

EPA/600/R-03/103  
September 2002

# **Considerations in the Design of Treatment Best Management Practices (BMPs) to Improve Water Quality**

National Risk Management Research Laboratory  
Office of Research and Development  
U.S. Environmental Protection Agency  
Cincinnati, OH 45268

## **Notice**

This document has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for publication. Mention of trade names, commercial products, or design procedures does not constitute endorsement or recommendation for use.

## **Foreword**

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Hugh W. McKinnon, Director  
National Risk Management Research Laboratory

## **Abstract**

For the past three decades, municipalities in the United States have successfully addressed pollution in the watershed by collecting and treating their wastewater. Currently, all municipalities provide secondary level treatment, and in some cases tertiary treatment, and industries provide best available/best practicable treatment. This has had great benefits. More rivers are meeting water quality standards, and the public health is being protected from waterborne disease. The challenge now facing us is to address pollution associated with storm water runoff, since this is now the last major threat to water quality.

It is less costly to prevent the generation of polluted runoff than to treat it. Today, many municipalities are implementing low-cost best management practices (BMPs) that prevent runoff. The lowest cost BMPs, termed non-structural or source control BMPs, include practices such as limiting pesticide use in agricultural areas or retaining rainwater on residential lots (currently termed “low impact development”). There are a set of higher cost BMPs, which involve building a structure of some kind to store stormwater until it can be discharged into a nearby receiving water. These can be more costly, especially in areas where land costs are high. The three most commonly used structural treatment BMPs that will be discussed in the document are ponds (detention/retention), vegetated biofilters (swales and filter/buffer strips) and constructed wetlands. Two categories of treatment considered in this document are ponds and vegetated biofilters. Ponds are probably the most frequently used BMP in the United States. There are three types of pond BMPs: wet ponds (retention ponds); dry ponds (notably extended detention ponds); and infiltration basins. Three different types of vegetative biofilter BMP types are discussed: grass swales, vegetated filter strips, and bioretention cells. Grass swales include three variations: traditional grass swales, grass swales with media filters and wet swales.

This document presents factors that should be considered in the design of treatment BMPs to improve water quality. The state-of-the-practice is such that existing design guides vary and the performance of treatment BMPs shows a wide range of pollutant removal effectiveness.

# Contents

Notice .....	ii
Foreword .....	iii
Abstract .....	iv
Table of Contents .....	v-vi
List of Figures .....	vii
List of Tables .....	viii
Acronyms and Abbreviations .....	x-xi
Acknowledgments .....	xii

## Chapter One

### Role of Best Management Practices (BMPs) in Improving Water Quality

1.1 Introduction .....	1 - 1
1.2 Impacts of Nonpoint Sources on Receiving Waters .....	1 - 2
1.3 Impacts of Urbanization on Receiving Waters - Physical and Chemical .....	1 - 8
1.4 Impacts of Urbanization on Receiving Waters - Biological Communities ..	1 - 10
1.5 Pollutant Loadings Associated with Urban Stormwater .....	1 - 13
1.6 Stormwater Management - EPA Regulatory Requirements .....	1 - 21
1.7 Role of BMPs in Developing an Urban Stormwater Management Plan .....	1 - 22
1.8 Current Peak Discharge Control Strategies .....	1 - 23
1.9 Design of Treatment BMPs to Improve Water Quality .....	1 - 25
1.10 Concerns with BMP Performances .....	1 - 25

## Chapter Two

### Watershed Hydrology Pertinent to BMP Design

2.1 Introduction .....	2 - 1
2.2 Amount and Distribution of Rainfall Intensity and Volume .....	2 - 1
2.3 Hydrologic Concepts for BMP Design .....	2 - 4
2.4 Peak Discharge Control Strategies .....	2 - 5
2.5 Water Quality Control Strategies .....	2 - 13

## Chapter Three

### Types of BMPs and Factors Affecting their Selection

3.1 Introduction .....	3 - 1
3.2 Types of BMPs .....	3 - 1
3.3 BMP Selection Criterion - Meeting Stormwater Management Goals .....	3 - 3
3.4 BMP Selection Criterion - On-Site vs Regional Controls .....	3 - 7
3.5 BMP Selection Criterion - Watershed Factors .....	3 - 11
3.6 BMP Selection Criterion - Terrain Factors .....	3 - 13
3.7 BMP Selection Criterion - Physical Suitability Factors .....	3 - 14

