90% event is consistently about 1.2 inches throughout the Coastal Plain and Piedmont region, and about 1 to 1.1 inches in the Western part of the State (see Column A in Table 2.2). This is a very conservative sizing criterion, as it assumes no runoff capture whatsoever for storm events that exceed the threshold.

- If a one-inch capture threshold is used, our method predicts that 83 to 85% of annual average annual runoff volume will be captured on the Eastern Shore and 87 to 93% in the Piedmont and Western Portions of the State. The actual capture efficiency may not be this high, as our method does not account for back to back storm events that might result in poor retention or exfiltration times during the second storm (i.e., because the BMP is still partially full from a first storm) or the fact that settling conditions are far from ideal during the larger, more turbulent events. On the other hand, it is also reasonable to assume that the fraction of the annual runoff volumes that bypasses the WQ_v may be partially treated by temporary storage provided for C_{pv}, Q_{p2} or Q_{p10}

- Consequently, it is recommended that one-inch of rainfall be used to define the 90% capture rule in most areas of the State to define the WQ_v. West of Frederick County, the 90% runoff capture rule can be achieved by sizing BMPs to capture the runoff from 0.9 inches of rainfall. This line will be geographically defined in the final manual.

Figure 2.2 *Sample Rainfall Analysis for Frederick, Maryland*

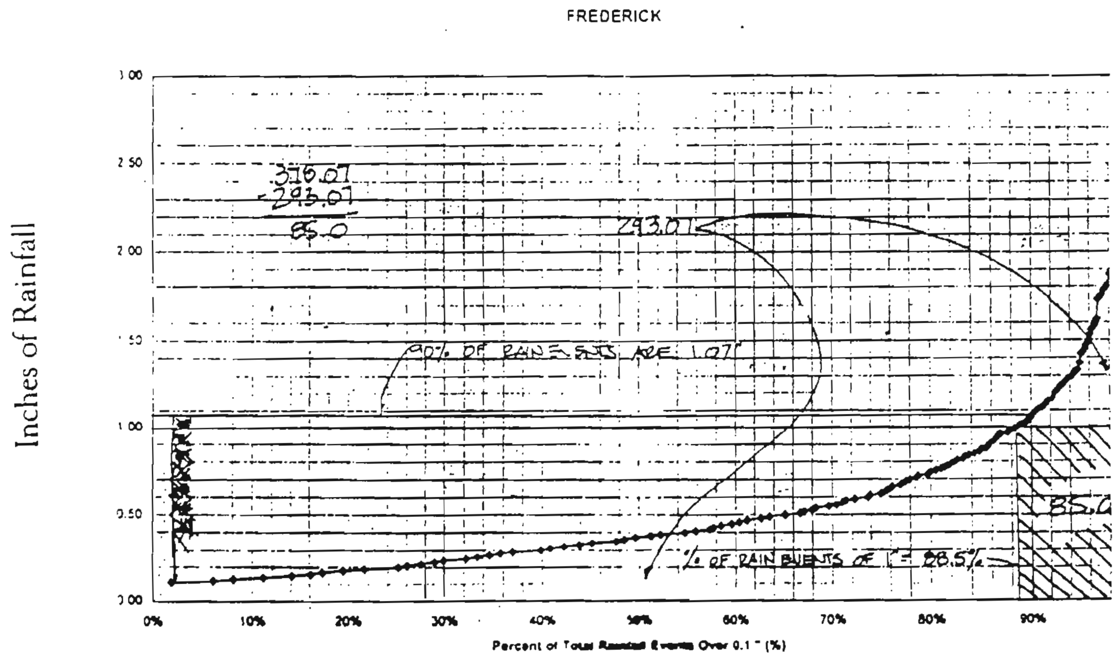


Table 2.2 Summary of Rainfall Frequency Analysis for Seven Maryland Stations
Source: Tim Schueler (EQR, 1996)

Weather Station	(A) Depth of rainfall that corresponds to the 90% storm event (daily rainfall)	(B) Fraction of Annual Rainfall Volume Captured by a One-inch SWM Facility
Salisbury,MD	1.20 inches	84.5 %
Cambridge,MD	1.20	83.3 %
Baltimore,MD	1.20	86.6 %
College Park,MD	1.18	88.4 %
Frederick,MD	1.07	89.9 %
Hagerstown,MD	1.06	89.7 %
Cumberland,MD	0.96	92.9 %

2.3.3 Pros and Cons for WQ_v Sizing Rules

This section provides a quick summary of the pros and cons associated with the two basic sizing rules to define the WQ_v:

The advantages of the *half-inch rule are* that it is simple, easy to compute and verify, and has been historically used by other states and localities. The disadvantages of the half- inch rule are as follows:

- it requires more WQ_v storage than needed for most residential developments, increasing stormwater construction costs for the most common type of development in the State.
- it provides no direct incentive to reduce impervious cover at development sites.
- research has shown that it does not capture 90% of annual storm pollutant loads above 50 to 70% impervious cover (Chang, 1990)

- many pollutants such as sediment, nitrogen and zinc have been shown not to exert a strong first flush behavior, either because they are predominately found in wetfall or are more strongly influenced by the intensity of rainfall

- higher pollutant concentrations reported for parking lots may not be fully treated

- not consistent with the recharge requirement and may cause confusion.

The advantages of the 90% *capture Rule* are that it remains relatively simple, requiring only the additional measurement of impervious cover at the site. Other benefits include:

- reduces the WQ_v storage needed for residential development, compared to the half-inch rule.

- Since the WQ_v is based on impervious cover, it provides strong incentives to reduce imperviousness at the site level to reduce stormwater treatment costs.

- provides a consistent design basis for both recharge (Re_v) and water quality volumes (WQ_v)

- many high impervious cover areas are also stormwater hotspots and may require greater stormwater treatment (e.g, parking lots, etc.). The 90% capture rule provides for more treatment at these higher levels of impervious cover. Consequently, parking lots need not be classified as a "hotspot"

There are three primary disadvantages to the 90% rule.

- The rule requires greater storage at highly impervious commercial sites, and may increase the cost of complying with stormwater quality requirements. For most commercial sites in Maryland with an impervious cover of 85% or less, this results in about a quarter-inch per acre more storage than the WQ_v computed under the half-inch rule).

- plan reviewers may encounter difficulty in verifying the amount of impervious cover at the site when plans are submitted, and will need a clear and simple definition of what constitutes impervious cover. Otherwise, disputes may arise between designers and plan reviewers about the actual amount of impervious cover present at the site.

- The 90% rule may result in a very small WQ_v for small residential sites of very low impervious cover (i.e., in the 5 to 15% range). While the volume is sufficient for pollutant removal, it may not be great enough to prevent nuisance problems in many BMPs that require a permanent pool for either treatment or pretreatment. (odors, stagnant water, draw downs, mosquitos, etc).

Based on the foregoing, it is recommended that the 90% rule be used as the basis for defining the WQ_v*. Numerically, the* WQ_v *is equivalent to:*

1.0 (Rv)(A) *(East and South of Frederick County)*
(0.9) (Rv)(A) *(Frederick County and West)*

Furthermore, as a basis for design, the following assumptions may be made:

For purposes of initially defining impervious cover, any area of site that will not have permanent vegetative cover shall be considered total impervious cover. Subsequent reductions in impervious cover (e.g., disconnecting rooftop runoff) must be demonstrated in accordance with the conditions outlined in Section 6).

A minimum WQ_v *of 0.2 inches/acre is set for residential sites that have less than 15% impervious cover.*

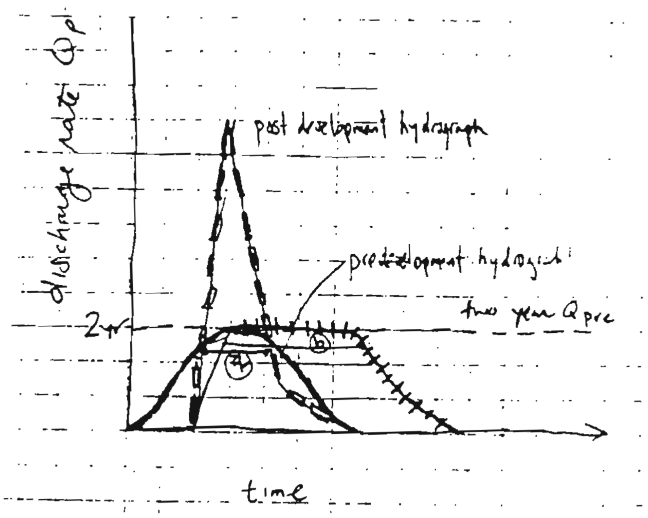
Section 2.4 Stream Channel Protection Requirements (Cp_v)

2.4.1 Basic Options for Stream Channel Protection

As many as five different design criteria have been suggested to protect downstream channels from erosion. It should be clearly noted that none of these criteria have yet been monitored in the field to demonstrate their effectiveness. Most are based on hydrologic or hydraulic modeling of streams. The Center has generally analyzed each of the five criteria, but the scope of the project has not allowed the kind of detailed comparative modeling and monitoring to make a full assessment. The five options are:

two year control (post development peak discharge rate from two year storm held to pre development levels). This represents the current criteria in the State of Maryland. It is very important to note that research studies indicate that this criteria does not protect channels from downstream erosion, and may actually exacerbate erosion since banks are exposed to a longer duration of erosive bankfull and sub-bankfull events. (MaCrae, 1993 and 1996, McCuen and Moglen, 1988). In addition, many communities have provided anecdotal evidence that two year control has failed to protect downstream channels from erosion. The primary reason is shown in schematic form in Figure 2.3. It demonstrates that while the magnitude of the peak discharge is unchanged from pre to post development under two year control, the duration of erosive flows sharply increases (i.e., relative distance of lines a and b). As a result, "effective work" on the channel (sensu Wolman et al, 1964) is shifted to smaller runoff events that range from the half year event up to the 1.5 year runoff event (MacRae, 1993). *Consequently, the two year control approach is considered ineffective for stream channel protection, and is not considered further* (although it remains a useful criterion for prevention of overbank flooding--see Section 2.5)

Figure 2.3 *Two year control effect on extending the falling limb of the hydrograph thereby increasing the duration of time that a channel is exposed to erosive velocities.*



two year over-control (post development peak discharge rate to 50% or less of predevelopment level). First proposed by McCuen and Moglen (1988), this design approach recognizes the inherent limitations of two year control. The approach emphasizes "overcontrol" of the two year storm. The most common numerical approach is to control the two year post development discharge rate to the one year predevelopment rate, using the 24 hour storm event. Subsequent analysis by Macrae (1996), however, indicates that this design criteria is still not fully capable of protecting the stream channel from erosion. His modeling suggests that "tail-end" of the post development hydrograph is subject to a considerable duration of effective work.

24 hour detention of the one year storm event (MDE, 1994). The Stormwater Regulations Review Committee has proposed this criteria. For most regions of the State, this criteria would result in up to 24 hours of detention for runoff generated by a rainfall depth of approximately 3 inches.

Smaller storms events (1 to 2 inches) would also experience some detention, but probably much less than 24 hours. The premise of this criteria is that runoff would be stored and released in such a gradual manner that critical erosive velocities would seldom be exceeded in downstream channels. The required volume needed for 1 year extended detention is significant; it is roughly equivalent to about 90 to 95% of the required volume needed for ten year peak discharge control (see Table 2.5). Consequently, the State recommends that the two year peak discharge management be eliminated when the 1 year ED is provided, as long as the ten year peak discharge control is achieved.

distributed runoff control (DRC): This criteria has been developed by MaCrae (1993) and involves complex field assessments and modeling to determine the hydraulic stress and erosion potential of bank materials. The criteria states that channel erosion is minimized if the alteration in the transverse distribution of erosion potential about a channel parameter is maintained constant with predevelopment values, over the range of available flows, such that the channel is just able to move the dominant particle size of the bed load. This Canadian method holds promise, but has not been tested on streams in this region, and requires significantly greater data collection and modeling than any of the other methods.

bankfull capacity/duration criteria: This criteria has been advanced by Tapley et al 1996, and states that the post-development, bankfull flow frequency, duration and depth must be controlled to predevelopment values at a designated control point(s) in the channel. The Rule of thumb for selecting control point(s) is to use a 10: 1 ratio of peak discharge from the one year storm for the developed site to the discharge from the stream for the same frequency storm (Tapley et al, 1996). In theory, this criteria should result in a high level of downstream protection. The practical problem is to define how the criteria will be interpreted; whether sub-bankfull events (that typically erode the toe of the streambank) should also be considered; and precisely where the "bankfull" should be measured. For example, the channel of many streams have been modified in the past by prior land uses and channelization, and may not represent the "true" channel. In other cases, the stormwater outfall discharge laterally to a stream, and it is therefore difficult to assign which flows the developer is actually responsible for controlling.

2.4.2 Pros and Cons of Channel Protection Sizing Criteria

If two year control and two year overcontrol are deemed inadequate to fully protect channels from erosion, then only three options remain, each of which has some limitations. For example, both the DRC and bankfull capacity sizing criteria options lack widely accepted or universal design methodologies that can be used on a State-wide basis. In each case, local stream cross-section and/or soil measurements are needed, and considerable contention between the designer and the reviewer can be expected on how and where the analysis should be performed. Given the many operational problems currently associated with either option, and the lack of a tested design methodology at present, the two options probably deserve further study, but are not ready for State-wide application.

This leaves us with only one remaining option-- the one-year 24 hour detention criteria. It, too, has some limitations:

- results in unacceptably small diameter orifices for sites less than ten acres in size,
- requires a storage volume roughly equivalent to that needed for ten year control,
- has not been "tested" by continuous simulation modeling to determine if acceptable detention times can be achieved for smaller storms (1.0 to 1.5 inches), and
- is only needed in streams that are susceptible to bank erosion (i.e., some Eastern shore ditches and channels may not experience erosion).

Based on the foregoing, it appears that the best option to provide channel protection (Cp_v) is 12 to 24 hour extended detention of the one-year 24 hour storm event. This Cp_v requirement only applies to sites greater than ten acres in size and does not apply to the Eastern Shore of Maryland. Local governments may wish to retain the option of employing the DRC or bankfull capacity/duration criteria as an alternative, should their analytical and design requirements become more simplified and refined in the future.

As a basis for design, detention time for the one year storm shall be defined as the center of mass of the inflow hydrograph and the center of mass of the outflow hydrograph, using the Harrington method. ED for CPv does not meet the WQv requirement. A simpler method is used to design extended detention ponds for WQ_v. The pond outlet can be sized assuming that the basin immediately fills, and then sizing pipes for a 24 hour draw down.

Section 2.5 Overbank Flood Control Requirements (Q_p)

The primary purpose of this sizing criteria is to prevent an increase in the frequency and magnitude of out-of-bank flooding (i.e., flow events that exceed the bankfull capacity of the channel, and therefore must spill over the floodplain, where they can damage property and structures).

To prevent overbank flooding, the State originally imposed the two year control requirement, which requires that the post development two year, 24 hour peak discharge rate (Q_p) be controlled to the predevelopment rate. Subsequently, many Counties are also required to control the peak discharge from the ten year, 24 hour storm event to predevelopment levels. The 10 year storm event was added to increase the range of large storms that were managed. The combined 2 and 10 year Q_p criteria appears to have been fairly effective at reducing the frequency of out-of-bank flooding. It should be noted that Montgomery County and the Eastern Shore Counties currently are not required to control the ten year storm. The rainfall depths associated with the one, two and ten year storm events are shown in Table 2.3.

Table 2.3 *Rainfall Depths Associated with One, Two and Ten Year storm Events (24 hour) for Eight Maryland Locations*

Maryland Location	**One-year 24 hour**	**Two year, 24 hour**	**Ten year, 24 hour**
Salisbury	3.0 inches	3.6 inches	5.6 inches
Cambridge	2.8	3.4	5.4
La Plata	2.7	3.3	5.3
Baltimore	2.6	3.2	5.1
College Park	2.7	3.3	5.3
Frederick	2.5	3.1	5.0
Hagerstown	2.5	3.0	4.8
Cumberland	2.4	2.9	4.5

A number of hydrologists, however, have noted that the 2/10 year approach may not always provide full downstream control from out-of-bank flooding, due to differences in timing of individual peak discharges in the downstream portion of the watershed. Depending on the shape of a watershed, it is possible that upstream peak discharge may arrive at the same time a local structure is releasing its peak discharge, thus increasing total discharge. This problem with coincident peaks has led several New Jersey jurisdictions to require what is known as **"overcontrol"**. In this case, the designer must control post development peak discharge to half of the predevelopment rate, unless watershed modeling clearly demonstrates that coincident peaks will not occur. Clearly, overcontrol results in a much greater and more costly storage volume. Consequently, it is not recommended as a State-wide criteria, but may be considered as a County option.

Another proposed modification to the 2/10 criteria is needed when one-year 24 hour ED (Cp_v) is employed at a site. As Table 2.6 indicates, the storage volume needed for Cp_v greatly exceeds that needed for two year Q_p, and therefore, the State suggests that a combination of 1 Year ED and Ten Year Control is sufficient to meet the Q_p requirement for overbank flooding for a wide range of storms. Limited modeling by MDE staff indicates that this combination is capable of preventing overbank flooding

2.5.1 Basis for Hydrologic Design

In addition to the overbank flooding design criteria, it is important to establish the basis for hydrologic and hydraulic evaluation of development sites. The following represent the minimum basis for design:

- The models TR-55 and TR-20 (or approved local equivalent) will be used for determining peak discharge rates,
- The standard for characterizing predevelopment land use shall be meadow in good condition,
- Modified Curve Numbers (CN) may be permitted for Karst regions (Laughland, 1996) and small sites (see pages 2.30 and 2.31 for proposed guidance).
- Off-site areas should be modeled as "present condition" for both the 2 and 10 year storm events,
- Off-site area should be modeled as "ultimate condition" for the 100 year storm event, and
- The length of overland flow used in time of concentration calculations is limited to no more than 150 feet for predevelopment conditions and 100 feet for post development conditions.

Section 2.6 Extreme Flood Requirements (Q_{p100})

The intent of this criteria is to prevent flood damage from infrequent but large storm events, maintain the boundaries of the predevelopment 100 year floodplain, and protect the physical integrity of the control structure. This is typically done in three ways:

100 Year Control: require storage to control the post development 100 year, 24 hour peak discharge rate (Q_{p100}) to predevelopment rates. Table 2.4 indicates the depth of rainfall (24 hour) associated with the 100 year storm at various locations in the State of Maryland. The Q_{p100} is the most stringent and expensive level of flood control, and may not be needed if the downstream development is located out of the 100 year floodplain, or if stream crossings have adequate capacity to convey the 100 year flood. In many cases, the conveyance system leading to a stormwater structure is designed based on the discharge rate for the ten year storm (Q_{p10}). In these situations, the conveyance systems may be the limiting hydrologic control.

Reserve Ultimate 100 Year Floodplain. The 100 year control requirement can be waived if development is excluded from the ultimate 100 year floodplain, or discharges directly into tidal waters.

Safe Overflow of the 100 year peak discharge through the structure. Depending on the type and size of stormwater facilities, they usually need to be designed to provide safe overflow of the 100 year peak discharge rate.

***Table 2.4** Rainfall Depths for the 100 Year, 24 hour Storm at Eight Maryland Locations*

Maryland Location	Rainfall Depth
Salisbury	8.1 inches
Cambridge	7.8 inches
La Plata	7.6 inches
Baltimore	7.1 inches
College Park	7.4 inches
Frederick	7.0 inches
Hagerstown	6.7 inches
Cumberland	6.2 inches

The Center recommends that the current practice of not providing 100 year peak discharge control be continued in the State, as long as the downstream ultimate floodplain is protected, and adequate conveyance and overflow are provided.

Section 2.7 Designation of Stormwater Hotspots

A stormwater hotspot is defined as a land use or activity that generates higher concentrations of hydrocarbons, trace metals or toxicants than are found in typical stormwater runoff, based on monitoring studies. Table 2.5 provides a list of designated hotspots for the state of Maryland. If a site is designated as a hotspot, it has important implications for how stormwater is managed. First and foremost, stormwater runoff from hotspots cannot be allowed to infiltrate into groundwater, where it can contaminate water supplies. Therefore, the recharge requirement is NOT applied to development sites that fit into the hotspot category. Second, a greater level of stormwater treatment is needed at hotspot sites to prevent pollutant washoff after construction. This typically involves preparing and implementing *a stormwater pollution prevention plan*, that involves a series of operational practices at the site that reduce the generation of pollutants from a site or prevent contact of rainfall with the pollutants.

Under EPA's stormwater NPDES program, some industrial sites are required to prepare and implement a stormwater pollution prevention plan. A list of industrial categories that are subject to the pollution prevention requirement can be found in Appendix C-X. In addition, Maryland's requirements for preparing and implementing a stormwater pollution prevention plan are described in the general discharge permit provided in Appendix C-X. The stormwater pollution prevention plan requirement applies to both existing and new industrial sites.

In addition, if a site falls into the "hotspot" category outlined in Table 2.5, a pollution prevention plan may also be required by the local reviewing authority. Golf courses and Nurseries may need an Integrated Pest Management Plan. Guidance on basic pollution prevention guidelines for "standard" industrial, commercial and automotive sites is provided in Appendix C-X.

Table 2.5 Classification of Stormwater Hotspots

The following land uses and activities are deemed *stormwater hotspots:*

- auto recycler facilities #
- commercial nursery
- fueling stations
- fleet storage areas (bus, truck, etc.) #
- industrial rooftops #
- marinas #
- outdoor container storage of liquids
- outdoor loading/unloading facilities
- public works storage areas
- SARA 312 generators *
- vehicle service and maintenance areas #
- vehicle and equipment washing/stream cleaning facilities #
  industrial sites for certain SIC codes outlined in Appendix C-X

* only if materials or containers are exposed to rainfall
(#) indicates whether the hotspot activity is required to prepare a stormwater pollution prevention plan under the NPDES program

Areas not normally considered hotspots:

- streets and highways
- residential development
- institutional development
- office developments
- non-industrial rooftops
- pervious areas, except golf courses and nurseries (which may need IPM Plan).

Section 2.8 Comparative Storage Requirements For Stormwater Sizing Criteria

What are the implications of the new stormwater sizing criteria for storage volume, and construction cost? To answer this questions, storage volumes were computed for three hypothetical development scenarios under the four new stormwater sizing criteria -- a 25 acre commercial development and a 25 and 50 acre residential subdivision. The comparative results are shown in Table 2.6. Please note that the actual storage needed for a particular storage component will be slightly less than shown since some attenuation may be provided by control of smaller storms. The number in parentheses in Table 2.6 indicates the percentage of the storage volume needed to control the ten year storm event (Q_{p10}). Also, note that the WQ_v is inclusive of the Re_v.

Table 2.6 indicates that the proposed sizing criteria for WQ_v and Re_v are relatively small in relation to the storage needed for overbank control (Q_{p2} and Q_{p10}). The major increase in storage volume, compared to current criteria, is for stream channel protection (Cp_v). As can be seen, the required storage volume for Cp_v surpasses the Q_{p2} is almost equivalent to the Q_{p10} Consequently, it makes sense to substitute Cp_v for Q_{p2} if stream channel protection is desired.

Table 2.6 *Comparison of Storage Needed For Six BMP Sizing Criteria Under Three Development Scenarios (Adapted From EQR, 1996)*

Storage Component	**25 acre Commercial**	**25 acre Residential**	**50 acre Residential**
Recharge (Re_v)	0.33 ac-ft (9%)	0.16 ac-ft (10%)	0.35 ac-ft (10%)
Water Quality (WQ_v)	1.32 ac-ft (36%)	0.65 ac-ft (40%)	1.41 ac-ft (43%)
Channel Protection (Cp_v) 1 year 24 ED	3.21 ac-ft (87%)	1.58 ac-ft (96%)	3.17 ac-ft (97%)
overbank: 2 year (Q_{p2})	2.31 ac-ft (62%)	1.01 ac-ft (63%)	2.05 ac-ft (63%)
Overbank ten year (Q_{p10})	3.70 ac-ft (100%)	1.63 ac-ft (100%)	3.25 ac-ft (100%)
Extreme flood 100 year (Q_{p100})	5.31 ac-ft	2.32 ac-ft	4.72 ac-ft
Notes: For full details on scenarios, see EQR, 1996. Note: "B" soils assumed for Recharge. Peak Factor of 1.6 (Qp_2) for 10 year storage and 2.3(Qp_2) for 100 year storage. The percentage in parentheses indicates storage as a percentage of the 10 year storage volume			

Section 2.9 General Performance Criteria for all BMPs

The following eight criteria apply to all new development* in the State of Maryland.

1. All new stormwater outfalls shall not discharge untreated stormwater directly into a jurisdictional wetland or waters of the State of Maryland

2. On the Eastern Shore, the post development peak discharge rate shall not exceed the pre-development peak discharge rate for the two year design storm event. Elsewhere in the State, the post development peak discharge rate shall not exceed the pre-development peak discharge rate for the ten year design storm event, if Cp_v is provided. In addition, safe passage for the 100 year storm event shall be provided.

3. Loss of annual recharge to groundwater shall be minimized through the use of structural and non-structural measures that promote infiltration. At a minimum, annual recharge from the post development site shall resemble the annual recharge from pre-development site conditions, based on soil type.

4. To protect stream channels from degradation, 12 to 24 hours of extended detention shall be provided for the one year storm event.

5. For new development, structural BMPs shall be designed to remove 80% of the average annual post development suspended sediment load (TSS). It is presumed that a BMP complies with this performance standard if it is:

   - sized to capture the prescribed water quality volume (WQ_v)
   - designed according to the specific performance criteria outlined in Section 5,
   - regularly maintained, and
   - properly constructed.

6. Stormwater discharges from land uses or activities with higher potential pollutant loadings, designated as hotspots, may require the use of specific structural BMPs and pollution prevention practices. In addition, stormwater generated from a hotspot land use may not be infiltrated.

7. Stormwater discharges to critical areas with sensitive resources (i.e., cold water fisheries, shellfish beds, swimming beaches, recharge areas, water supply reservoirs, Maryland Critical Area) may be subject to additional performance criteria, or may need to utilize or restrict certain BMPs, as outlined in Section 4.

8. All BMPs must have an enforceable operation and maintenance plan to ensure the system functions as designed. In addition, every BMP must have an acceptable method of pretreatment.

* The term "new development" will be defined within the context of existing and proposed COMAR statutes.

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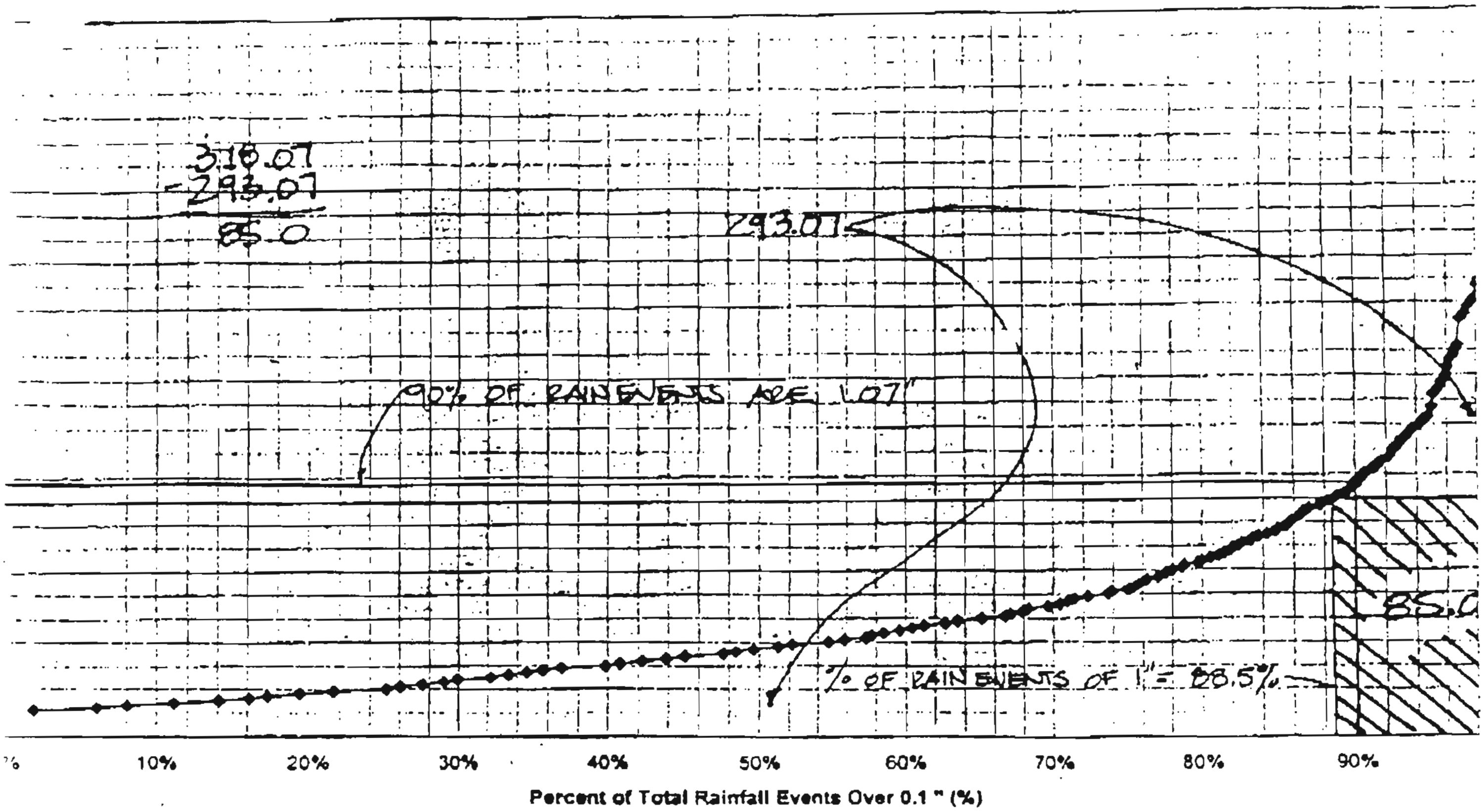
Attachments

1. Complete Rainfall Frequency Analyses for Seven Maryland Locations
2. CN Adjustments for Karst Regions
3. CN Adjustments for Small Storm Hydrology

FREDERICK



Total number of rain events = 745
Maximum rainfall event = 2.73"

TOTAL RAINFALL OF EVENTS UNDER 1" = 254.89
HIGHLIGHTED # + 85.00
339.89

TOTAL RAINFALL = 378.07
− 339.89
38.18

85 / (85 + 38.18) = 85 / 123.18 = .69

100 − 88.5 = 11.5%

PERCENT CAPTURE FREQUENCY = 88.5% + .69(11.5)
= 88.5 + 7.93
= 96.4%

Sheet1

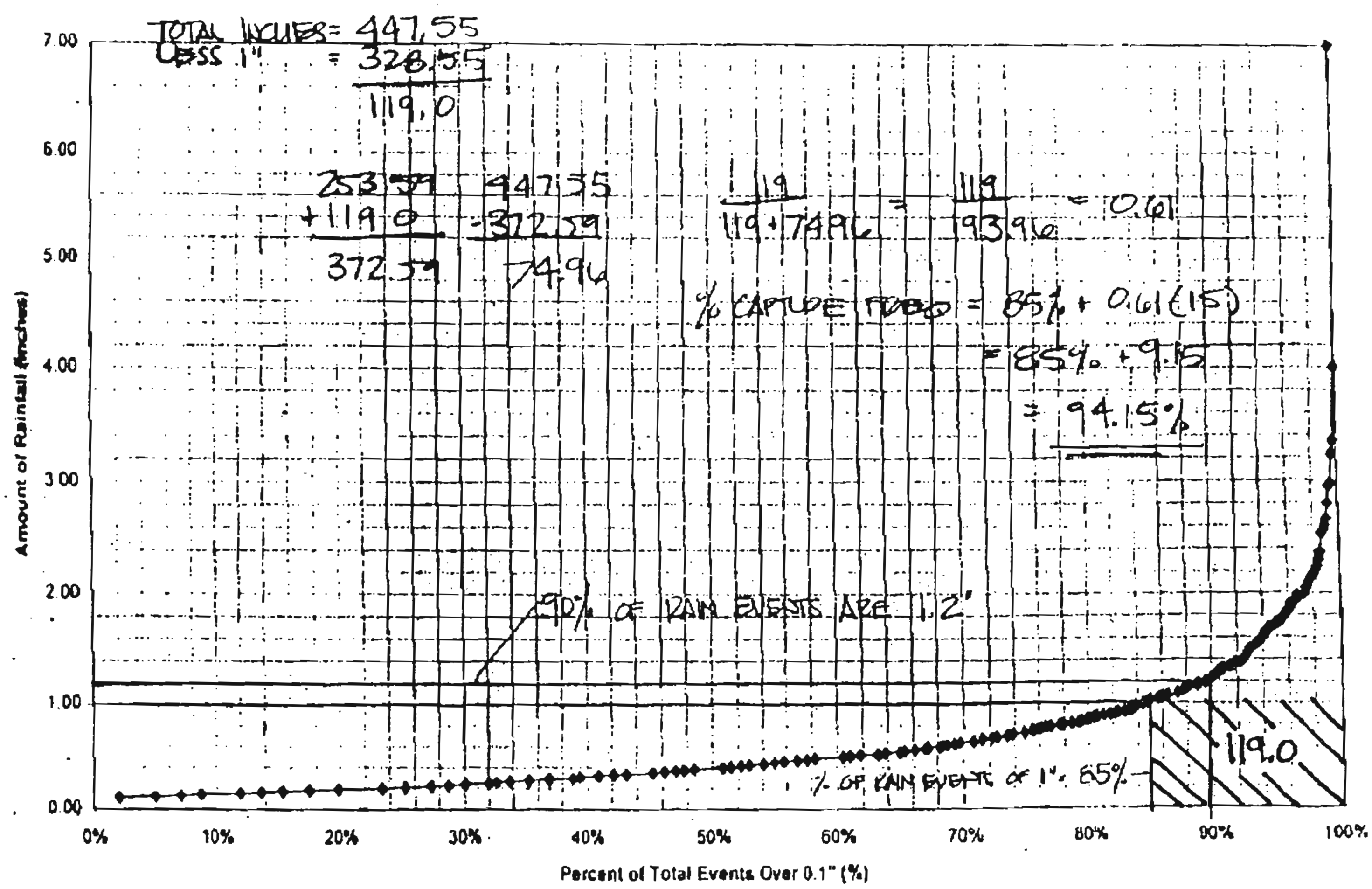
Frederick

	in	less 1"	under 1"	# of events over 1"
1	2.73	1.73	0	1
2	2.38	1.38	0	1
3	2.3	1.3	0	1
4	2.14	1.14	0	1
5	2.1	1.1	0	1
6	2.08	1.08	0	1
7	2.01	1.01	0	1
8	2.01	1.01	0	1
9	2	1	0	1
10	2	1	0	1
11				
TALS	378.07	293.07	254.89	85

EXAMPLE

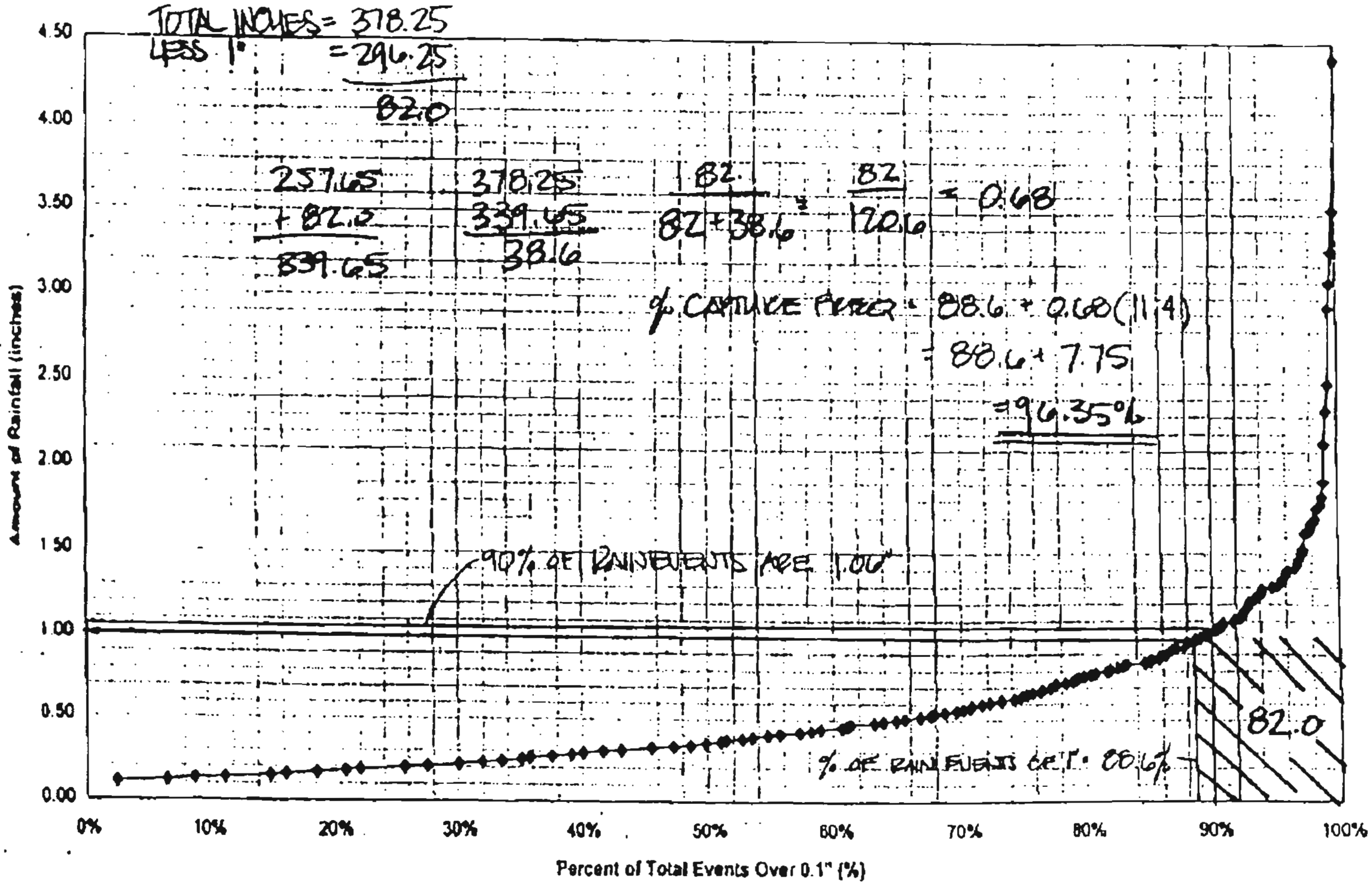
CAMBRIDGE

CAMBRIDGE



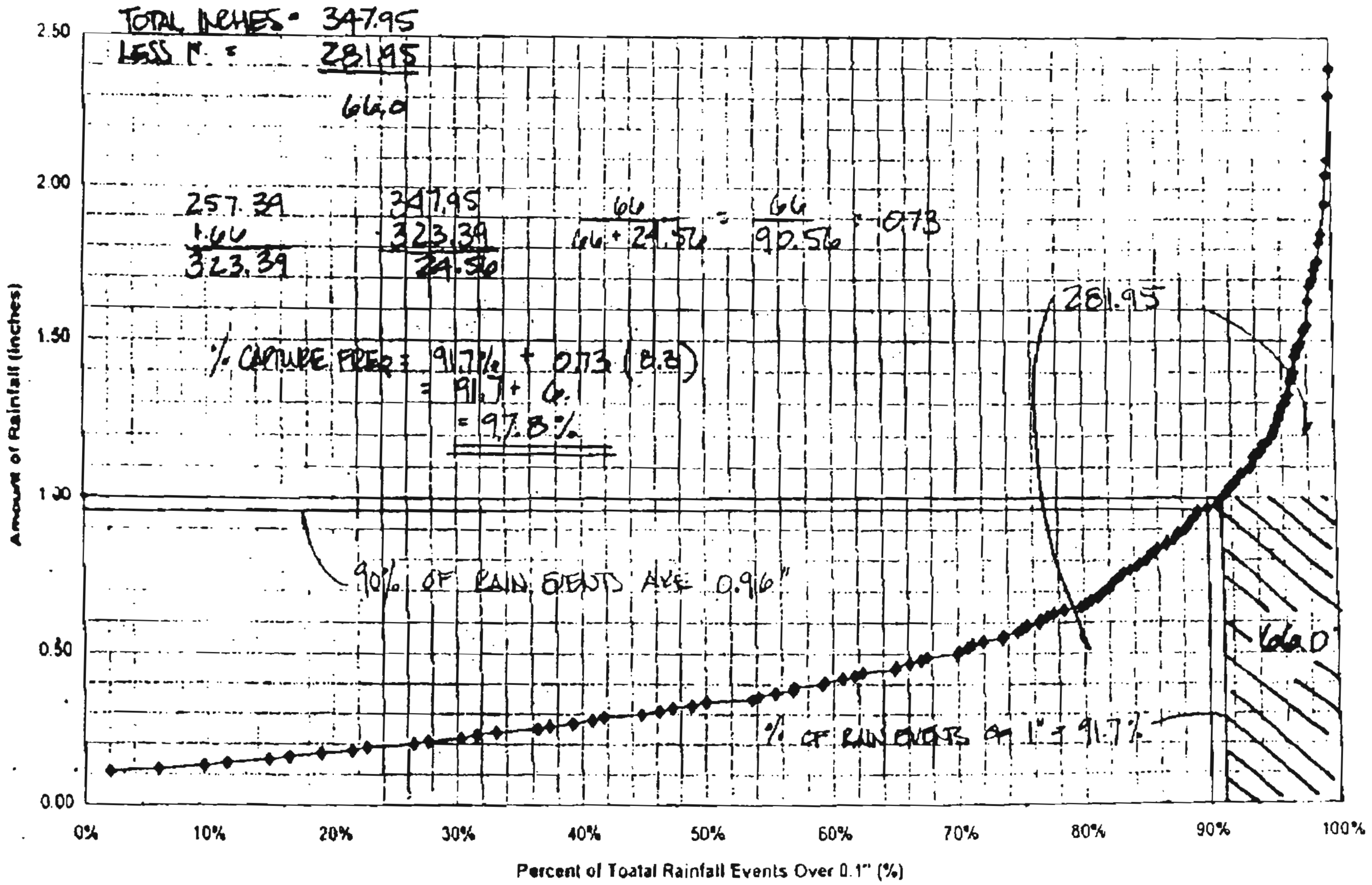
Total number of rain events = 762
Maximum rainfall event = 7.0"