3.8	BMP Selection Criterion - Community and Environmental Factors . . . . .	3 - 16
3.9	BMP Selection Criterion - Location and Permitting Factors . . . . .	3 - 17
3.10	Federal Regulations That Impact Stormwater BMP Design . . . . .	3 - 19
3.11	State and Municipal Requirements That Impact Stormwater BMP Design . . . . .	3 - 25

**Chapter Four**

**BMP Effectiveness in Removing Pollutants**

4.1	Introduction . . . . .	4 - 1
4.2	Current Flow Control Watershed Management Strategies . . . . .	4 - 1
4.3	Pollutant Loading Estimates . . . . .	4 - 2
4.4	Effectiveness of Treatment BMPs using Current Design Approaches . . . . .	4 - 5
4.5	Importance of Particle Size Distribution . . . . .	4 - 8
4.6	Approaches to Implementing BMPs for Improved Water Quality in the Urban Watershed . . . . .	4 - 9
4.7	Removal Processes Occurring in Treatment BMPs . . . . .	4 - 12
4.8	Treatment-Train Approach to Improve Water Quality . . . . .	4 - 17

**Chapter Five**

**Types of Pond BMPs and Their Ability to Remove Pollutants**

5.1	Introduction . . . . .	5 - 1
5.2	Design of Wet Ponds to Maximize Sedimentation . . . . .	5 - 5
5.3	Design of Extended Detention Basins for Water Quality Improvements . . . . .	5 - 14
5.4	Maintenance of Pond BMPs . . . . .	5 - 17

**Chapter Six**

**Types of Vegetative Biofilters and Their Ability to Remove Pollutants**

6.1	Introduction . . . . .	6 - 1
6.2	Grass Swale . . . . .	6 - 1
6.3	Vegetative Filter Strip . . . . .	6 - 5
6.4	Bioretention Cell . . . . .	6 - 5
6.5	Role in Water Quality Improvement . . . . .	6 - 5
6.6	Design of Grass Swales for Pollutant Removal . . . . .	6 - 10
6.7	Design of Vegetative Filter Strips for Pollutant Removal . . . . .	6 - 11
6.8	Design of Bioretention Cells for Pollutant Removal . . . . .	6 - 15

<b>Glossary</b> . . . . .	G-1
<b>References</b> . . . . .	R-1

## List of Figures

Figure 1-1	Change in Floodplain Elevations . . . . .	1 - 5
Figure 1-2	Relationship Between Impervious Cover and the Volumetric Runoff Coefficient . . . . .	1 - 6
Figure 2-1	Stormwater Control Points Along the RFS for Maryland . . . . .	2 - 2
Figure 2-2	Fifteen Rain Zones of the United States . . . . .	2 - 2
Figure 2-3	A Watershed Where the Drainage From a Small Development Site Joins the Flow From Large Watershed . . . . .	2 - 9
Figure 2-4	Alternative Hydrographs From the Watershed . . . . .	2 - 10
Figure 4-1	Urban Stormwater Treatment Train Process Flow Diagram . . . . .	4 - 19
Figure 5-1	Wet Pond Typical Detail . . . . .	5 - 2
Figure 5-2	Typical Dry Pond . . . . .	5 - 3
Figure 5-3	Extended Detention Basin, Typical Detail . . . . .	5 - 4
Figure 5-4	Infiltration Basin, Typical Detail . . . . .	5 - 6
Figure 6-1	Grass Swale . . . . .	6 - 3
Figure 6-2	Wet Swale . . . . .	6 - 4
Figure 6-3	Typical Vegetative Filter Strip . . . . .	6 - 6
Figure 6-4	Typical Bioretention Cell . . . . .	6 - 7
Figure 6-5	Pollutant Removal Efficiency Versus Filter Strip Length . . . . .	6 - 13