HAGERSTOWN



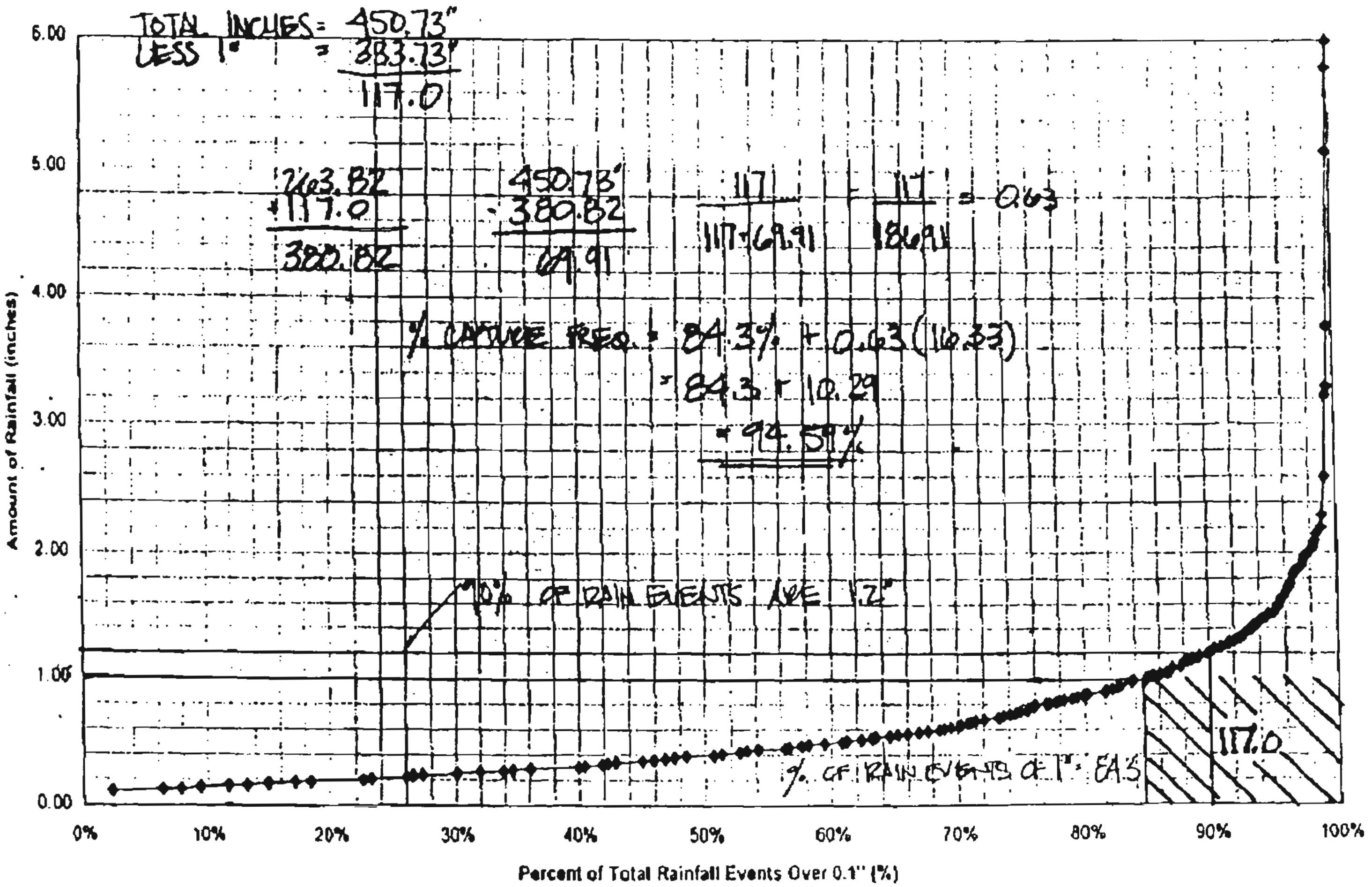
Total number of rain events = 749
Maximum rainfall event = 4.41"

CUMBERLAND



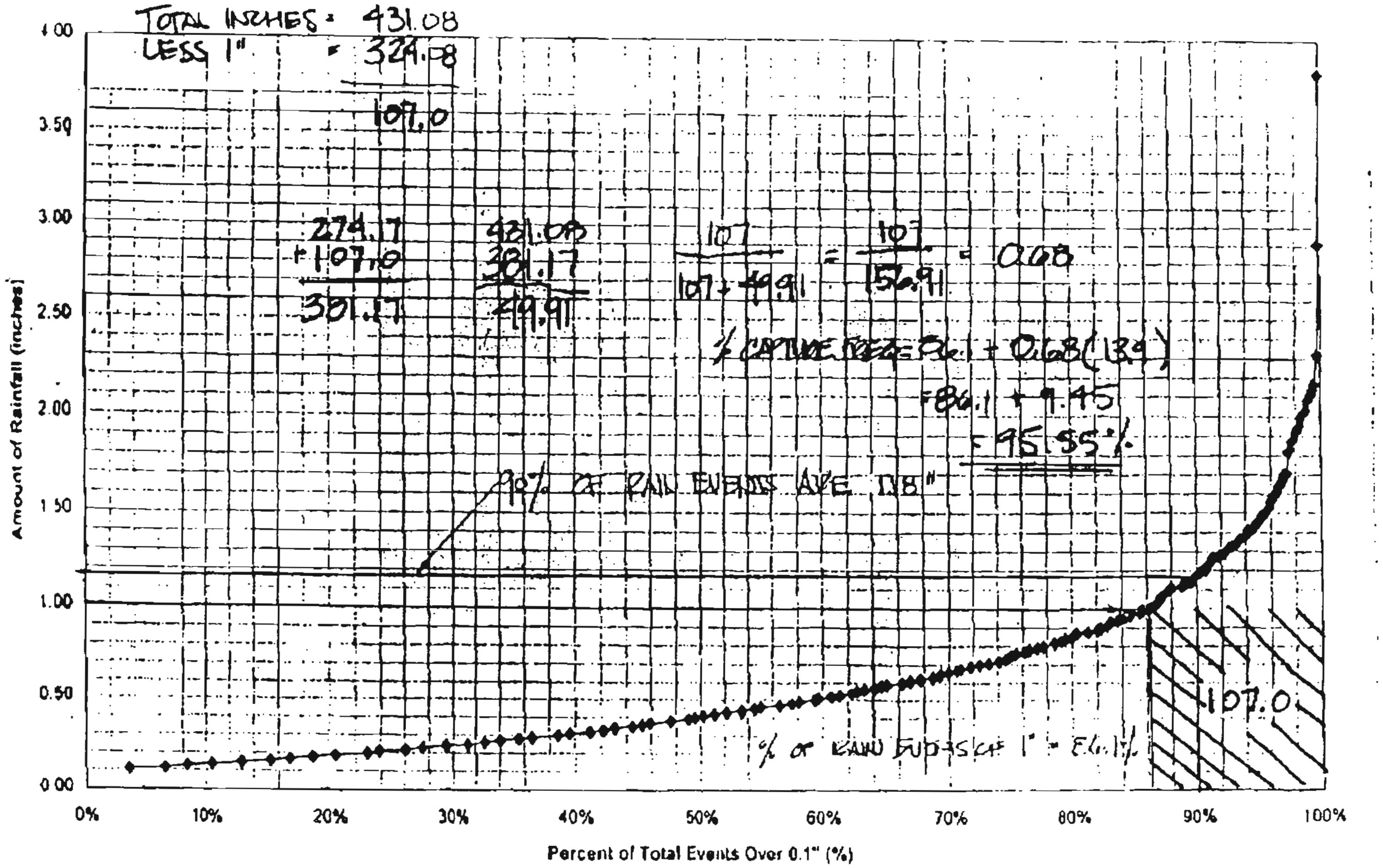
Total number of rain events = 755
Maximum rainfall event = 2.4"

SALISBURY



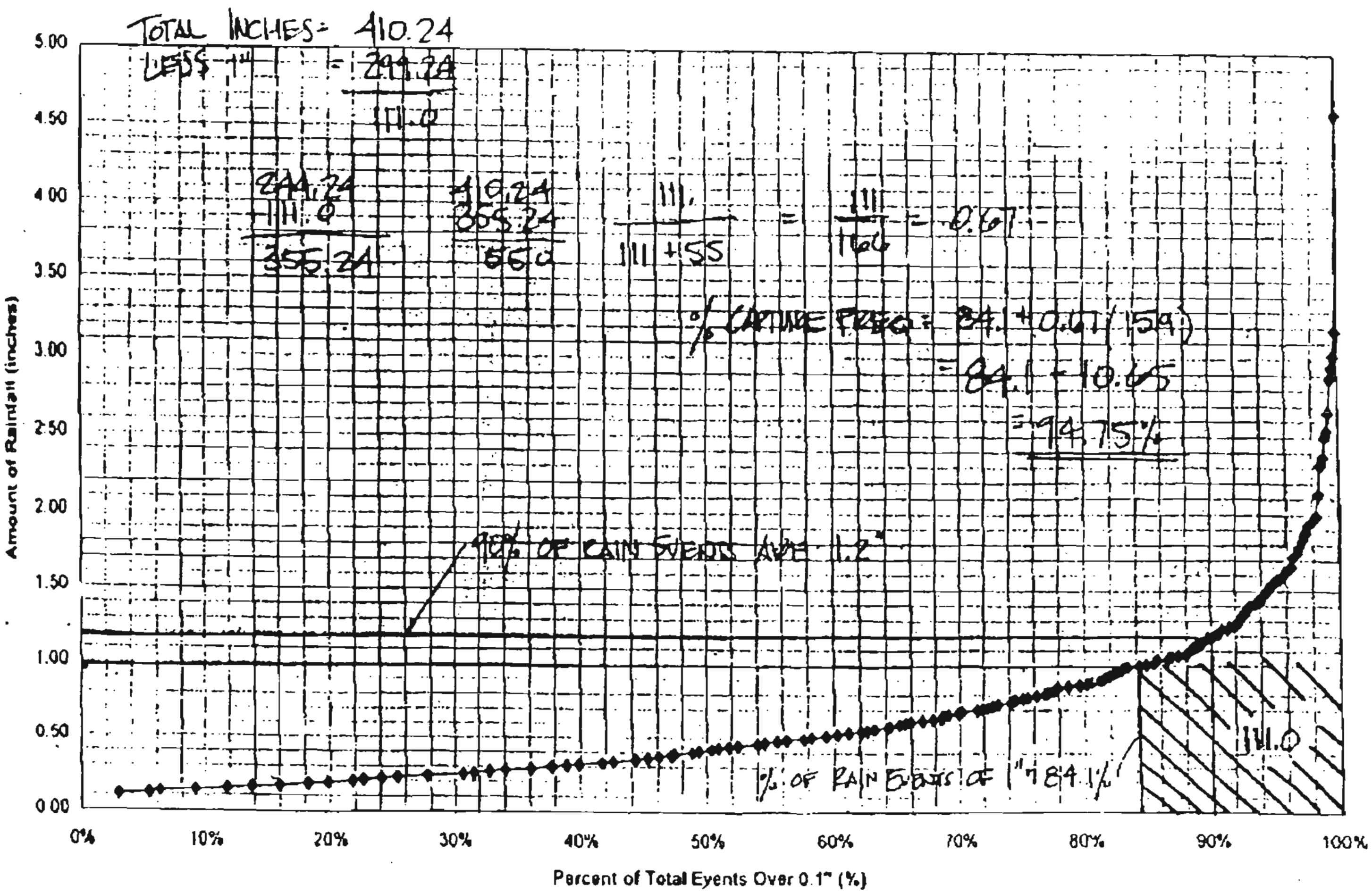
Total number of rain events = 776
Maximum rainfall event = 6.0"

COLLEGE PARK



Total number of rain events = 776
Maximum rainfall event = 3.82"

BALTIMORE CITY



Total number of rain events = 707
Maximum rainfall evens = 4.61"

2 24

Table 2 — Results of RCN Adjustments

Year Storm	Adjusted RCNs ASI	Adjusted RCNs KGBW	Difference ASI minus KGBW
2	54	57	-3
10	51	45	+6
100	47	40	+7

Table 3 — Adjustment Factors for Drainage Area Sizes

Percent Karst	Storm Year 2	Storm Year 10	Storm Year 100
100	0.33	0.43	0.50
90	0.35	0.46	0.56
80	0.38	0.51	0.62
70	0.47	0.58	0.68
60	0.55	0.66	0.74
50	0.64	0.73	0.80
40	0.73	0.80	0.85
30	0.82	0.86	0.89
20	0.91	0.92	0.93
10	1.00	0.98	0.97
0	1.00	1.00	1.00

Section 3.0 Acceptable Urban BMP Options

This section presents a classification scheme for structural and non-structural urban best management practices (BMPs) to be incorporated into the design manual. They include six broad groups of structural BMPs. The primary benefits of the classification system is that it provides:

- greater clarity and simplicity in the manual's organization
- better integration of structural and nonstructural practices
- minimum objective criteria for defining acceptable structural practices
- a smaller set of practices to guide general BMP selection
- greater flexibility for designers, within the framework of general performance criteria.

Section 3.1 Structural Urban BMP Options

The dozens of different BMP designs currently used in the State of Maryland are assigned into six general categories. The six categories include one category of runoff quantity controls (Qp or Cp_v), and five categories of runoff quality controls (WQ_v or Re_v):

For Q_p or Cp_v:

1. stormwater detention (including 24 hour ED of 1 year storm)

For WQ_v and/or Re_v:

1. stormwater ponds
2. stormwater wetlands
3. infiltration practices
4. filtering practices
5. open channel practices

Within each category, detailed performance standards are being developed with respect to feasibility, conveyance, pretreatment, treatment, environmental/landscaping and maintenance requirements (which are outlined in Section 5).

To be considered an effective structural practice, a design must be capable of:

1. providing adequate stormwater detention and/or streambank erosion control, OR
2. capturing and treating the full water quality volume (WQv), and

3. are presumed capable of meeting the CZARA[1] TSS removal criteria of 80%, and,
4. having acceptable longevity rate in the field.

1. Stormwater Detention

Definition: Practice that temporarily detains stormwater runoff to ensure that the post-development peak discharge rate is equal to the pre-development rate for the design storm event (Q_{p2}, Q_{p10} and Q_{p100}). The practice may also be used to provide temporary extended detention to protect downstream channels from erosion (C_{pv} 12 to 24 hour ED for the one-year design storm event).

These practices DO NOT provide significant pollutant removal benefits. Design variants include:

- stormwater detention ponds (Figure 3.1)
- underground vaults

Note 1. Infiltration is not normally recommended for Q_p or Cp control because of large storage requirements associated with the truncated hydrograph method.

Note 2. Stormwater detention storage for Qp and Cpv control can be provided above the WQ_v in stormwater ponds and wetlands; thereby meeting all storage requirements in a single facility.

2. Stormwater Ponds

Definition: Practices that have a combination of a permanent pool, extended detention or shallow marsh that is equivalent to the storage volume needed to fulfill the entire WQ_v. Design variants include:

- micropool extended detention pond (Figure 3.2)
- wet pond (Figure 3.3)
- wet extended detention pond (Figure 3.4)
- multiple pond system (Figure 3.5)
- "pocket" pond

[1]CZARA refers to the Coastal Zone Management Reauthorization Act of 1992, which prescribes that urban BMPs meet a performance criteria of 80% TSS removal.

Note 3. Conventional dry extended detention ponds (i.e. 100% ED, no pools) are NOT considered an acceptable pond option for WQ_v due to poor pollutant removal and chronic maintenance problems.

Note 4. The term "pocket" refers to a pond or wetland that has such a small contributing drainage area that little or no baseflow is available to sustain water elevations during dry weather. Instead, water elevations are heavily influenced and, in some cases, maintained by a locally high water table.

Note 5. Extended detention storage for Cp_v and WQ_v must be provided separately. (i.e., the WQ_v cannot be met simply by providing Cp_v storage for the one year storm)

3. Stormwater Wetlands

Definition: Practices that include significant shallow marsh areas to treat urban stormwater but often may also incorporate small permanent pools and/or extended detention storage to achieve the full WQ_v. Design variants include:

- shallow wetland (Figure 3.6)
- ED shallow wetland (Figure 3.7)
- pond/wetland system (Figure 3.8)
- "pocket" wetland (Figure 3.9)
- submerged gravel wetland (Figure 3.10)

Note 5. Stormwater wetlands can provide stormwater detention above WQv

4. Infiltration Practices

Definition: Practices that capture and temporarily store the *WQv* before allowing it to infiltrate into the soil over a two day period. Design variants include:

- infiltration trench (Figure 3.11)
- infiltration basin (Figure 3.12)
- porous pavement (Figure 3.13)

Note 6. Infiltration generally is not normally a practical option to provide stormwater detention (Qp) under the truncated hydrograph method. In addition, infiltration is not allowed to meet the Cpv requirement, unless the event is fully retained.

Note 7. Filtration generally is not allowed if the site is a designated stormwater hotspot.

Note 8. Drywells are not included as an infiltration design, but rather a non-structural practice as outlined in Section 6.3.

5. Filtering Practices

Definition: Practices that capture and temporarily store the *WQv* and pass it through a filter bed of sand, organic matter, soil or other media. Filtered runoff may be collected and returned to the conveyance system, or allowed to exfiltrate into the soil. Design variants include:

- surface sand filter (Figure 3.14)
- underground sand filter (Figure 3.15)
- perimeter sand filter (Figure 3.16)
- organic filter (Figure 3.17)
- pocket sand filter (Figure 3.18)
- bioretention areas (Figure 3.19)

Note 9: Most filtering practices cannot provide stormwater detention or downstream channel protection (Q_p and Cp_v).

Note 10: Most filtering practices are off-line and serve less than ten acres

6. Open Channel Practices

Vegetated open channels that are explicitly designed to capture and treat the full *WQv* within dry or wet cells formed by checkdams or other means. Design variants include:

- dry swale (Figure 3.20)
- wet swale (Figure 3.21)
- off-line bioretention cell (Figure 3.22)

Note 11. Grass channels (also known as biofilters) are not considered a structural practice but may be used for pretreatment or non-structural purposes.

Section 3.2 Structural BMPs that do not fully meet the WQ_v requirement

Many practices do not meet the criteria for being a structural practice, due to poor longevity, poor performance or inability to capture and treat the full *WQv* at a site. Some of these practices include:

- catch basin inserts
- dry extended detention ponds
- water quality inlets, oil/grit separators and hydro-dynamic structures
- filter strips
- grass channels
- street sweeping
- deep sump catchbasins
- dry wells
- grass channel (biofilter).
- on-line storage in the storm drain network

In some cases, however, these practices may be used for pretreatment, or can be used to meet recharge requirements (Re_v), or may be used as part of an overall BMP system.

Note 12. Many of the design variants of acceptable structural BMPs are highly restricted for geotechnical, environmental or maintenance reasons (e.g., infiltration basins or pocket ponds) These restrictions are outlined in Section 4.

Note 13. New structural BMP designs are continually being developed, including many proprietary designs. Most of the design variants should fit in one of the six BMP categories referenced above. New BMP design variants, however, cannot be accepted for inclusion on the list until independent pollutant removal performance and monitoring data has determined that it can meet the CZARA TSS requirement or the Critical Area phosphorous requirement.

Figure 3.1 Conventional Stormwater Detention

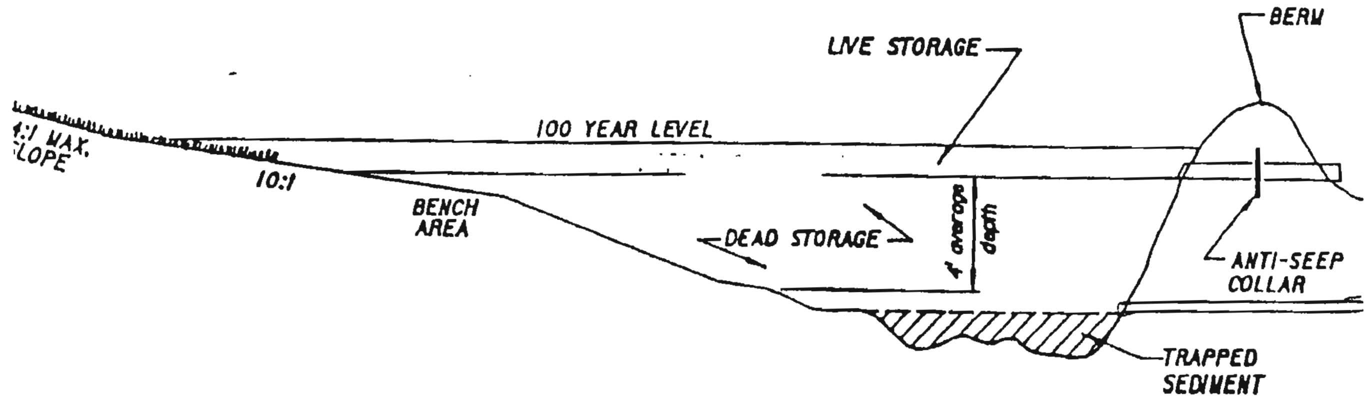


Figure 3.2 Micropool Extended Detention Pond

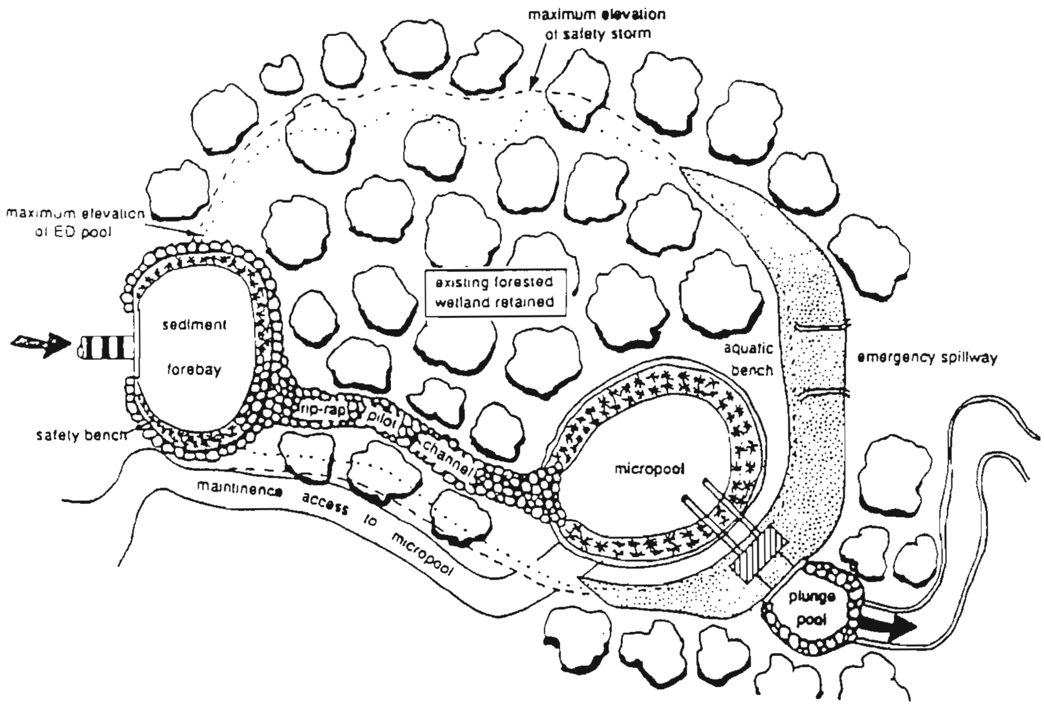


Figure 3.3 Wet Pond

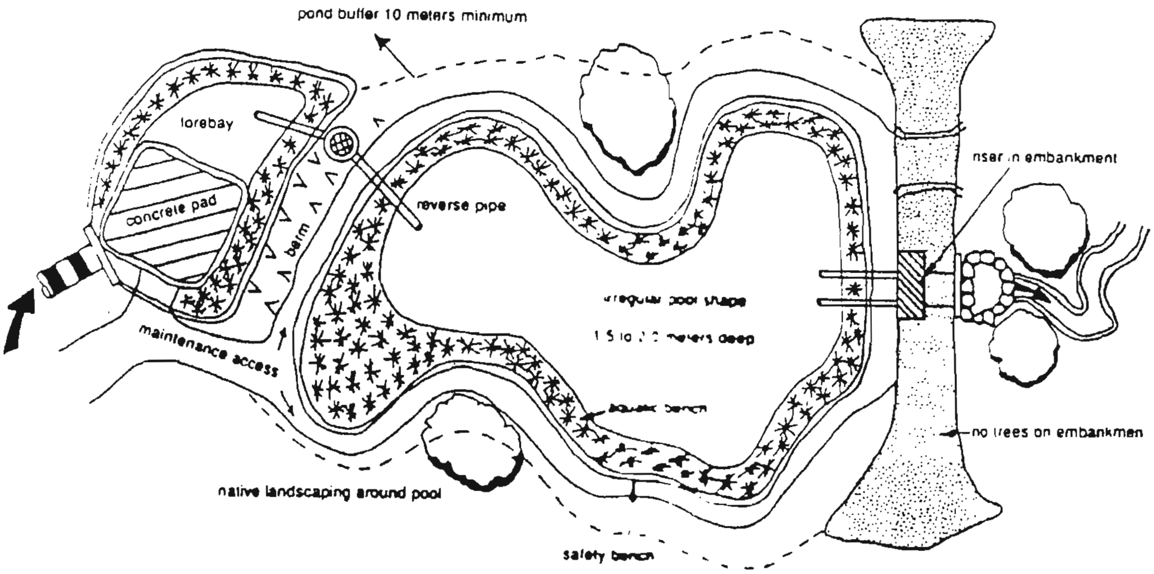


Figure 3.4 Wet Extended Detention Pond

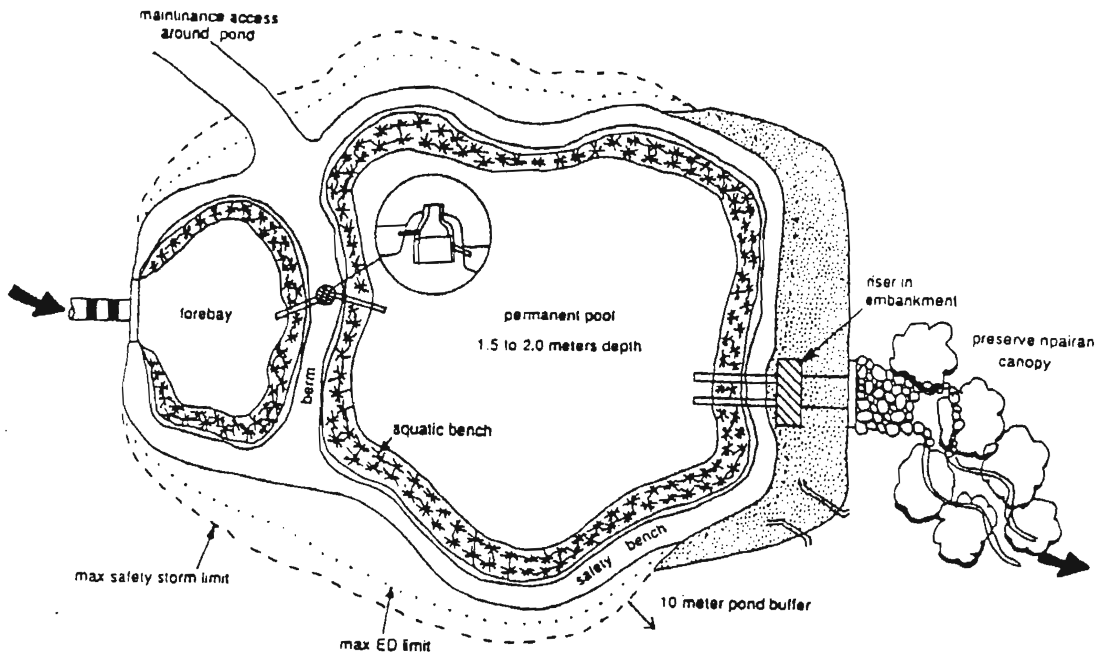


Figure 3.5 Multiple Pond System

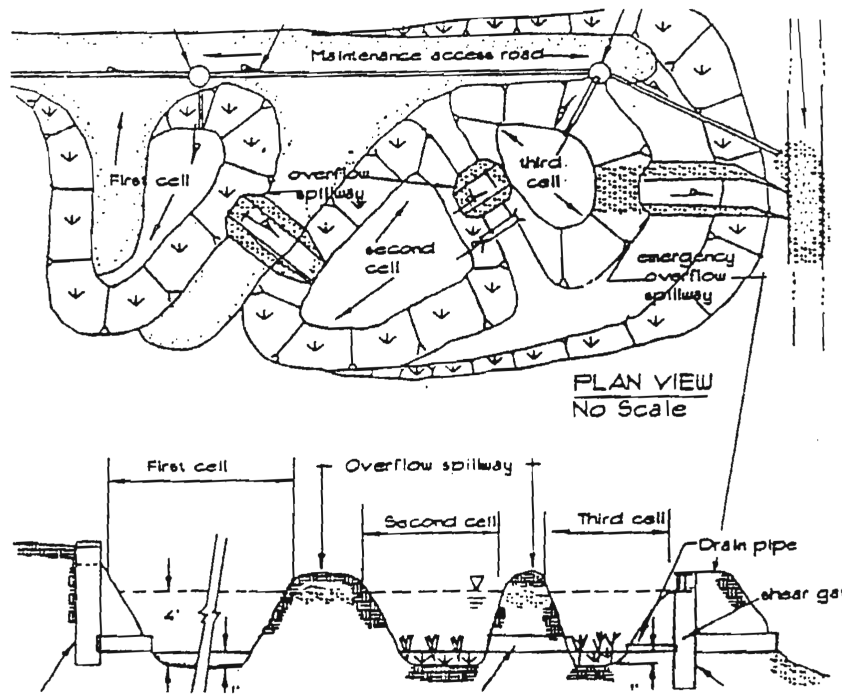


Figure 3.6 Shallow Wetland

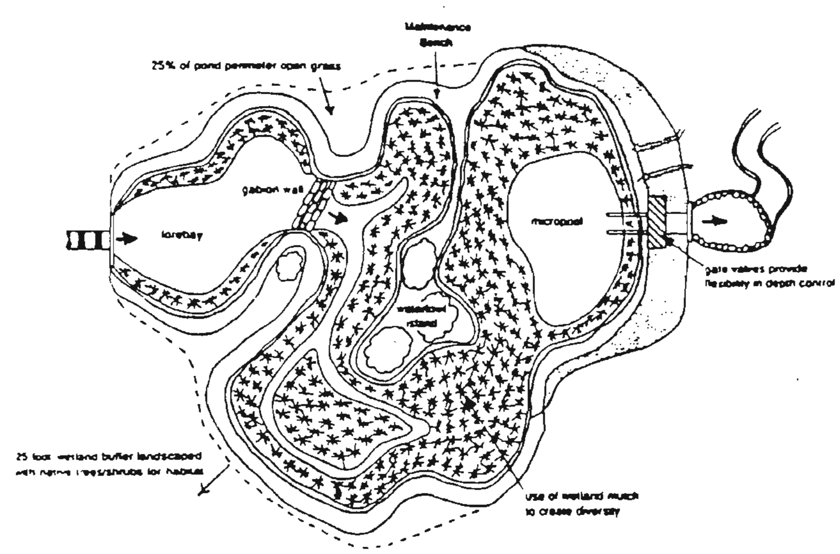


Figure 3.7 ED Shallow Wetland

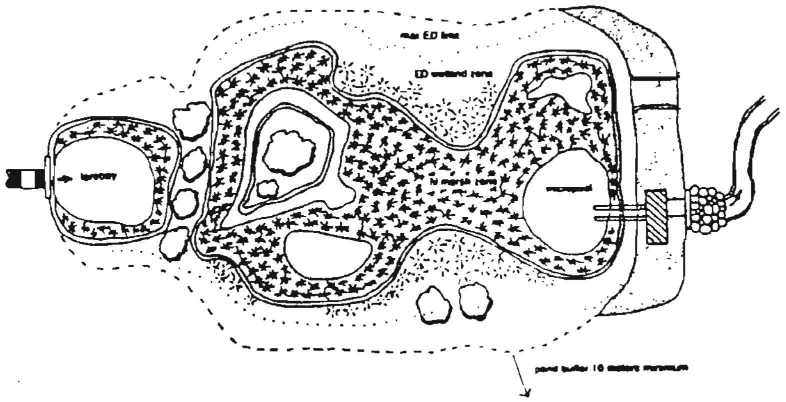


Figure 3.8 Pond/Wetland System

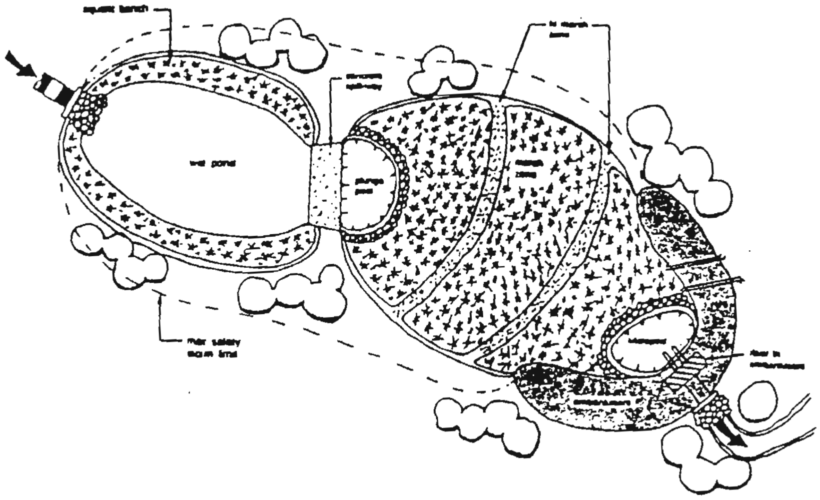


Figure 3.9 "Pocket Wetland"

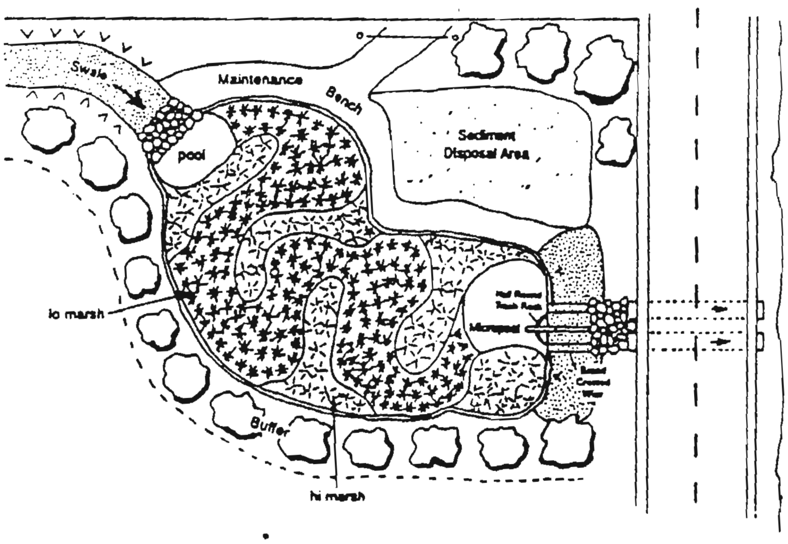


Figure 3.10 Submerged Gravel Wetland

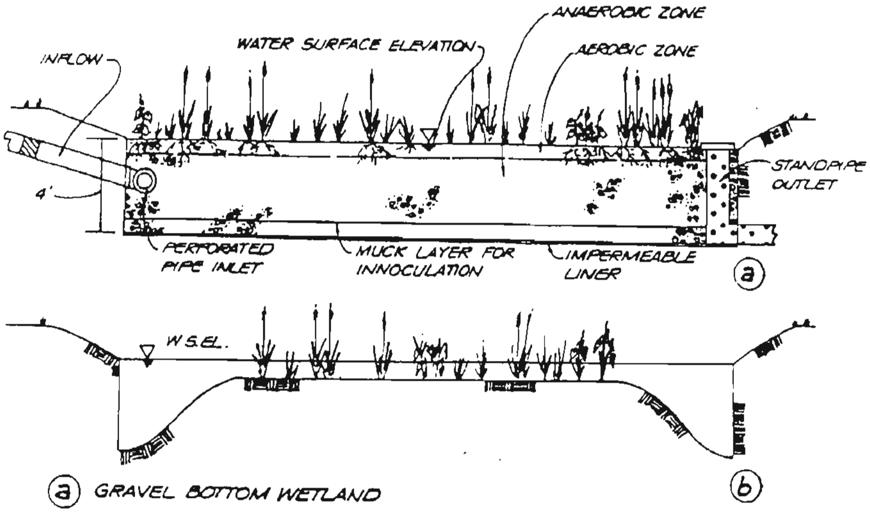


Figure 3.11 Infiltration Trench

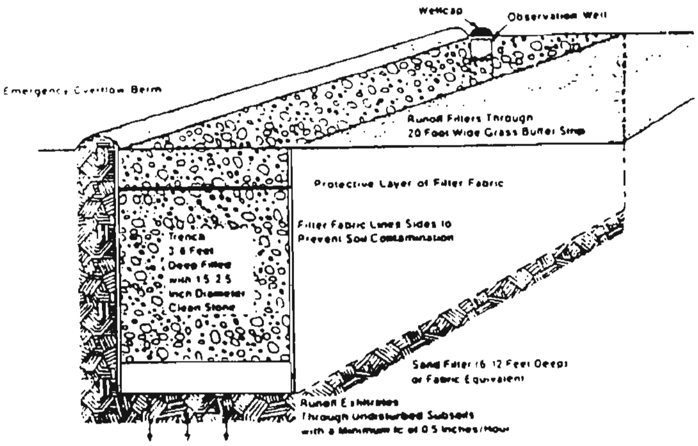


Figure 3.12 Infiltration Basin

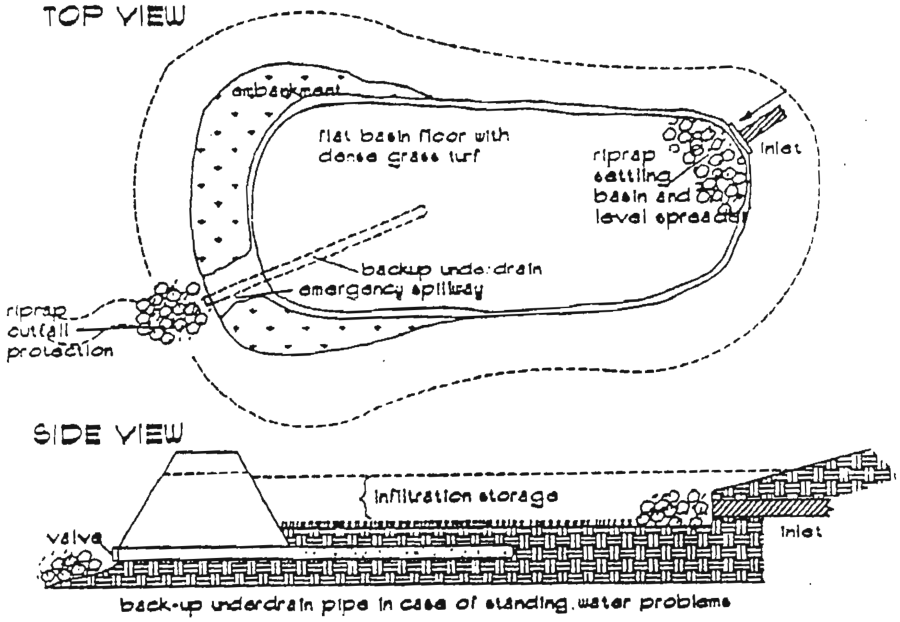
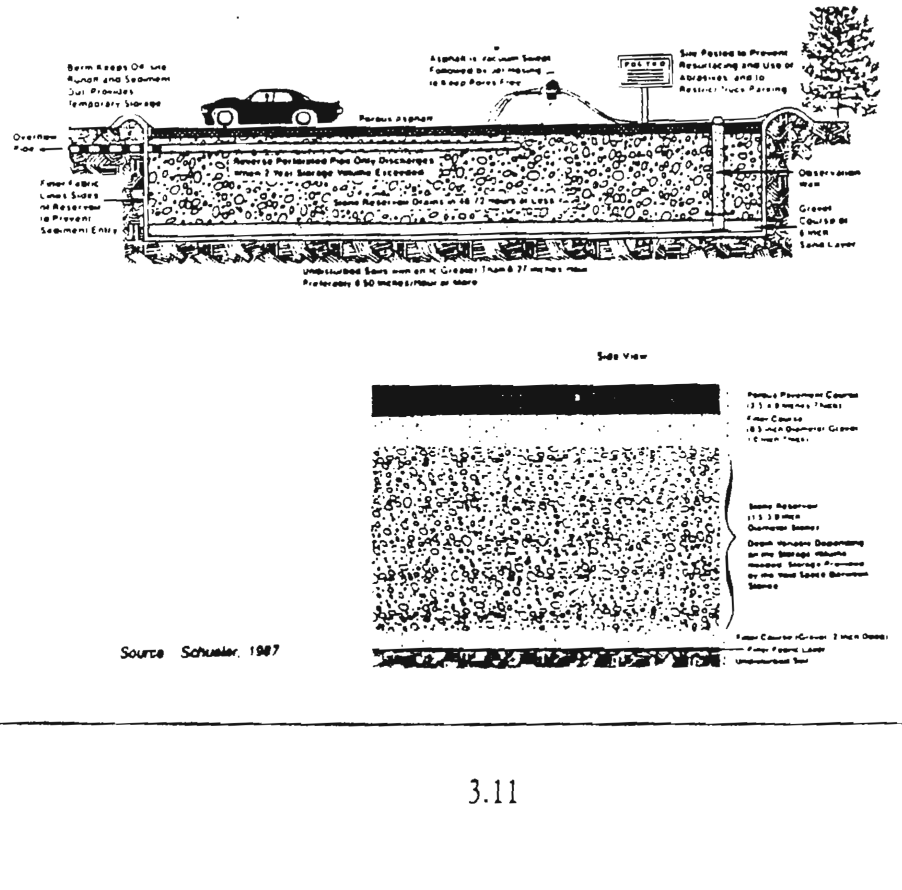


Figure 3.13 Porous Pavement



Source Schueler, 1987

Figure 3.14 Surface Sand Filter

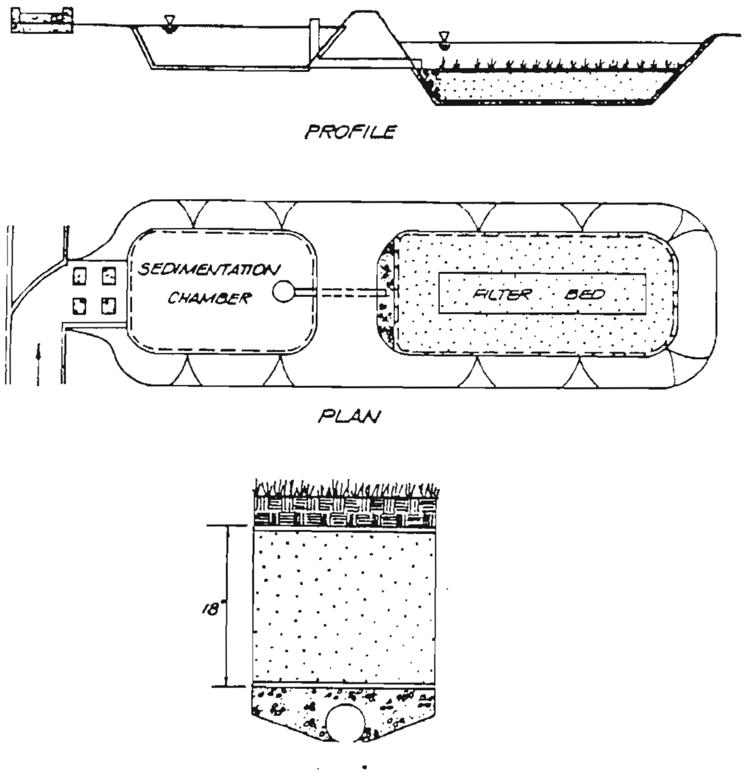


Figure 3.15 Underground Sand Filter

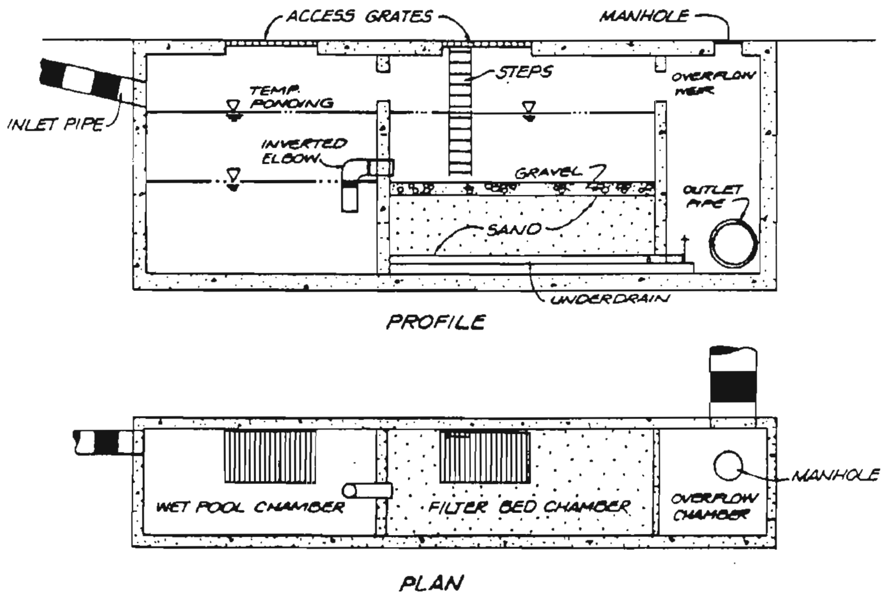
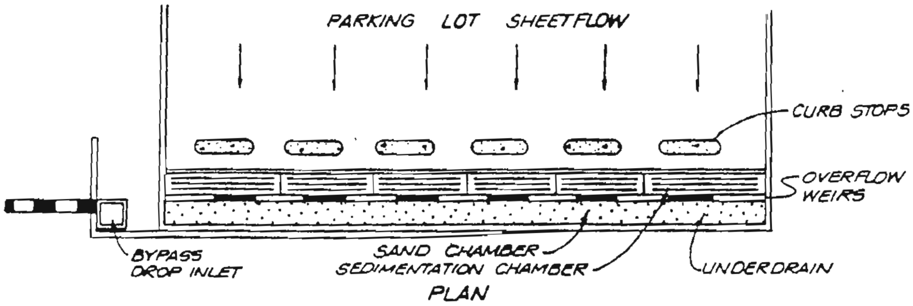