## List of Tables

Table 1-1	Impacts of Urbanization on Receiving Waters . . . . .	1 - 9
Table 1-2	Changes Due to Urbanization and Effects on Aquatic Organisms . . . . .	1 - 11
Table 1-3	Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms . . . . .	1 - 12
Table 1-4	National Event Mean and Median Concentrations for Chemical Constituents of Stormwater . . . . .	1 - 14
Table 1-5	Regional Groupings by Annual Rainfall . . . . .	1 - 15
Table 1-6	Mean and Median Nutrient and Sediment Stormwater Concentrations for Residential Land Use Based on Rainfall Regions . . . . .	1 - 16
Table 1-7	Percentage of Metal Concentrations Exceeding Water Quality Standards by Rainfall Region . . . . .	1 - 16
Table 1-8	Stormwater Pollutant Event Mean Concentration for Different U.S. Regions . . . . .	1 - 17
Table 1-9	Typical Urban Areas and Pollutant Yields . . . . .	1 - 18
Table 1-10	Median Stormwater Pollutant Concentration for All Sites by Land Use . . .	1 - 19
Table 1-11	Comparison of Water Quality Parameters in Urban Runoff With Domestic Wastewater . . . . .	1 - 19
Table 1-12	Runoff and Pollutant Characteristics of Snowmelt Stages . . . . .	1 - 20
Table 1-13	Impairments Associated with Current Flow Control Strategies . . . . .	1 - 24
Table 2-1	Typical Values of Individual Storm Event Statistics for 15 Zones of the United States . . . . .	2 - 3
Table 2-2	Comparison of Model Attributes and Functions . . . . .	2 - 6
Table 2-3	Design Storm Frequencies and Assumed Benefits . . . . .	2 - 7
Table 2-4	Qualitative Assessment of Peak Discharge Control Strategies with Respect to the Physical Impact Category . . . . .	2 - 8
Table 3-1	ASCE Source Control BMPs . . . . .	3 - 2
Table 3-2	Treatment BMPs . . . . .	3 - 2
Table 3-3	Summary of Studies on Environmental Impacts for Pond and Wetland BMPs . . . . .	3 - 4
Table 3-4	Summary of Studies on Environmental Impacts for Vegetative Biofilter BMPs . . . . .	3 - 5
Table 3-5	Summary of Studies on Environmental Impacts for Infiltration BMPs . . . . .	3 - 6
Table 3-6	Summary of Studies on Environmental Impacts for Filter BMPs . . . . .	3 - 7
Table 3-7	Treatment BMPs vs Watershed Factors . . . . .	3 - 12
Table 3-8	BMP Selection - Terrain Factors . . . . .	3 - 14
Table 3-9	BMP Selection - Physical Suitability Factors . . . . .	3 - 15
Table 3-10	BMP Selection - Community and Environmental Factors . . . . .	3 - 17
Table 3-11	Permitting Checklist . . . . .	3 - 18
Table 3-12	State or Regional Planning Authority Requirements for Water Quality Protection	



	.....	3 - 26
Table 3-13	Municipal or Regional Planning Authority Requirements .....	3 - 27
Table 3-14	Minimum Drainage Area Requirements for States .....	3 - 28
Table 3-15	Minimum Area Requirements for Local Agencies .....	3 - 28
Table 3-16	Peak Discharge Control Criteria for States .....	3 - 29
Table 3-17	Peak Discharge Rate Control Requirements, Municipalities .....	3 - 30
Table 3-18	Water Quality Regulatory Requirements, States .....	3 - 31
Table 3-19	Water Quality Requirements, Municipalities .....	3 - 31
Table 4-1	Median Pollutant Removal of Stormwater Treatment Practices .....	4 - 5
Table 4-2	Median Effluent Concentration of Stormwater Treatment Practice Groups ..	4 - 6
Table 4-3	Removal Processes Occurring in Treatment BMPs .....	4 - 13
Table 4-4	Treatment BMP Expected Performance .....	4 - 13
Table 4-5.	Pollutant Removal (%) by Mulch from Stormwater Runoff .....	4 - 17
Table 4-5	Expected Median Effluent Concentration of Selected Pollutants .....	4 - 20
Table 5-1	Hydrologic and Hydraulic Design Criteria for Standard Extended Detention Wet Pond System .....	5 - 7
Table 5-2	Recommended Criteria for Wet Pond Design for Nutrient Removal .....	5 - 8
Table 6-1	Estimated Pollutant Removal Capability of Biofilters .....	6 - 8
Table 6-2	Land Use and Biofilter Suitability .....	6 - 9
Table 6-3	Physical Site Conditions and Biofilter Suitability .....	6 - 10
Table 6-4	Pollutant Removal Efficiencies for Grass Swales .....	6 - 11
Table 6-5	Pollutant Removal Performance of Bioretention Practices (% Removal) ...	6 - 16