Figure 3.16 Perimeter Sand Filter



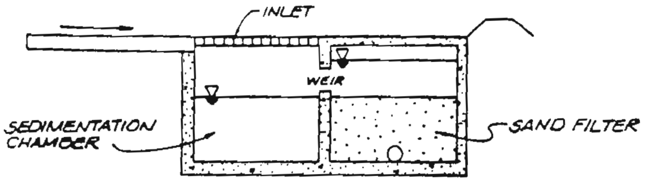
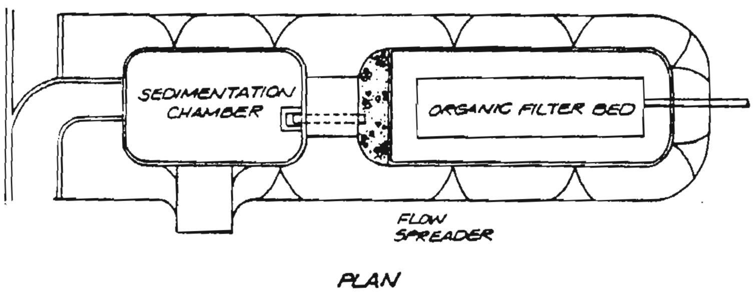


Figure 3.17 Organic Sand Filter



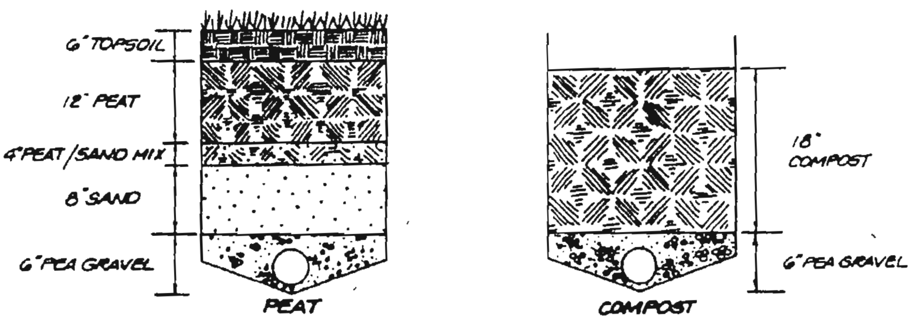


Figure 3.18 Pocket Sand Filter

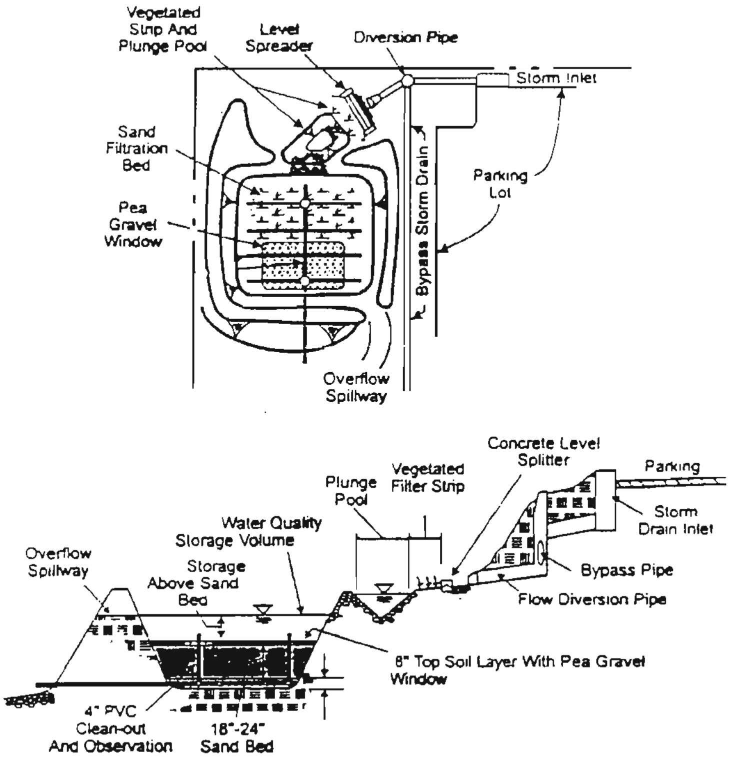


Figure 3.19 Bioretention Area

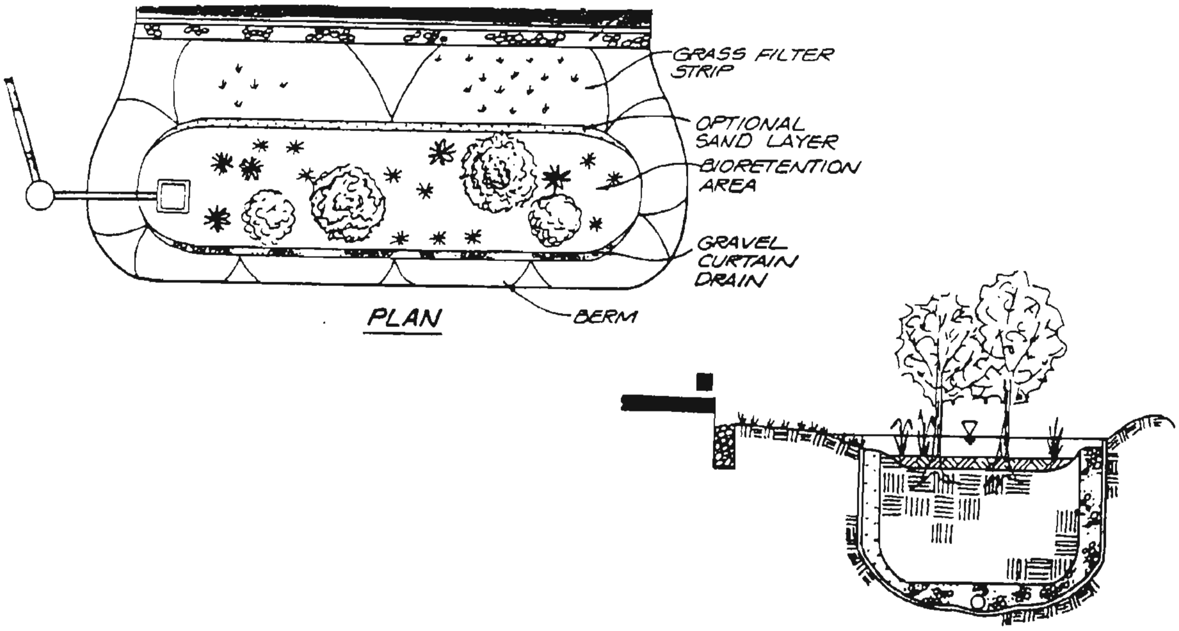


Figure 3.20 Dry Swale

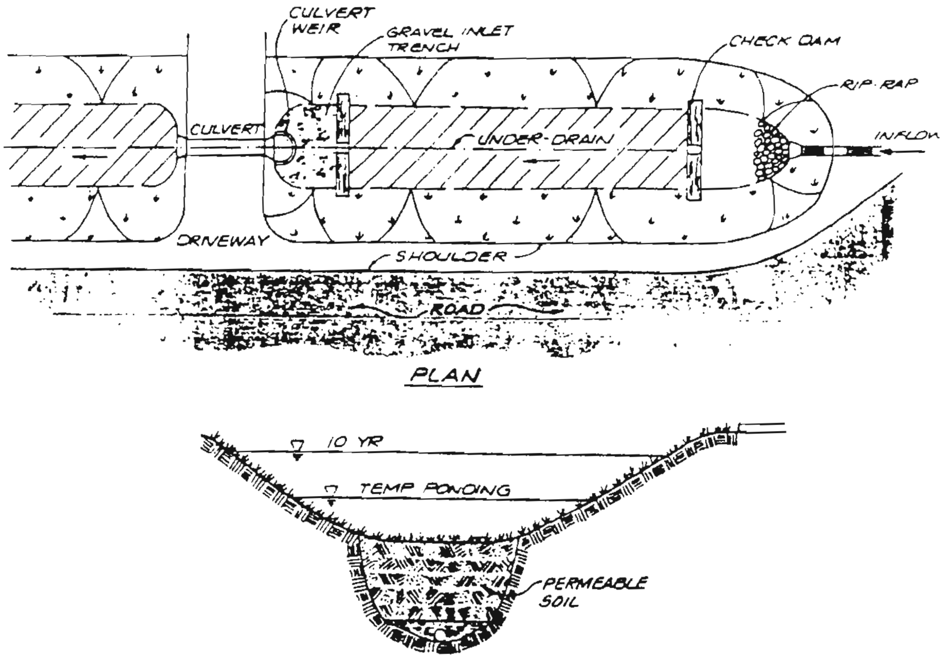


Figure 3.21 Wet Swale

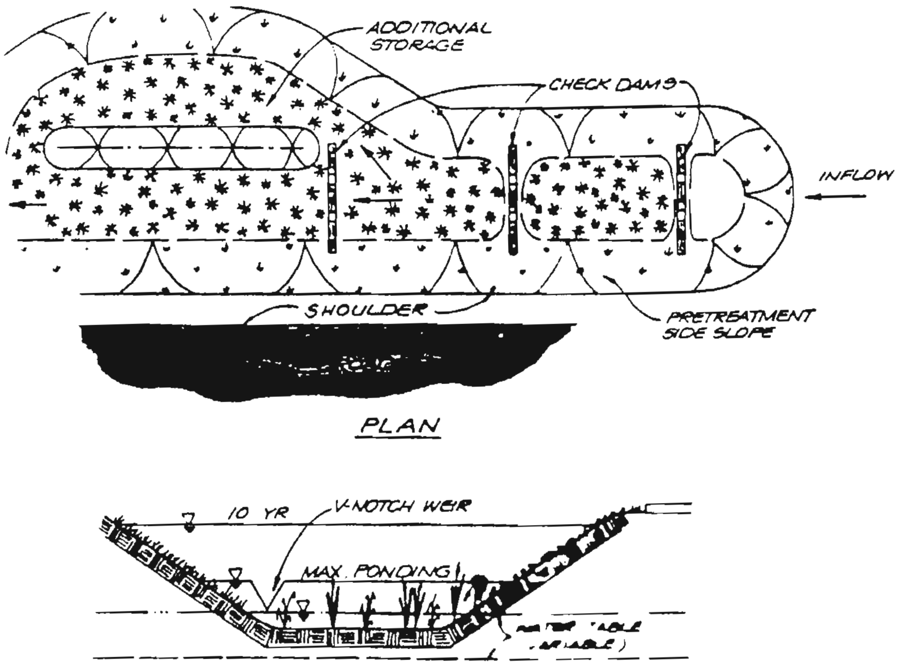
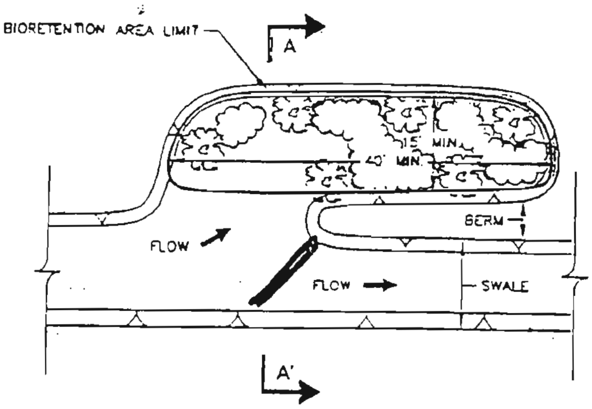


Figure 3.22 Off-line Bioretention Cell



Section 3.3 Non-structural Best Management Practices

Non-structural practices are increasingly recognized as a critical feature of every stormwater BMP plan, particularly with respect to site design. In most cases, non-structural practices must be combined with structural practices to meet stormwater requirements. The key benefit of nonstructural practices, however, is that they can reduce the generation of stormwater from the site; thereby reducing the size and cost of stormwater storage. In addition, they can provide partial removal of many pollutants. The non-structural practices have been classified into seven broad groups. To promote greater use, a series of credits and incentives are provided for designers that use these progressive site planning techniques:

1. Natural Area Conservation
2. Disconnection of Rooftop Runoff
3. Disconnection of Non-Rooftop Runoff
4. Stream Buffers
5. Use of Open Channels

6. Environmentally Sensitive Rural Development
7. Impervious Cover Reduction

Section 6 outlines the precise credits and incentives associated with each group of practices, as well as the conditions that must be met to obtain the credit.

Section 3.4 Pollution Prevention

Definition: Practices that reduce the generation of pollutants from a development site and/or prevent contact of rainfall with the pollutants.

Under the stormwater NPDES program, some industrial sites are required to prepare and implement a stormwater pollution prevention plan. A list of industrial categories that are subject to the pollution prevention requirement can be found in Appendix C-X. In addition, the requirments for preparing and implementing a stormwater pollution prevention plan are described in the general discharge permit provided in Appendix C-X. The stormwater pollution prevention plan requirement applies to both existing and new industrial sites.

In addition, a site may be designated a "stormwater hotspot" as outlined in Section 2.8, which may also require a pollution prevention plan, and may limit the type and location of structural BMPs that are employed at the site. Golf courses and nurseries may need to prepare an Integrated Pest Management Plan.

Section 3.5 Ability of the BMP List to Meet CZARA 80% TSS Removal Requirement

The BMPs used in the State of Maryland must achieve an 80% TSS removal rate according to the recently issued CZARA Coastal Zone 6217 requirements (US EPA, 1993).

Based on the 90% capture sizing criteria and published pollutant removal performance data, it can be presumed that 18 of the 21 BMPs should comply with the 80% TSS removal criterion, *if they are designed in accordance with the BMP performance criteria outlined in Section 5.* Table 3.2 shows the average sediment removal rate that was computed or projected for the 21 BMPs on the list. It should be clearly noted that the averages are from research studies that vary widely in respect to geography, climate, design, treatment volume, sampling intensity, and removal efficiency calculation method. In particular, the averages for some pond and wetland designs reflect facilities that were under-sized or poorly designed, which tends to skew averages lower than they would otherwise be. Consequently, the numbers in Table 3.2 should be *considered only as a conservative indicator of expected pollutant removal performance.*

Table 3.2 TSS REMOVAL PERFORMANCE LIST

GENERAL BMP LIST	N	TSS	80%?
P-1 Micropool ED	7 (a)	47/52*	NO
P-2 Wet Pond	28	70/78*	Yes (b)
P-3 Wet ED Pond	6	76	Yes (b)
P-4 Multiple Pond	see W-3	nd	Yes
P-5 Pocket Pond	0	nd	Yes (pr)
W-1 Shallow Marsh	15	62/81*	Yes (b)
W-2 ED Wetland	5	57/62*	Yes(b)
W-3 Pond/Wetland	9	76/84*	Yes
W-4 Pocket Marsh	1	55	Yes (b)
W-5 Gravel Wetland	3	88	Yes
I-1 Infil. Trench	0	nd	Yes
I-2 Shallow I-Basin	0	nd	Yes
I-3 Porous Pavement	2	89	Yes
F-1 Surface Sand Filter	6	86	Yes
F-2 Underground SF	see F-1	nd	Yes
F-3 Perimeter SF	3	57/79*	Yes (c)
F-4 Organic SF	2	81	Yes
F-5 Pocket Sand Filter	0	nd	Yes
F-6 Bioretention	0	nd	Yes (pr)
O-1 Dry Swale	2	93	Yes
O-2 Wet Swale	5	81	Yes
O-3 Off-line Swale	0	nd	Yes (pr)

Notes: Nd = No data (a) data from dry ED ponds without micropools (b) 80% removal can be achieved under proposed design criteria, current database is biased by under-sized or poorly designed facilities (c) one of three facilities had low sediment removal because incoming sediment levels were very close to irreducible concentration (pr) projected, based on similar facilities

Mean (median) TSS Removal from CWP Urban BMP Pollutant Removal Performance Database (Lundgren, 1996)

As can be seen from Table 3.2, most BMPs on the list are capable of meeting the 80% TSS removal requirement. Seven of the BMPs, however, had mean removal rates ranging from 55% and 75% (these are indicated by shading). As noted earlier, this appears due to the fact that datasets include some under-sized or poorly designed practices that reduce the overall average. This is clearly evident when the median removal is calculated, which is often considered a better measure of central tendency than the mean (see below):

Median Values for Several Practices on the BMP List.

P-1	Micropool ED Pond	52%
P-2	Wet Pond	78%
P-3	Wet Extended Detention Pond	76%
W-1	Shallow Marsh	81%
W-2	ED Marsh	62%
W-3	Pond/Wetland	84%
W-4	Pocket Marsh	N/A
F-3	Perimeter Sand Filter	79%

Based on this analysis, it appears that P-2, P-3, W-1, W-3, and F-3 are capable of meeting the 80% TSS removal criterion. This still leaves three practices that appear to not fully meet the requirement. They are:

P-1 Micropool ED Pond,
W-2 ED Wetland, and
W-4 Pocket Wetland.

Monitoring indicates that these three practices generally can remove TSS in the 50 to 60% range. An analysis of the individual monitoring studies indicate that most demonstration projects suffered from undersizing or poor design. Still, it seems reasonable to require a supplementary practice with each of them to consistently meet the 80% goal. These supplementary practices may include biofilters, filter strips, micropool, or forebays. In particular, it should be noted that the performance data for micropool ED ponds (P-1), was drawn from seven dry ED ponds *without micropools*. The micropools are thought to enhance settling and prevent resuspension, and their inclusion is predicted to improve performance significantly.

In addition, performance monitoring data was not available to assess eight practices, and their sediment removal rate had to be projected based on the performance of similar systems. They are:

P-4	Multiple pond system	(presumed to be similar to W-3),
P-5	Pocket Pond	(presumed to be similar to P-2),
I-1	Infiltration Trench	(published rate based on land application studies (Schueler, 1987),
I-2	Infiltration Basin	(published rate based on land application studies (Schueler, 1987),
F-2	Underground Sand Filter	(presumed to be similar to F-1),
F-5	Pocket Sand Filter	(presumed to be similar to F-1),
F-6	Bioretention	(presumed to be similar to O-1), and
0-3	Off-line Swale	(presumed to be similar to O-1) .

3.5.2 Phosphorus Removal Capability of the BMP List

The Critical Area Law requires that phosphorus loadings from either new development or redevelopment in the Intensely Developed Areas (IDAs) be reduced to 10% below predevelopment levels. The methodology for complying with this requirement is set forth in the Technical Guide for 10% Compliance (Herson et al, 1992). A key component of the method is a table of estimated pollutant removal rates for individual BMP designs that are used to compute the phosphorus load reduction achieved at a site (Table 3, page 22 in Herson et al, 1992).

The Center has compared the phosphorus removal rates for the various BMPs utilized in the Technical Guide with the mean removal rates computed from the new BMP database. For direct comparison, we have used the (1 inch)(impervious area) column in the technical guide. The comparison of removal rates is shown in Table 3.3. In general, we *find that the current removal rates in the Technical Guide are supported by the mean phosphorus removal rates computed from our database.* In most cases, the newly computed mean phosphorus efficiencies are within 5% of the published value in the Technical Guide.

We recommend a few changes to the current 10% Rule Table: (1) increasing removal rate of wet extended detention ponds (P-3) from 55 to 65% and (2) increasing the removal rate for pocket marsh (W-4) from 35% to 40%.

In addition, seven practices on the BMP list are currently not included on current 10% Rule Table. For the sake of consistency, we have suggested phosphorus removal rates for these practices.

Table 3.3 Comparison of Old and New Critical Area Phosphorus Removal Rates

BMP LIST	N	TP*	10%
P-1 Micropool ED	7 (a)	23	30
P-2 Wet Pond	28	50	55
P-3 Wet ED Pond	6	69	55
P-4 Multiple Pond	W 3		65
P-5 Pocket Pond	0	nd	nd
W-1 Shallow Marsh	15	42	40
W-2 ED Wetland	5 (b)	23	40
W-3 Pond/Wetland	9	57	55
W-4 Pocket Marsh	1	65	35
W-5 Gravel Wetland	3	72	NI
I-1 Infil. Trench	0	nd	65
I-2 Shallow I-Basin	0	nd	65
I-3 Porous Pavement	2	65	65
F-1 Surface SF	6	51	40- 50
F-2 Underground SF	see F-1	nd	NI
F-3 Perimeter SF	3	44	40- 50
F-4 Organic SF	2	46	40
F-5 Pocket SF	0	nd	NI
F-6 Bioretention	0	nd	NI
O-1 Dry Swale	2	91	25-30*
O-2 Wet Swale	5	17	25-30
O-3 Off-line Swale	0	nd	NI

Notes: Nd = No data NI = not included on 10% critical area BMP List (a) data from dry ED ponds without micropool (b) includes poorly designed or under-sized facilities.

*Mean total phosphorous removal rates (%) from CWP Pollutant Removal Performance Database (Lundgren, 1996).

Table 3.4 Updated Critical Area Keystone Phosphorus Removal Rates

GENERAL BMP LIST	TP %
P-1 Micropool ED	30
P-2 Wet Pond	55
P-3 Wet ED Pond	65
P-4 Multiple Pond	65
P-5 Pocket Pond	50
W-1 Shallow Marsh	40
W-2 ED Wetland	40
W-3 Pond/Wetland	60
W-4 Pocket Marsh	40
W-5 Gravel Wetland	60
I-1 Infil. Trench	65
I-2 Shallow I-Basin	65
I-3 Porous Pavement	65
F-1 Surface Sand Filter	50
F-2 Underground SF	50
F-3 Perimeter SF	50
F-4 Organic SF	50
F-5 Pocket Sand Filter	40
F-6 Bioretention	50
O-1 Dry Swale	75
O-2 Wet Swale	25
O-3 Off-line Swale	50

3.5.3 Pollutant Removal Performance of BMPs Not on the List

Table 3.4 provides a summary of known or projected TSS and TP performance data for BMPs that were not included in the formal BMP List. These BMPs were not included on the list either due to poor performance, poor longevity, or inability to effectively treat concentrated runoff. As can be seen, most have a mediocre capability to remove sediment or phosphorus.

Table 3.5 TSS and TP Removal Rates for BMPs Not on the List

Practice	TSS *	TP
detention facility-2	0%	0
dry ED pond-7	47%	23
open channels-7	-13%	-23
biofilter-2	72%	37
dry well-pr	65%	nd
catchbasin-1	15%	5
filterstrip-1	69%	7
water quality inlets-1	0%	0

*Mean percent removal as indicated by CWP Pollutant Removal Performance Database (Lundgren, 1996).

Section 4.0 A Guide to BMP Selection and Location in the State of Maryland

Section 4.1 Introduction

This section outlines a process for selecting the best BMP or group of BMPs at a development site, and provides guidance on factors to consider on where to put the BMP on the site. The process is used to screen the 22 designs on the BMP list that could meet the pollutant removal targets for the WQ_v. The process asks the designer to go through a six step screening process, that progressively examines:

- Watershed Factors
- Terrain Factors
- Stormwater Treatment Suitability
- Physical Feasibility Factors
- Community and Environmental Benefits
- Locational Considerations

More detail on the step-wise screening process is provided below:

Step No. 1 Watershed Factors

Is the project located in a watershed that has special watershed design objectives or constraints that must be met? Matrix No.1 outlines BMP restrictions or additional design requirements that must be considered if the project lies within the Maryland Critical Area, Cold-water watersheds, Sensitive Watersheds, Aquifer Protection Areas, Water Supply Reservoirs, and Shellfish/Beach Protection Zones.

Step No. 2 Terrain Factors

Is the project located in a portion of the State that has particular constraints imposed by local terrain and or underlying geology? Matrix No. 2 details BMP restrictions for karst regions (portions of Carrol, Frederick and Washington Counties) and low relief areas of the lower Eastern Shore.

Step No. 3 Stormwater Treatment Suitability

Can the BMP meet all of my stormwater treatment requirements for my site, or will a combination of BMPs be needed? In this step, the designer can screen the BMP list using Matrix No. 3 to determine if a particular BMP can meet the Re_v, C_{pv} and/or Q_p storage requirements, In addition, this third matrix allows the designer to determine if the BMP is capable of treating hotspot runoff, and provides relative indexes for land consumption and safety risk that might preclude a BMP. At the end of this step, the designer can screen the BMP options down to a manageable number, and determine if a single BMP or multiple BMP system is needed to meet the four stormwater sizing criteria for the site.

Step No. 4 Physical Feasibility

Are there any physical constraints at the project site that might restrict or preclude the use of a particular BMP? In this step, the designer screens the BMP list using Matrix No. 4 to determine if the soils, water table, drainage area, slope or head conditions present at a particular development site that might limit the use of a BMP. In many cases, the designer can use the matrix to identify geotechnical or other tests to confirm physical feasibility.

Step No. 5 Community and Environmental Benefits/Drawbacks

Do the remaining BMPs have any important community or environmental benefits or drawbacks that would influence the selection process? In this step, a matrix is used to compare the 22 BMPs on the list in regard to maintenance, habitat, community acceptance, cost and other environmental factors

Step No. 6 Locational Considerations

What environmental features must be avoided or considered when locating the BMP system at my development site, so as to fully comply with State and Federal laws and permits? In this step, the designer follows an environmental features checklist that asks whether any of the following are present at the site: wetlands, waters of the US, stream or shoreline buffers, forest conservation areas, etc. Brief guidance is then provided on "fingerprinting techniques" to locate the BMP so as to avoid impacts to sensitive resources. If the BMP is located within sensitive environmental features, a brief summary of State and federal permitting requirements will be provided.

Summary. The six step approach is intended to compactly present comparative information for the 22 BMPs on the list in a condensed format. Some of the comparative information in the matrices reflects our recent interviews with engineers across the State, and general research into the physiographic differences in the State.

The advantage of the six step approach is that it allows manual readers to use whatever matrices they need for design, and also provides a step-wise approach for the novice designer or plan reviewer. **A more user-friendly and attractive format will be developed for the final manual.**

Section 4.2 Watershed Factors

In some cases, higher pollutant removal or environmental performance is needed to fully protect aquatic resources and human health and safety within a particular watershed. Therefore, a shorter list of BMPs may need to be considered for selection within these watersheds or zones. They include:

Maryland Critical Area Intensively Developed Areas (IDAs). BMPs located within the Intensively Developed Area (IDA) of the Maryland Critical Area (a zone extending 1000 feet landward from mean high tide) must demonstrate compliance with the "10% Rule" The rule mandates that post development stormwater phosphorus loads must be reduced to 10% below pre-development loads, using the methodology developed by Herson et al, 1994. Updated estimates of long term keystone pollutant removal rates can be found in Section 3.5.

Coldwater Streams (Maryland Use III). These cold and cool water streams have habitat qualities capable of supporting trout and other sensitive aquatic organisms. Therefore, the design objective is to maintain habitat quality by preventing stream warming, maintaining natural recharge, preventing bank and channel erosion, and preserving the natural riparian corridor. Some BMPs can have adverse downstream impacts on cold-water streams, and their use is highly restricted.

Sensitive Streams (Maryland Use IV, or Impervious Cover less than 15%). These streams also possess high quality warm-water aquatic resources. The design objectives are to maintain habitat quality through the same techniques used for cold-water streams, with the exception that stream warming is not as severe of a design constraint. Designers may need to provide Cp_v to protect stream channels from erosion. These streams are specially designated by local authorities (e.g., Piney Branch Special Protection Area in Montgomery County), or may be designated if a project triggers the 401 or 404 permit process.

Wellhead Protection. Areas that recharge existing public water supply wells present a unique management challenge. The key design constraint is to prevent possible groundwater contamination by preventing infiltration of hotspot runoff. At the same time, recharge of unpolluted stormwater is encouraged to maintain flow in streams and wells during dry weather.

Reservoir Protection. Watersheds that deliver surface runoff to a public water supply reservoir or impoundment are a special concern. Depending on the treatment available at the water intake, it may be necessary to control several pollutants of concern to a higher level, such as bacteria, nutrients, sediment or metals. One particular management concern is enhanced treatment for pollutant hotspots that pose a greater risk to drinking water safety.

Shellfish/Bacteria. Watersheds that drain to specific shellfish harvesting areas or public swimming beaches require a higher level of BMP treatment to prevent closings due to bacterial contamination from stormwater runoff. In these watersheds, BMPs are explicitly designed to maximize bacteria removal.

BMP SELECTION MATRIX No. 1: SPECIAL WATERSHED DESIGN REQUIREMENTS

BMPs	Critical Area	Cold-water	Sensitive	Ground. Protection	Reservoir Protect	Shellfish Beach
Ponds	Drainage area may limit except for P5. P1 has low removal rate	P2, P3, and P4 restricted, limit ED to 12 hrs offline design shading	Require Control of Cpv, usually 1year 24 ED	May require liner if A soils are present pretreat hotspots 2 to 4 ft SD	Require Cpv Control	Moderate bacteria removal, but design to prevent geese. permanent pool
Wetlands	Drainage area may limit, W-4 excepted	W1, W2 and W3 restricted	Same as above			Provide 48 hr ED for max coliform dieoff
Infiltration	are often infeasible due to soils or water table in tidal area	Useful, if site has right soil	may be difficult to infiltrate the Cpv	SD from wells and water table. No hotspot runoff infiltrate rooftop runoff	SD from bedrock and water table. Pretreat runoff	OK, but a min 4 ft SD is required
Filtering Systems	OK	OK, but evaluate for stream warming	Must be combined another ED basin to provide Cpv	yes, if designed w/ no exfilter	Filtering may be required for pretreat.	mod. to high coliform removal
Open Channels	OK	OK	Must be linked w/ ED basin to provide Cpv	OK, but hotspot runoff must be adequately treated		poor coliform removal for O-2 and O-3

SD = Separation Distance

Each of the 22 BMPs on the list are presumed capable of achieving a long-term removal rate of 80% for total suspended solids, which has been identified as a base criterion for BMP performance under the recently issued CZARA 6217 guidance (see Section 3).

Section 4.3 Terrain Factors

Three key factors to consider are low-relief, karst and mountainous terrain. In the state of Maryland, *Low Relief Areas* can be defined as the Eastern Shore Counties, particularly below Choptank River, while most of the *Karst* and major carbanaceous rock areas are found in portions of Carrol County, Frederick County and Washington County. Mountainous areas are found in the Western part of the State.

BMP SELECTION MATRIX No. 2: TERRAIN FACTORS

BMPs	Low Relief	Karst	Mountainous
Ponds	Maximum ponding depth of 4 feet	Require poly or clay liner max ponding depth geotechnical tests	Maximum pool depth 8 ft
Wetlands	OK	require polyliner geotechnical testing	Maximum pool depth 8 ft Embankment heights restricted
Infiltration	NOT Recommended. Minimum distance to water table of 2 feet	NOT ALLOWED	Max slope 8% trenches must have flat bottom
Filtering Systems	Several designs limited by low head (F1 and F2)	Use poly-liner or impermeable membrane to seal bottom	OK
Open Channels	Not generally feasible due to low slopes	OK	Often infeasible if slopes are 4% or greater

Note: SD = separation distance to seasonally high water table or bedrock

Section 4.4 Stormwater Treatment Suitability

The third matrix examines the capability of each BMP to meet the stormwater treatment sizing criteria outlined in Technical Memo No. 3. Thus, it shows whether a BMP has the:

Ability to Provide Recharge Requirement (Re_v). It should be noted that other practices, not on the BMP list, are capable of meeting the Re_v requirement (e.g. grass channel, filter strip, disconnection of rooftop runoff and other practices outlined in Technical Memo No. 1). Thus, if a BMP on the matrix cannot meet the Re_v requirement, it informs the designer that supplemental recharge practices may be needed in the overall BMP design.

Ability to Provide Channel Protection (Cp_v). The matrix indicates whether the BMP can typically provide the Cp_v that may be needed in some watersheds. The finding that a particular BMP cannot meet the requirement does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one practice may be needed at the site to meet requirements (e.g., a bioretention area and a downstream ED pond).

Ability to Provide Quantity Control (Q_{p2} and/or Q_{p10}) The matrix shows whether a BMP can typically meet the over-bank flooding criteria for the site. Again, the finding that a particular BMP cannot meet the requirement does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one practice may be needed at the site to meet requirements (e.g., a bioretention area and a downstream stormwater detention pond)

Safety Index-- A comparative rating from 1 to 5 that expresses the potential safety risk of a BMP, The lower score indicates a safe BMP, while a higher score indicates that there may be potential safety risks to children associated with deep pools. The safety factor is included at this stage of the screening process since liability and safety are a paramount concern in many residential settings.

Space Consumption Index. A comparative rating from 1 to 5 that expresses how much space a BMP typically consumes at a site. A lower score indicates that the BMP consumes a relatively small amount of land, whereas a high score indicates the BMP may consume a relatively high fraction of land. Again, this factor is included in this early screening stage since many BMPs are severely constrained by land consumption.

Ability to Accept Hotspot Runoff. This last column examines the capability of a BMP to treat runoff from designated hotspots, as defined in Section 2.7. A BMP may be capable of accepting hotspot runoff, or may have some design restrictions as noted.

BMP Selection Matrix No. 3 STORMWATER TREATMENT SUITABILITY

GENERAL BMP LIST	Rev Ability	Cpv Control	Qp2 Control	safety index	space index	accept hotspot runoff
P-1 Micropool ED	no	yes	yes	1.5	1.5	yes *
P-2 Wet Pond	no	yes	yes	4.0	3.0	yes*
P-3 Wet ED Pond	no	yes	yes	4.5	2.0	yes*
P-4 Multiple Pond	no	yes	yes	4.0	3.5	yes*
P-5 Pocket Pond	no	yes	yes	3.0	1.5	yes*
W-1 Shallow Marsh	no	yes	yes	2.0	5.0	yes*
W-2 ED Wetland	no	yes	yes	2.5	3.0	yes*
W-3 Pond/Wetland	no	yes	yes	3.5	4.0	yes*
W-4 Pocket Marsh	no	yes	depends	2.0	2.5	yes*
W-5 Gravel Wetland	no	yes	depends	1.5	3.0	yes
I-1 Infil. Trench	yes	depends	depends	1.0	2.0	NO
I-2 Shallow I-Basin	yes	depends	depends	1.0	3.5	NO
I-3 Porous Pavement	yes	depends	depends	1.0	1.0	NO
F-1 Surface Sand Filter	no, unless exfilter	depends	no	2.0	2.0	yes **
F-2 Underground SF	no	no	no	3.0	1.0	yes
F-3 Perimeter SF	no	no	no	1.0	1.5	yes
F-4 Organic SF	no	no	no	1.5	2.0	yes**
F-5 Pocket Sand Filter	no, unless exfilter	no	no	1.5	2.0	yes**
F-6 Bioretention	yes	depends	no	1.0	3.5	yes**
O-1 Dry Swale	yes	no	no	1.0	3.0	yes**
O-2 Wet Swale	no	no	no	1.5	3.0	NO
O-3 Off-line Swale	yes	no	no	1.5	3.5	yes **

* only if four foot separation distance is maintained from the floor of the pond to the seasonally high water table (2 feet on Lower Eastern Shore)

** only if bottom of facility is lined with impermeable filter fabric that prevents leachate infiltration

Section 4.5 Physical Feasibility

At this point, the designer has whittled down the BMP list to a manageable number and can evaluate the remaining options given the actual physical conditions present on the site. This matrix will ultimately cross-reference the testing protocols needed to confirm physical conditions at the site. The six primary factors are:

Soils. The key evaluation factors are based on an initial investigation of the NRCS hydrologic soils groups at the site, followed by subsequent geotechnical tests to confirm permeability and other factors.

Water Table. Depth to the seasonally high water table from the bottom or floor of the practice

Drainage Area. Indicates the minimum or maximum drainage area that is considered suitable for the practice. If the drainage area present at the site is slightly greater than the maximum allowable drainage area needed for a practice, more than one practice can be installed. The minimum drainage areas indicated for ponds and wetlands should not be considered hard and fast limits, and may be increased or decreased depending on water availability (baseflow or groundwater) or the anti-clogging mechanisms employed.

Slope. This column evaluates the effect of slope on the practice. Specifically, the slope restrictions refer to local slope (how flat the area of practice installation must be) and up-gradient slopes (i.e., how steep can the contributing drainage area or flow length be)

Head. This column provides a typical estimate of the elevation difference needed from the inflow to the outflow to allow for gravity operation within the practice.

Other Factors. This column includes other physical restrictions such as depth to bedrock, proximity to wells and foundations, water balance, etc.

BMP SELECTION MATRIX No. 4: PHYSICAL FEASIBILITY

GENERAL BMP LIST	SOILS	WATER TABLE	DRAIN AREA (acres)	SLOPE	HEAD	Other
P-1 Micropool ED	A soils may require pond liner B soils may require testing	2 feet If hotspot or aquifer	10 min*	no more than 15%	6 to 8 ft	baseflow bedrock
P-2 Wet Pond			25 min*			
P-3 Wet ED Pond						
P-4 Multiple Pond						
P-5 Pocket Pond	NR	below WT	5 max		4 ft	
W-1 Shallow Marsh	A soils may require liner	2 feet if hotspot or aquifer	25 min	no more than 8%	3 to 5 ft	baseflow bedrock
W-2 ED Wetland						
W-3 Pond/Wetland						
W-4 Pocket Marsh	NR	below WT	5 max		2 to 3 ft	
W-5 Gravel Wetland	NR	2 feet			2 to 4 ft	
I-1 Infil. Trench	Fc > 0.52 inch/hr PT if Fc < 2.00 in/hr	4 feet		flat as possible	1 ft	Bedrock
I-2 Shallow I-Basin			10 max		3 ft	
I-3 Porous Pavement			5 max**		1 ft	
F-1 Surface Sand Filter	NR	2 feet	10 max **	no more than 6%	5 ft	
F-2 Underground SF			2 max **		5 to 7ft	
F-3 Perimeter SF			2 max **		2 to 3 ft	
F-4 Organic SF			5 max**		2 to 4 ft	
F-5 Pocket Sand Filter			2 max **		2 to 5 ft	
F-6 Bioretention	Made Soil				5 ft	
O-1 Dry Swale			5 max	usually 1 to 4% max	3 to 5 ft	
O-2 Wet Swale	NR	below WT	5 max		1 ft	
O-3 Bioretention Cell	Made Soil	2 feet	2 max		1 ft	

Notes: NR = not restricted, WT = water table, PT = pretreatment * unless adequate water balance and anti-clogging device installed ** drainage area can be larger in some instances.

Section 4.6 Community and Environmental Factors

The fifth step involves an assessment of community and environmental factors that the BMP can provide. Again an index approach is used, where the given BMP is ranked from 1 to 5, with the lower score indicating that the practice has either a high benefit (or low drawbacks), and a higher score indicating that the particular practice has a low benefit or a major drawback for that factor.

Maintenance. This column assesses the maintenance burden for the practice, in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging) and reported failure rates.

Community acceptance. This column assesses community acceptance, as measured by three factors: market and preference surveys, reported nuisance problems, and visual orientation (i.e., is it prominently located or is it in an out of the way or underground location). It should be noted that a low rank may merely indicate the need for a better landscaping plan.

Construction Cost. The BMPs are ranked according to their relative construction cost per impervious acre treated. Please note that these rankings are preliminary, and await completion of the Center's ongoing BMP Cost Study.

Habitat. The BMPs are evaluated on their ability to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include: size, water features, wetland features and vegetation coverage in BMP and buffer.

Other Factors. This column indicates other factors that should be considered in BMP selection.

BMP SELECTION MATRIX No. 5: COMMUNITY AND ENVIRONMENTAL FACTORS

GENERAL BMP LIST	Main. Burden	Comm. Accept	Const. Cost	Habitat	Other Factors
P-1 Micropool ED	3.5	4.0	1.0	3.5	trash/debris
P-2 Wet Pond	1.5	1.5	2.0	2.5	High pond premium
P-3 Wet ED Pond	2.0	2.0	2.0	3.0	
P-4 Multiple Pond	2.0	1.5	3.0	1.5	
P-5 Pocket Pond	4.0	3.0	1.5	4.0	drawdowns
W-1 Shallow Marsh	3.5	2.0	3.5	1.5	
W-2 ED Wetland	3.0	2.5	2.5	2.0	Limit ED depth
W-3 Pond/Wetland	2.0	1.5	3.0	1.0	
W-4 Pocket Marsh	4.0	3.0	2.0	3.5	drawdowns
W-5 Gravel Wetland	4.0	4.0	3.0	4.5	Possible odors
I-1 Infil. Trench	5.0	2.0	3.5	5.0	Avoid large stone
I-2 Shallow I-Basin	5.0	4.0	3.0	4.5	Frequent pooling
I-3 Porous Pavement	5.0	1.0	3.0	5.0	
F-1 Surface SF	3.5	2.5	4.0	5.0	Minimize concrete
F-2 Underground SF	4.0	1.0	4.5	5.0	Out of sight
F-3 Perimeter SF	3.5	1.0	4.0	5.0	Traffic bearing
F-4 Organic SF	3.5	2.5	4.0	5.0	Change compost
F-5 Pocket Sand Filter	4.0	2.5	3.0	5.0	
F-6 Bioretention	2.0	1.5	2.5	4.0	Landscaping
O-1 Dry Swale	2.0	1.5	2.5	4.5	
O-2 Wet Swale	2.0	1.5	1.5	4.0	Possible mosquitos
O-3 Bioretention Cell	2.0	1.5	1.5	4.0	

Section 4.7 Locational Considerations

In the last step, the designer follows a checklist to determine where the selected BMP or BMPs can be located at the site, given the environmental features that are present. The checklist also indicates what, if any, permits must be secured to construct the BMP. The checklist will be modeled after the MDE Stormwater Management Assessment and Flow Chart Documents, already developed by Comstock (1995). Some of the locational factors would include:

Wetlands. Including the limited conditions under which a degraded wetland can be modified to accept stormwater (e.g., retrofits), and forested wetlands, and requirements for State and Federal CWA Sec. 401 and 404 permits.

Streams: Outline the general restrictions for placing ponds and wetlands within waters of the US, and outlining the permit process to follow if they are located in the uppermost 300 feet of a perennial stream. Guidance on dealing with intermittent channels, agricultural drainage, ditches and other situations. Additional guidance on location of detention or Cp_v facilities in and near streams.