## Acronyms and Abbreviations

ASCE	= American Society of Civil Engineers
BMP	= best management practice
BOD	= biochemical oxygen demand
CERCLA	= Comprehensive Environmental Response, Compensation and Liability Act
CZARA	= Coastal Zone Act Reauthorization Amendments
CZMA	= Coastal Zone Management Act
COD	= chemical oxygen demand
CWA	= Clean Water Act
EPA	= Environmental Protection Agency
EPT	= ephemeroptera (mayflies), plecoptera (stoneflies), and trichoptera (caddisflies)
ESA	= Endangered Species Act
EMC	= event mean concentration
FIFRA	= Federal Insecticide, Fungicide and Rodenticide Act
FWPCA	= Federal Water Pollution Control Act
IBI	= index of biotic integrity
MDE	= Maryland Department of the Environment
MTBE	= methyl tertiary butyl ether
NEPA	= National Environmental Policy Act
NGPE	= native growth protection easement
NMFS	= National Marine Fisheries Service
NOAA	= National Oceanographic and Atmospheric Administration
NPDES	= National Pollution Elimination Discharge Program
NRCS	= Natural Resources Conservation Service
NURP	= Nationwide Urban Runoff Program
OCZM	= Office of Coastal Zone Management
RCRA	= Resource Conservation and Recovery Act
RFS	= rainfall frequency spectrum
SCS	= Soil Conservation Service
SWMM	= StormWater Management Model
TMDL	= total maximum daily loads
TN	= total nitrogen
TP	= total phosphorus
TSS	= total suspended solids
UDFCD	= Urban Denver Flood Control District
USDA	= US Department of Agriculture
USFWS	= US Fish and Wildlife Service
USGS	= US Geological Survey

USTM = United Stormwater model  
WEF = Water Environment Federation  
WEPP = Water Erosion Prediction Model  
W<sub>q<sub>v</sub></sub> = water quality volume  
WWF = wet weather flow

## **Acknowledgments**

Many people participated in the creation of this document. Technical direction was provided by USEPA's National Risk Management Research Laboratory (NRMRL). Technical writing was carried out in several stages, but culminated into a final product as a cooperative effort between the NRMRL and the contractors named below. The contractors produced a three-volume series "BMP Design Guide - Volume 1, General Considerations", "BMP Design Guide - Volume 2, Vegetative Biofilters" and "BMP Design Guide - Volume 3, Pond BMPs" which included detailed design guidance. That three-volume series will be published separately by USEPA. This document overviews factors which should be considered in the design of treatment best management practices (BMPs) to improve water quality.

### **Authors of Three-Volume Series**

Michael Clar, Ecosite, Inc, Ellicott City, MD

Bill J. Barfield, Oklahoma State University, Stillwater, OK

Shaw Yu, University of Virginia, Charlottesville, VA

### **USEPA Contributors/Authors**

Thomas O'Connor, Water Supply and Water Resources Division, NRMRL, Edison, NJ

Chi-Yuan Fan, Water Supply and Water Resources Division, NRMRL, Edison, NJ

Daniel Sullivan, Water Supply and Water Resources Division, NRMRL, Edison, NJ

Richard Field, Water Supply and Water Resources Division, NRMRL, Edison, NJ

Anthony Tafuri, Water Supply and Water Resources Division, NRMRL, Edison, NJ

Asim Ray, Senior Environmental Employment Program, Edison, NJ

### **Peer Reviewers of Three-Volume Series**

Ben R. Urbonas, Urban Watersheds, LLC, Denver, CO

Eugene D. Driscoll, Oakland, NJ

Jesse Pritts, Office of Water, Washington, DC

Norbert Huang, Office of Water, Washington, DC

King Boynton, Office of Water, Washington, DC

### **Technical Edit Review**

Gelane Gemechisa, Environmental Careers Organization, Edison, NJ