Stream and Shoreline Buffers. Restrictions or conditions for locating BMPs within the Critical Area Buffer Zone and local stream buffer zones will be highlighted.

Forest Conservation Area. Discussion of BMP location within the context of the Forest Conservation Act, including prohibition from locating BMPs in Priority 1 Forest Retention Areas, or within 100 feet of specimen trees. Opportunities for reforestation in stormwater buffer areas will be noted.

Steep Slopes: Construction of BMPs are generally restricted on slopes greater than 15%.

Floodplains. BMP restrictions if located within the 100 year floodplain may require approval under the MDE Waterway Construction Regulations (COMAR 26.17.05).

Existing and Proposed Utilities. Restrictions and setbacks from sewer lines, roads, cables and other utilities at the site.

Residential Setbacks. Required setback distances from residential structures.

NOTE: THE CENTER WILL DRAFT THIS SECTION IN THE SUMMER OF 1997 FOR STATE AND LOCAL REVIEW.

Section 5.0 Minimum Design Criteria for Urban BMPs

5.1 Introduction

This section outlines performance criteria for urban best management practices for inclusion into the design manual. Specific performance standards are presented for the five groups of practices, as outlined in Section 3. These include pond systems, wetland systems, infiltration systems, filtering systems and open channel systems.

Each set of BMP performance standards, in turn, is organized by six general criteria:

General Feasibility (including reference to specific testing methods)
Conveyance
Pretreatment
Treatment/Geometry
Environmental/Landscaping
Maintenance

Several caveats apply to all performance criteria. First, these draft criteria represent our thinking as to the ideal criteria for effective and long-lived BMPs, and may, in some cases, be a significant change from current practice. We have marked these with a pound sign (#). Second, we have tried to distinguish performance criteria (which must be met at all sites) from recommended design guidance (which are not required or applicable to all sites or conditions). Thus, in the text, performance criteria are indicated in *italics*, whereas recommended design guidance are shown in normal typeface.

Section 5.2 Stormwater Ponds

5.2.1 Feasibility Criteria

Stormwater ponds must have a minimum contributing drainage area of ten acres or more (25 or more are preferred), unless groundwater is confirmed as the primary water source (i.e., pocket pond).

To avoid stream impacts, on-line ponds cannot be located more than 300 feet downstream of the origin of a first order stream (#).

Stormwater ponds cannot be located within a jurisdictional waters, including wetlands, without obtaining a Section 404 permit under the Clean Water Act, and a State of Maryland wetlands and waterway permit.

The use of stormwater ponds on coldwater streams capable of supporting trout (Use III and IV) is highly restricted.

5.2.2 Conveyance Criteria

The principal spillway, emergency spillway, and embankment shall be designed in accordance with MD SCS Pond Specifications Code 378, as amended (1995 or current edition). A copy is provided in Appendix A-1.

The use of reinforced concrete is recommended for the principal spillway to increase its longevity. Reinforced concrete pipe with "O-ring" gaskets (ASTM C361) should be used to creater watertight joints.

The principal spillway should be equipped with a removable trash rack.

In addition, small ponds and embankments that are not subject to the 378 pond specifications must meet minimum criteria, as outlined below:

Criteria for sub-378 Code ponds:

1. Assume stable outfall for 10 yr. storm.
2. Hazard class "A" justification.
3. Principal spillway/riser should meet freeboard, anti-floatation, anti-vortex/trashrack, anti-seep collar restriction.
4. Material and construction specification for embankment and pipe/riser should be used from 378 Code with the exception of cut-off trnech, which is unlikely to be present.

Sound engineering does not authroize inferior materials or construction practices. The sound engineering requires appropriate material specifications that meet MD 378 (i.e., watertight pipe). The design engineer needs to make proper decisions based on the site (i.e., need for a cut-off trench, etc.). The exemption is not a variance from common sense or the opportunity to use inappropriate pipeor other materials. When in doubt, use 378.

Inlet Protection

Inlet pipes to the pond can be partially submerged.

A forebay must be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow rate to the pond.(#)

Adequate Outfall Protection

Flared end pipe sections that discharge at or near the stream invert are preferred, unless the floodplain is environmentally sensitive. In this case, a step-pool arrangement should be used to bring discharge to the stream.

The channel immediately below the pond outfall shall be modified to prevent erosion and conform to natural dimensions in the shortest possible distance, typically by use of large rip-rap placed over filter cloth.

A stilling basin shall be used to reduce flow velocities from the principal spillway to non-erosive velocities (5 fps for the one year or two year storm, depending on whether Cp_v or Q_{p2} is provided).

If the pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided to reduce stream warming.

If the pond has a dry pilot channel, a low flow underdrain pipe shall be located 2 to 3 feet below the rip rap to prevent excessive warming of dry weather flows. The pilot channel shall also be protected by shade trees (#).

Pond Liners

Liners are not normally needed for most stormwater ponds, unless the pond is located above karst topography, fractured bedrock or gravelly sands. If geo-technical tests confirm the need for a liner, acceptable options include (a) 6 to 12 inches of clay soil (minimum 15% passing the #200 sieve and a minimum permeability of 1×10^{-5} cm/sec), (b) a 30 ml poly-liner (c) bentonite, or (d) use of chemical additives (see SCS Agricultural Handbook No. 387, dated 1971, or Engineering Field Manual).

5.2.3 Pretreatment Criteria

Sediment Forebay. *Each pond shall have a sediment forebay.* The forebay shall consist of a separate cell, formed by an earthen berm, gabion or rip-rap wall.

The forebay shall be sized to generally contain 0.25 inches of runoff per impervious acre of contributing drainage (with a minimum of 0.1 inches per impervious acre), and shall be 4 to 6 feet deep. Exit velocities from the forebay shall not be erosive during the two year design storm (5 fps) (#).

Direct maintenance access by appropriate equipment shall be provided to the forebay.

The bottom of the forebay may be hardened to make sediment removal easier (#).

A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment deposition over time.

5.2.4 Treatment Criteria

Minimum Water Quality Volume (WQ_v)

Provide water quality treatment storage to capture the computed WQv from the contributing site through any combination of permanent pool, extended detention or marsh (except 100% ED) (#).

It is generally desirable to provide water quality treatment off-line when topography, head and space permit (i.e, apart from stormwater quantity storage).

Water quality storage can be provided in multiple cells. Performance is enhanced when multiple or redundant treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and marsh).

Minimum Pond Geometry

Ponds should be wedge-shaped, narrowest at the inlet and widest at the outlet. The minimum length to width ratio for the pond is 1.5 (i.e., length relative to width). Greater flowpaths and irregular shapes are recommended.

Maximum depth of the permanent pool should not exceed eight feet, with an average of 4 to 6 feet.

5.2.5 Environmental/Landscaping Criteria

Pond Benches

The perimeter of all deep pool areas (four feet or greater in depth) shall be surrounded by two benches:

- *A safety bench* that extends 15 feet outward from the normal water edge to the toe of the pond side slope. The maximum slope of the safety bench shall be 6%.
- *An aquatic bench* that extends up to 15 feet inward from the normal shoreline and has a maximum depth of eighteen inches below the normal pool water surface elevation.

Landscaping Plan

A landscaping plan for the stormwater pond and its buffer shall be prepared that indicates how aquatic and terrestrial areas will be vegetatively stabilized and established (#).

Wherever possible, wetland plants should be encouraged in the pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes (ED wetlands) or within shallow areas of the pool itself.

The best elevations for establishment of wetland plants, either through transplantation or volunteer colonization, are within six inches (plus or minus) of the normal pool.

Pond Buffers and Setbacks

A pond buffer shall be provided that extends 25 feet outward from the maximum water surface elevation of the pond. The pond buffer should be contiguous with other buffer areas, as are required by local regulation (e.g., stream buffers). An additional 15 foot setback shall be provided to permanent structures (#).

Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To prevent excessive geese populations, trees, shrubs and native ground covers should be planted in the non-forested areas of the buffer.

Trees may not be planted or allowed to grow on or within 15 feet of the embankment.

The only mowing required within the buffer is along maintenance rights of way and the embankment (at least once a year). The remaining buffer can be managed as a meadow (mowing twice a year) or forest.

5.2.6 Maintenance Criteria

Maintenance Measures.

Maintenance responsibility for the pond and the pondscape shall be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed prior to plan approval.

Sediment removal in the forebay should occur every 5 to 7 years, or after 50% of total forebay capacity has been lost (#).

Sediments excavated from stormwater ponds that do not have hotspot land uses in their contributing drainage area are not considered toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing shall be required if a hotspot land use is present (#).

An on-site disposal area shall be reserved for future sediment disposal.

Maintenance Access.

A minimum 12 foot wide maintenance right of way easement shall extend to the pond from a public or private road (#).

Maintenance access shall have a maximum slope of no more than 15% and shall be appropriately stabilized to withstand maintenance equipment and vehicles.

The maintenance access shall extend to the forebay, safety bench and riser, and be designed to allow vehicles to turnaround.

Non-clogging Low Flow Orifice.

The preferred method is a submerged reverse-slope pipe that extends downward from the riser to a release point one foot below the normal pool elevation (#).

The low flow orifice shall have a minimum internal diameter of 3 inches, unless it is adequately protected from clogging by an effective trash rack.

Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 18 inches below the normal pool.

The use of horizontal perforated pipes protected by geotextile and gravel are not recommended as means to provide extended detention due to chronic clogging problems. Vertical pipes may be used as an alternative if at least one foot of standing water is present (#).

Riser in Embankment.

The riser shall be located within the embankment for purposes of maintenance access, safety and aesthetics.

Access within the riser is to be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls. The principal spillway opening can be "fenced" with pipe or rebar at 8 inch intervals for safety purposes.

Adjustable Gate Valve.

Both the ED pipe and the pond drain shall be equipped with an adjustable gate valve (typically a handwheel activated knife gate valve).

Both the ED pipe and the pond drain shall be sized one pipe size greater than the calculated design diameter (#).

Valves shall be located inside of the riser at a point where they (a) will remain dry and (b) can be operated in a safe and convenient manner.

To prevent vandalism, the handwheel shall be chained to a ringbolt, manhole step or other fixed object.

Pond Drain.

Each pond shall have a ductile iron drain pipe that can completely or partially drain the pond. The drain pipe shall have an inverted elbow within the pond to prevent sediment deposition, and a diameter capable of draining the pond within 24 hours. This requirement is waived for the Lower Eastern Shore, where positive drainage is difficult to achieve due to very low relief.

Care shall be exercised during pond drawdowns to prevent downstream discharge of sediments or anoxic water and potential rapid drawdown failure. The approving jurisdiction shall be notified before draining a pond.

Safety Features.

Fencing of ponds is not generally desirable. Safety is provided by managing the contours of the pond to eliminate dropoffs and other hazards.

Side slopes to the pond shall not exceed 3:1 (h:v), and shall terminate on a safety bench. Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool. The bench requirement may be waived if slopes are 4:1 or gentler.

The principal spillway opening shall not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced.

Warning signs prohibiting swimming and skating may be posted. A sample sign is provided in Figure X.

Section 5.3 Stormwater Wetlands

The performance criteria for stormwater ponds outlined in Section 5.2 also apply to stormwater wetlands. In addition, the following additional criteria also apply to stormwater wetlands:

5.3.1 Feasibility Criteria

A water balance must be performed to demonstrate that the stormwater wetland can withstand a thirty day drought at summer evaporation rates without completely drawing down (#). See Appendix C-6 for shortcut assessment method.

Stormwater wetlands may not be located within existing jurisdictional wetlands without a 404/401, and State Non-tidal Wetlands permit. In some isolated cases, a wetlands permit may be granted for the conversion of a existing degraded wetland in the context of local watershed restoration efforts.

5.3.2 Conveyance Criteria

A minimum dry weather flow path of 2:1 shall be provided across the stormwater wetland, which can be achieved by constructing internal berms (e.g., hi marsh wedges or rock filter cells) (#). Microtopography are encouraged to enhance wetland diversity.

5.3.3 Pretreatment Criteria

Sediment regulation is critical to sustain stormwater wetlands. Consequently, *a forebay must be located at the inlet, and a micropool must be located at the outlet.* A micropool is a four to six foot deep pool used to protect the low flow pipe from clogging and prevent sediment resuspension.

5.3.4 Treatment Criteria

The surface area of the entire stormwater wetland must be at least one percent of the contributing drainage area (1.5% for the shallow marsh design).

At least 25% of the total WQ_v must be in deepwater zones with a depth greater than four feet (the inclusion of a forebay and micropool will usually meet this criteria) (#).

A minimum of 30% of the total surface area shall have a depth of six inches or less, and at least 60% of the total surface area must be shallower than 18 inches (#).

The bed of the wetland shall be graded to create maximum internal geometry and microtopography.

If extended detention is provided in a stormwater wetland, *the ED volume may not comprise more than 50% of the total WQv, and its maximum water surface elevation may not extend more than three feet above the normal pool (#).*

To promote greater nitrogen removal, rock beds may be used as a medium for the growth of wetland plants. The rock should be one to three inches in diameter, located at or near the normal pool elevation, and open to flow through from either direction (#).

5.3.5 Environmental/Landscaping Criteria

A landscaping plan must be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of the plan include: delineation of pondscaping zones, selection of corresponding plant species, planting plan, including the sequence for preparing wetland bed (including soil amendments, if needed), and sources and species of plant material.

Structures such as fascines, coconut rolls, straw bales, or filter fence may be needed to maintain high marsh sediment levels in high energy areas of the stormwater wetland.

The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers, but discourages utilization by resident geese.

The wetland buffer shall extend at least 25 feet outward from the maximum water surface elevation, with an additional 15 foot setback to structures (#).

5.3.6 Maintenance Criteria

A reinforcement planting will be required after second growing season if a minimum coverage of 50% is not achieved in the planted wetland zones.

Section 5.4 Stormwater Infiltration

5.4.1 Feasibility Criteria

To be suitable for infiltration, underlying soils shall have and infiltration rate (fc) of 0.52 inches or greater, as initially determined from SCS soil textural classification, and subsequently confirmed by field geo-technical tests (as outlined in Appendix C-2).

Soils shall also have a clay content of less than 30%, and a silt/clay content of less than 40%.

Infiltration cannot be located on slopes greater than 6% or fill soils.

To protect groundwater from possible contamination, runoff from designated hotspot land uses or activities shall not be infiltrated (#).

The bottom of the infiltration facility must be separated by at least four feet vertically from the seasonally high water table or bedrock layer, as documented by on-site soil testing. This distance is reduced to 2 feet on the Lower Eastern Shore.

Infiltration facilities must be located 100 feet horizontally from any water supply well.

The maximum contributing area to an individual infiltration practice shall be no greater than 5 acres (#).

Infiltration practices shall not be placed in a location that could cause water problems to downgrade properties.

The minimum geotechnical testing is one test hole per 5000 sf, with a minimum of two borings per facility (taken within the proposed limits of the facility).

5.4.2 Conveyance Criteria

The overland flow path of surface runoff exceeding the capacity of the infiltration system shall be evaluated to preclude erosive concentrated flow during the two and ten year event. If flow velocities are computed to exceed 3 fps, a non-erosive overflow channel shall be provided to a stabilized water course. (#)

All infiltration systems should be designed to fully de-water the entire WQv within 48 hours after the storm event (#).

If runoff is delivered to an infiltration practice in a storm drain pipe or along the main conveyance system, it must be designed as an off-line practice. Pretreatment shall be provided for storm drain pipes systems discharging directly to infiltration system.

The truncated hydrograph method shall be used if infiltration is used to control Cp_v or Q_p (MDE, 1988).

5.4.3 Pretreatment Criteria

Pretreatment Volume

A minimum pretreatment volume of 0.25 inches of runoff per impervious acre of contributing drainage (with a minimum of 0.1 inches per impervious acre) prior to the discharge to a infiltration facility is mandatory, and can be provided in the form of a sedimentation basin, sump pit, grass swale w/checkdams, plunge pool or other measure to contain sediments. *Exit velocities from the pretreatment chamber shall not be erosive (5 fps) during the two year design storm (#).*

Techniques to Prevent Premature Clogging

Each infiltration system shall have redundant methods to protect the long term integrity of the infiltration rate. Three or more of the following techniques must be installed in every facility: (#)

- grass channel
- grass filter strip (minimum 20 feet and only if sheet flow if predicted)
- bottom sand layer
- upper filter fabric layer
- use of washed bank run gravel as aggregate
- leaf screens (dry wells)

The sides of infiltration practices shall be lined with an acceptable filter fabric that prevents soil piping but has greater permeability than the parent soil (Appendix C-X).

5.4.4 Treatment Criteria

Infiltration practices are best used in conjunction with other BMP systems, and often require downstream detention.

Infiltration practices shall be designed to exfiltrate the entire WQ_v through the floor of each practice, using the design methods outlined in Appendix B-X (taken from most recent edition of Maryland Standards and Specifications for Stormwater Management Infiltration Practices).

Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction. The construction sequence and specifications for each infiltration practice must be precisely followed, as outlined in Appendix A-X.

A void ratio (Vv/Vt) of 0.32 shall be used to design porosity of stone reservoirs for infiltration practices.

5.4.5 Environmental/Landscaping Criteria

A dense and vigorous vegetative cover must be established over the contributing pervious drainage areas before runoff can be accepted into the facility.

5.4.6 Maintenance Criteria

Infiltration practices should never serve as an sediment control during the construction phase, and the ESC plan for the site must clearly indicate the method used to prevent sediment entry to the infiltration site. Normally, this is done by using diversion berms around the perimeter of the infiltration practice, along with immediate vegetative stabilization and/or mulching.

An observation well shall be installed in every infiltration system, consisting of a well-anchored six inch diameter perforated PVC pipe with a lockable cap installed flush with the ground surface.

Direct access must be provided to all infiltration practices for maintenance and rehabilitation. If a stone reservoir or perforated pipe is used to temporarily store runoff prior to infiltration, it must not be covered by an impermeable surface (except for porous pavement).

OSHA trench safety standards may be triggered if an infiltration trench is excavated more than five feet vertically.

Section 5.5 Stormwater Filtering Systems

Stormwater filtering systems include a wide range of design variations. Consult Claytor and Schueler (1996) for construction specifications for individual designs.

5.5.1 Feasibility Criteria

Stormwater filters require a minimum head ranging from 2 to 6 feet (the perimeter (Delaware) sand filter can be designed to function with a head a low as 12 inches).

The maximum contributing area to an individual stormwater filtering system is typically greater than 10 acres (#).

Sand and organic filtering systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with imperviousness less than 65% will require full sedimentation pretreatment techniques.

5.5.2 Conveyance Criteria

If runoff is delivered to filtering practices in a storm drain pipe or along the main conveyance system, it must be designed as an off-line practice.

An overflow must be provided within the practice to pass a percentage of the WQ_V to a stabilized water course.

A flow regulator (or flow splitter diversion structure) must be supplied to divert the WQ_V to the filtering practice.

Stormwater filters must be equipped with a minimum 4" perforated pipe underdrain (6" is preferred) in a gravel layer. A permeable filter fabric (Appendix C-X) must be placed between the gravel layer and the filter media.

5.5.3 Pretreatment Criteria

Dry or wet pretreatment must be provided prior to filter media equivalent to at least 25% of the computed WQv. The typical method is a sedimentation basin that has a length to width ratio of 2:1. The Camp-Hazen equation is used to compute the required surface area for sand and organic filters requiring full sedimentation.

For bioretention systems, a grass filter strip below a level spreader, gravel diaphragm and mulch layer can be substituted for the pretreatment volume.

5.5.4 Treatment Criteria

The entire treatment system (including pretreatment) must temporarily hold at least 75% of the WQv.

The filter bed typically has a minimum depth of 18" (the perimeter (Delaware) filter may have a minimum filter bed depth of 12").

The filter media shall consist of a medium sand (meeting ASTM C-33 concrete sand). Organic media may also be utilized consisting of a peat/sand mix or a leaf compost. Peat should be a reed-sedge hemic peat (#).

The filter area shall be sized based on the principles of Darcy's Law. A coefficient of permeability (k) shall be used as follows:

	Sand:	3.5 ft/day (City of Austin 1988)
	Peat:	2.0 ft/day (Galli 1990)
	Leaf compost:	8.0 ft/day (Claytor and Schueler, 1996)

Bioretention systems shall consist of the following treatment components: A four foot deep planting soil bed, a surface mulch layer, and a 6" deep surface ponding area. The surface area is sized based on the principles of Darcy's Law and a coefficient of permeability of 0.5 ft/day.

5.5.5 Environmental/Landscaping Criteria

A dense and vigorous vegetative cover must be established over the contributing pervious drainage areas before runoff can be accepted into the facility.

Surface filters (e.g., surface sand and organic) shall have a grass cover to aid in the pollutant adsorption. The grass cover must be permeable and capable of withstanding frequent periods of inundation and drought (see Appendix D for grass species selection guide).

Bioretention facilities shall follow specific planting recommendations as follows: Native plant species should be specified over non-native species, vegetation should be selected based on a specified zone of hydric tolerance, a selection of trees with an understory of shrubs and herbaceous materials should be specified, woody vegetation should not be specified at inflow locations, trees should be specified primarily along the perimeter of the facility (see Appendix D for bioretention species selection guidance).

5.5.6 Maintenance Criteria

Sediment shall be cleaned out of the sedimentation chamber when the depth exceeds 12 inches. Vegetation within the sedimentation chamber shall be limited to a height of 18 inches. The sediment chamber outlet devices shall be cleaned/repaired when drawdown times exceed 36 hours. Trash and debris shall be removed as necessary.

Silt/sediment shall be removed from the filter bed when the depth exceeds one inch. When the capacity of the filter begins to substantially diminish (i.e., when water ponds on the surface of the filter bed for more than 48 hours), manual removal of the top few inches of discolored material shall be preformed.

Organic filters or surface sand filters with a grass cover shall be mowed a minimum of 3 times per growing season to maintain heights less than 18 inches.

A stone drop of at least six inches shall be provided at the inlet of bioretention facilities (pea gravel diaphragm). Areas devoid of mulch should be re-mulched on an annual basis. Dead or severely diseased species shall be replaced.

If the depth to filter bed is greater than two feet, a ramp shall be provided for direct maintenance access.

Construction specifications for sand filters and bioretention area are specified in Appendix A-X

Section 5.6 Open Channel Systems

5.6.1 Feasibility Criteria

Open channel systems must have longitudinal slopes less than 4.0% to qualify for water quality treatment credit. Filter strips may have slopes as steep as 6.0% (#).

Open channel systems, designed for water quality treatment, are primarily applicable for land uses with lower imperviousness (e.g., roads and highways, residential, and pervious surfaces). Filter strips may be suitable for small parking lots provided the overland flowpath is limited to 75 feet for impervious contributing areas and 150 feet for pervious contributing areas (#).

5.6.2 Conveyance Criteria

The peak velocity for the 2 year storm must be non-erosive (generally less than 3.5 to 5.0 fps) for the soils, and vegetative cover provided.

Open channels must be designed to safely convey the ten year storm with a minimum of 6 inches of freeboard.

Channels shall be designed with moderate side slopes (flatter than 3:1) for most conditions. In no event, can the side slope be as steep as 2:1.

The maximum allowable temporary ponding time within a channel shall be less than 48 hours (except for the wet swale, which shall not be used in residential land use applications).

Open channel systems which directly receive runoff from impervious surfaces must have a 6 inch drop onto a protected shelf (pea gravel diaphragm) to minimize the clogging potential of the inlet.

An underdrain system shall be provided for the dry swale to ensure a maximum temporary ponding time of 48 hours.

5.6.3 Pretreatment Criteria

Pretreatment of 0.1 inch of runoff per impervious acre storage must be provided. This is usually done by providing checkdams at pipe inlets and/or driveway crossings (#).

A pea gravel diaphragm and mild side slopes shall be provided along the top of channels to provide pretreatment for lateral sheet flows.

5.6.4 Treatment Criteria

Grass channels, designed for water quality treatment must have a peak velocity for the "water quality storm less than 1.0 fps, and a residence time of at least 10 minutes (#)(*).

Dry and wet swales must be designed to temporarily store the WQv within the facility to be released over a maximum 48 hour duration (#).

Open channels shall have a bottom width no wider than 8 feet to avoid potential gullying and channel braiding (#).

Dry and wet swales shall maintain a maximum average depth of 12" at the "mid-point" of the channel, and a maximum depth of 18" at the low point (for storage of the WQv) (#).

Filter strips shall maintain a maximum overland flow length to the treatment facility of 150 feet for pervious surfaces and 75 feet for impervious surfaces. The minimum filter strip length shall be 25 feet (#).

5.6.5 Environmental/Landscaping Criteria

Wet swales are not permitted for residential land use applications to avoid concerns related to nuisance conditions, or potential mosquito breeding conditions.

Landscape design shall specify proper grass species and wetland plants based on specific criteria and the soils and anticipated hydric conditions (see Appendix D).

5.6.6 Maintenance Criteria

A stone drop of at least six inches shall be provided at the inlet of open channel facilities directly draining impervious surfaces (pea gravel diaphragm).

Open channel systems and grass filter strips shall be mowed when required during the growing season to maintain grass heights of 4 to 6 inches. Wet swales, employing wetland vegetation, do not require frequent mowing.

Sediment build-up within the bottom of the channel or filter strip shall be removed when 25% of the original design volume has been exceeded.

Construction specifications for open channel systems are specified in Appendix A.

Sources:

City of Austin, TX. 1988. Water Quality Management. In, Environmental Criteria Manual. Environmental and Conservation Services. Austin, TX

Claytor and Schueler. 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection. Silver Spring, MD.

Galli, J. 1996. Montgomery County Stormwater Management Manual. Montgomery County DEP. MWCOG. Washington, D.C.

Galli, J. 1990. Peat-Sand Filters: A Proposed Stormwater Management Practice for Urbanized Areas. MWCOG. Washington, DC

Maryland Dept. of the Environment. Water Management Administration. 1995. Draft Standards and Specifications for Stormwater Management Practices. Baltimore, MD

Maryland Dept. of the Environment. Water Management Administration. 1994-1995. Meeting Minutes, Notes, and Correspondence from Stormwater Management Regulations Committee. Baltimore, MD

Schueler. 1987. Controlling Urban Runoff: a practical manual for planning and designing urban BMPs. MWCOG. Washington, DC.

Schueler. 1992. Design of Stormwater Wetland Systems. MWCOG. Anacostia Restoration Team. Washington, D.C.

Stormwater Advisory Committee. 1996. Draft Performance Standards and Guidelines for Stormwater Management in Massachusetts. MA CZM Program. Boston, MA.

Technical Appendices:

Note: These appendices provide more detailed construction specifications for individual practices or group of practices. The full appendices are not included in the Technical Support Document, but the key sources from which they will be developed and adapted are cited above. It is anticipated that they will be incorporated into appendices for the final manual for the sake of clarity, as follows:

Part A. Construction Specifications

A-1 MD NRCS 378 Standards for Ponds
A-2 Infiltration trenches
A-3 Infiltration basins
A-4 Porous Pavement
A-5 Sand Filters

Part C: Assorted Design Tools

Section 6.0 Incentives and Credits for Innovative Site Planning Techniques

Section 6.1 Introduction

The stormwater sizing criteria (outlined in Section 2) have been developed to provide a strong general incentive to reduce impervious cover at development sites. All four sizing criteria are directly related to impervious cover. Any reductions in impervious cover result in smaller required storage volumes and, consequently, lower construction costs. In addition, we have explored six additional specific"credits" or incentives for better environmental site design within the context of the Design manual. These areas expand on the 12/8/94 report of the Environmental design work group to the State Stormwater Regulations Committee.

Other site design strategies are also listed after the six specific "credit" categories. These principles, if employed by site designers, will aid in reducing impervious cover which in turn will reduce the volume requirements for the four stormwater management criteria (i.e., Re_v, WQ_v, Cp_v or Q_{p2}, and Q_{p10}).

Section 6.2 Natural Area Conservation Credits

Definition: Practices that protect and conserve natural areas at a development site, thereby retaining its pre development hydrologic and water quality characteristics.

As an incentive to conserve natural areas at a site, a simple WQ_v credit would be granted for all conservation areas permanently protected by conservation easement or other means. Examples include:

- forest conservation areas
- stream and critical area buffers
- other lands in protective easement (floodplains, open space, wetlands)

The credit allows the designer to deduct conservation areas from total site area when computing the water quality volume (after the volumetric runoff coefficient, Rv has been calculated). As an example, for a ten acre site with three acres of impervious area and three acres of conservation area, the required WQ_v would be:

WQ_v = (1 inch) (0.3) (7 acres) instead of (1)(0.3)(10)

As an additional incentive, the post development curve number (CN) used to compute the Cp_v or Qp2, and Q_{p10} for all natural areas protected by conservation easement can be assumed to be forest in good condition (60).

To receive the credit, the site areas cannot be disturbed during project construction (cleared or graded), the limits of disturbance must be clearly shown on all construction drawings, and a conservation easement must be executed to ensure permanent protection.

Section 6.3 Credit for Disconnection of Rooftop Runoff

Definition: Practices that disconnect rooftop runoff by directing it to pervious areas where it is either infiltrated or filtered (by overland flow) into the soil. This can be done by grading the site to promote overland filtering, or by providing bioretention areas on single family residential lots.

If rooftop runoff is adequately disconnected, the impervious area can be deducted from total impervious cover (therefore reducing WQ_v). In addition, all runoff that is disconnected from rooftops counts toward the Re_v requirement (i.e., an amount equal to one inch times the rooftop area is credited).

The deduction is subject to the following restrictions:

- Runoff cannot be from a designated hotspot
- System must be designed to ensure no basement seepage
- The contributing length of rooftop to a discharge location shall be 75 feet or less
- The contribution area shall be less than or equal to 10,000 sq. feet
- The length of the "disconnection" shall be equal to, or greater than the contributing length
- Disconnections will only be credited for lot sizes greater than 6000 sq. ft. in area
- The vegetative "disconnection" shall be on a slope less than, or equal to 5.0%
- Downspouts must be at least 10 feet away for the nearest impervious surface to discourage "re-connections"
- Disconnections are encouraged on relatively permeable soils (HSGs A and B) without testing. In more impermeable soils (HSGs C and D), the water table and permeability shall be tested by a geotechnical engineer to determine if a spreading device is needed to provide sheetflow over the grass surface. In some cases, drywells, french drains or other temporary underground storage devices may be needed to compensate for a poor infiltration capability (see Figure 6.1).

Section 6.4 Credit for Disconnection of Surface Impervious Cover (non-rooftop)

Definition: Practices that disconnect surface impervious cover runoff by directing it to pervious areas where it is either infiltrated or filtered (by overland flow) into the soil. This can be done by grading the site to promote overland filtering, or by providing bioretention areas on single family residential lots.

These "disconnected" areas can be subtracted from either total site area or impervious area when computing WQ_v. They also contribute to the recharge requirement, Re_v.

The deduction is subject to the following restrictions:

- The maximum contributing length shall be 75 feet for impervious areas
- Runoff cannot be from a designated hotspot
- The length of the "disconnection" must be equal to or greater than the contributing length
- The vegetative "disconnection" shall be on a slope less than or equal to 5.0%
- Disconnections shall be over relatively permeable soils (HSGs A and B) will not require geotechnical testing. If the site has impermeable soils (HSGs C and D), however, testing by a geotechnical engineer is needed to determine if a spreading device, such as a drywell, french drains, gravel trench or other temporary underground storage devices is needed to compensate for poor infiltration capability.

Residential bioretention is one example of how runoff can be effectively disconnected (see Figure 6.2)

Section 6.5 Stream Buffer and Filter Strip Credit

Definition: "Treat" stormwater runoff from pervious and some impervious areas immediately adjacent to a designated stream buffer through site grading. The use of a filter strip is also recommended to treat overland flow in the green space of a development site. The credits include:

a. The area draining to stream buffer is subtracted from total site area in the WQ_v calculation
b. The area draining to stream buffer contributes to recharge requirement, Re_v
c. A *wooded* CN can be used for the contributing area if it drains to a forested stream buffer.

The credit is subject to the following conditions:

- The minimum filter strip length shall be 50 feet
- The maximum contributing length shall be 150 feet for pervious surfaces and 75 feet for impervious surfaces

- The maximum slope shall be less than or equal to 5.0%
- Runoff shall enter the filter strip as sheet flow. A level spreading device shall be utilized where sheet flow can no longer be maintained

Figure 6.3 illustrates how a stream buffer or filter strip can be used to treat stormwater from adjacent pervious and impervious areas.

Section 6.6 Use of Open Channels in Lieu of Curb and Gutter

Definition: Use of open channels to reduce the volume of runoff and pollutant load during smaller storms that are not considered "structural practices" on the BMP list. These practices include the open channel and the grass channel.

These practices will meet the minimum recharge Re_v requirement. If the **grass channel** and **filter strip** are designed according to the following design criteria, they will be considered to meet the WQ_v.

The credit is obtained if a grass channel meets the following criteria.

- The bottom width shall be less than 6 feet
- The side slopes shall be 3:1 or flatter
- The maximum slope shall be less than or equal to 4.0%
- The maximum flow velocity for runoff from the 1" rainfall shall be less than or equal to 1.0 fps
- The minimum residence time within the channel shall be at least 10 minutes

An example of a grass channel is provided in Figure 6.4

For open channels, Rev credit is allowed if A soils are present and the channel length to contributing area ratio is 200 feet or greater. An example of an open channel design is provided in Figure 6.5.

Section 6.7 Environmentally-sensitive rural development

Definition: Combined use of environmental site design techniques on low density or rural

These criteria can be met without the use of structural practices in certain low density residential developments when the following conditions are met:

- Total impervious cover footprint is less than 15 % of site area
- Total site area is less than 10 acres
- A minimum of 25% of the site is protected in natural conservation areas (by permanent easement or other similar measure)
- Rooftop runoff is disconnected in accordance with the criteria outlined under Section 6.5
- Grass channels are used to convey runoff versus curb and gutter

The designer must still provide stormwater detention for all roadway and connected impervious surfaces (i.e, Cp_v or Q_{p2}, and Q_{p10}).

Section 6.8 Other Strategies for Impervious Cover Reduction

Definition: Site planning practices that reduce the creation of impervious area in new residential and commercial development and therefore reduce the WQ_v for the site.

Examples of progressive site design practices that minimize the creation of impervious cover include:

- Clustered Development
- Narrower residential road sections
- Shorter road lengths
- Smaller turnarounds and cul-de-sacs radii
- Permeable spill-over parking
- Smaller parking demand ratios
- Smaller parking stalls
- Angled one way parking
- Stream protection clusters
- Smaller front yard setbacks
- Shared parking and driveways
- Narrower sidewalks on one side of street

It should be noted that most site designers have little ability to control these requirements, which are typically enshrined in local subdivision, parking and street codes. Including these in the manual, however, might encourage some local governments to modify their current policies.

Note: The Stormwater Manual will include an example of a residential subdivision that shows specifically how the credits are to be taken, and the impact on stormwater storage volumes.

Figure 6.1 Example of Drywell

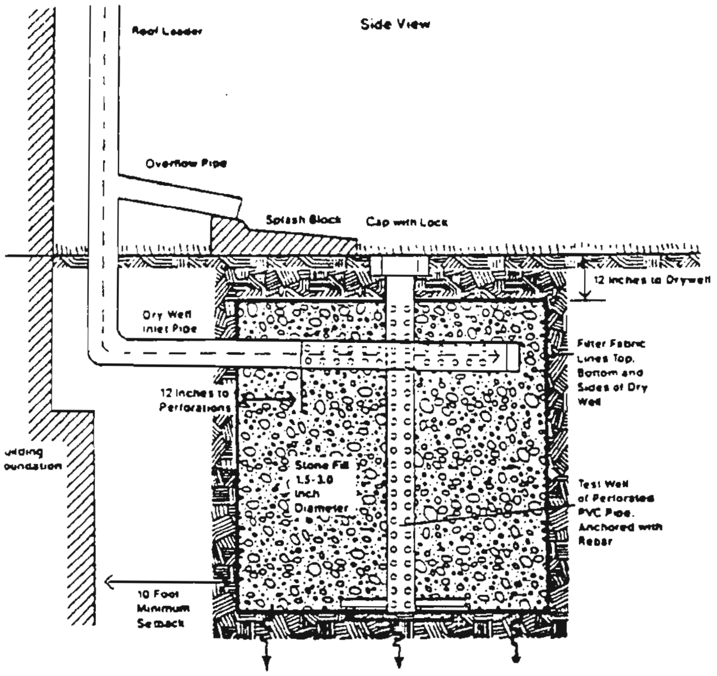


Figure 6.2 Residential Bioretention

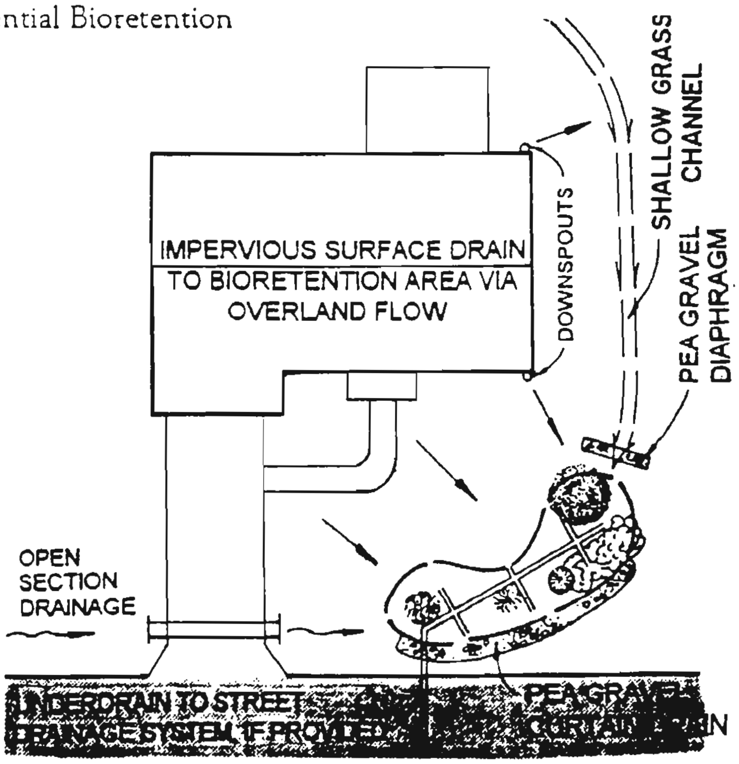


Figure 6.3 Filter Strip and Stream Buffer

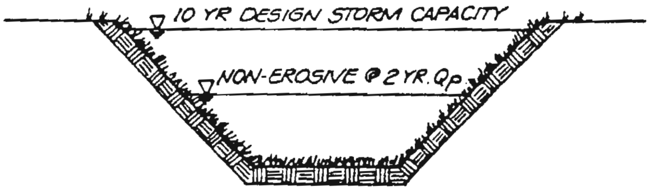


Figure 6.4 Grass Channel

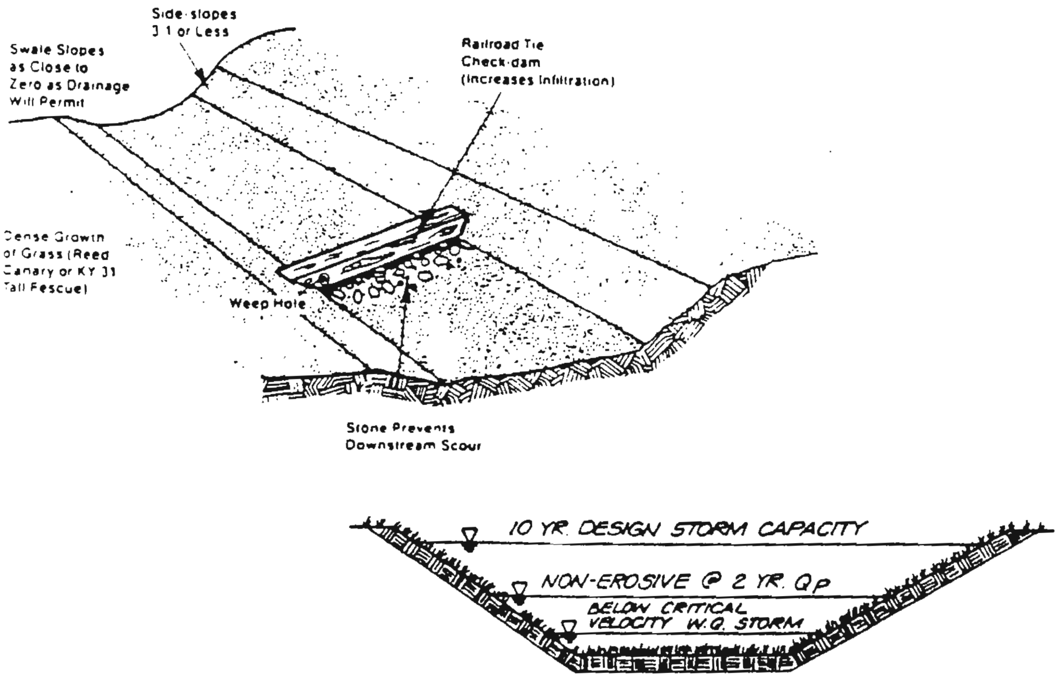
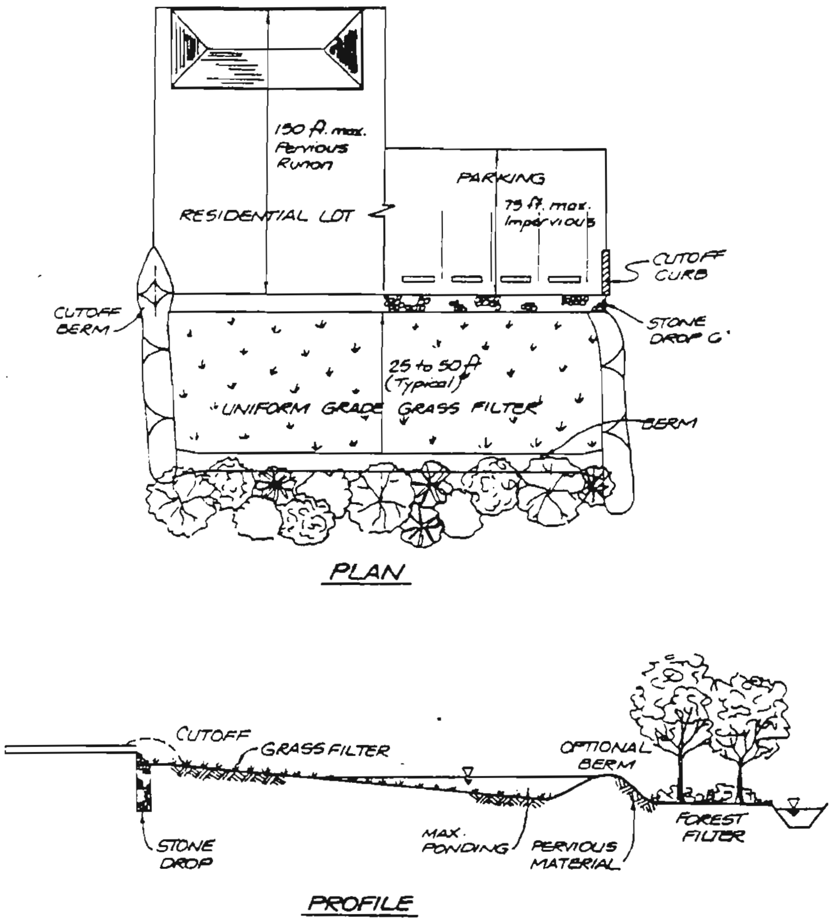


Figure 6.5 Open Channel Design (Conveyance)



Section 7
Stormwater Management
Landscaping Guide

NOTE: THE NARRATIVE FOR SECTION 7 IS UNDER REVISION, AND WILL BE TRANSMITTED UNDER SEPARATE COVER.

THE REVISED LANDSCAPING LIST IS PROVIDED ON THE FOLLOWING PAGES