## ATTACHMENT A

## DESIGN OF TREATMENT CONTROL BMPs USING THE STORMWATER QUALITY DESIGN FLOW(SQDF) OR THE STORMWATER QUALITY DESIGN VOLUME (SQDV)

Unlike flood control measures that are designed to handle peak flow rates, stormwater Treatment Control BMPs are designed to treat the more frequent, lower-flow rate storm events, or the first flush portions of runoff from larger storm events (typically referred to as the first-flush events). Small, frequent storm events represent most of the total average annual rainfall for the area. The flow rate and volume from such small events is targeted for treatment.

The primary control strategy for designing Treatment Control BMPs is to treat the Stormwater Quality Design Flow (SQDF) or the Stormwater Quality Design Volume (SQDV) of the stormwater runoff. This section explains how to calculate the SQDF or the SQDV of the stormwater runoff. In addition, Treatment Control BMPs must be designed to safely convey or bypass peak design storms.

The methods presented in this appendix are intended to be used for sizing of project-based Treatment Control BMPs in Project WQMPs, or determining the required SQDV or SQDF contribution from an individual project in allocating capacity in a regional or watershed BMP program. Methods for estimating hydrology from larger watershed for the sizing of regional or watershed BMPs that address larger areas may require alternative approaches for determining appropriate sizing of BMPs.

### Stormwater Quality Design Flow (SQDF) Calculations

The Stormwater Quality Design Flow (SQDF) is defined by the Permits as the maximum flow rate of runoff produced from a rainfall intensity of 0.2-inch of rainfall per hour[8].

Calculation Procedure

1. The Stormwater Quality Design Flow in Orange County is defined as $Q_{P,SQDF}$.

[8] As defined in Section XII.B.3.B of the California Regional Water Quality Control Board, Santa Ana Region, Waste Discharge Requirements for the County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County within the Santa Ana Region, Urban Stormwater Runoff Management Program, Orange County, Order No. R8-2002-0010, NPDES Permit No. CAS618030; and in Section F.1.b.(2)(c) of the California Regional Water Quality Control Board, San Diego Region, Waste Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer Systems (MS4s) Draining the Watersheds of the County of Orange, the Incorporated Cities of Orange County and the Orange County Flood Control District within the San Diego Region, Board Order No. R9-2002-0001, NPDES CAS0108740

2. Calculate the stormwater quality design flow for the site (or each sub-drainage area that will discharge to a separate BMP) produced by 0.2-inch / hour rainfall by using the rational method equation:

$$Q_{P,\,SQDF} = C * I * A$$

Where:

C = runoff coefficient obtained from **Table A-1**.

I = rainfall intensity (0.2 in / hr)

A = area of the site or sub-drainage area in acres

***Table A-1***

***C Values Based on Impervious/Pervious Area Ratios***

| % Impervious | % Pervious | C |
|---|---|---|
| 0 | 100 | 0.15 |
| 5 | 95 | 0.19 |
| 10 | 90 | 0.23 |
| 15 | 85 | 0.26 |
| 20 | 80 | 0.30 |
| 25 | 75 | 0.34 |
| 30 | 70 | 0.38 |
| 35 | 65 | 0.41 |
| 40 | 60 | 0.45 |
| 45 | 55 | 0.49 |
| 50 | 50 | 0.53 |
| 55 | 45 | 0.56 |
| 60 | 40 | 0.60 |
| 65 | 35 | 0.64 |
| 70 | 30 | 0.68 |
| 75 | 25 | 0.71 |
| 80 | 20 | 0.75 |
| 85 | 15 | 0.79 |
| 90 | 10 | 0.83 |
| 95 | 5 | 0.86 |
| 100 | 0 | 0.90 |

### *Example Stormwater Quality Design Flow (SQDF) Calculation*

The steps below show an example calculation for a 30-acre site with runoff coefficient of 0.45 (40% impervious).

*Step 1:*

Design Flow = $Q_{P,\,SQDF} = C * I * A$

*Step 2:*

Calculate the peak rate of flow

$Q_{P,\,SQDF} = 0.45 \times 0.2 \times 30 = 2.7$ cfs = Stormwater Quality Design Flow for the BMP.

### Stormwater Quality Design Storm Volume (SQDV) Calculations

Hydrologic calculations for design of volumetric-based stormwater quality BMPs in Orange County shall be in accordance with one of the four following approaches specified in the permits:

i. The volume of runoff produced from a 24-hour 85th percentile storm event, as determined from the local historical rainfall record[9]; or

ii. The volume of runoff produced by the 85th percentile 24-hour runoff event, determined as the maximized capture urban runoff volume for the area, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual and Report on Engineering Practice No. 87, (1998); or

iii. The volume of annual runoff based on unit basin storage volume, to achieve 80 percent (Santa Ana Permit area), or 90 percent (San Diego Permit area) or more volume treatment by the method recommended in California Stormwater Best Management Practices Handbooks (1993), or

iv. The volume of runoff, as determined from the local historical rainfall record, that achieves approximately the same reduction in pollutant loads and flows as achieved by mitigation of the 85th percentile 24-hour runoff event.[10]

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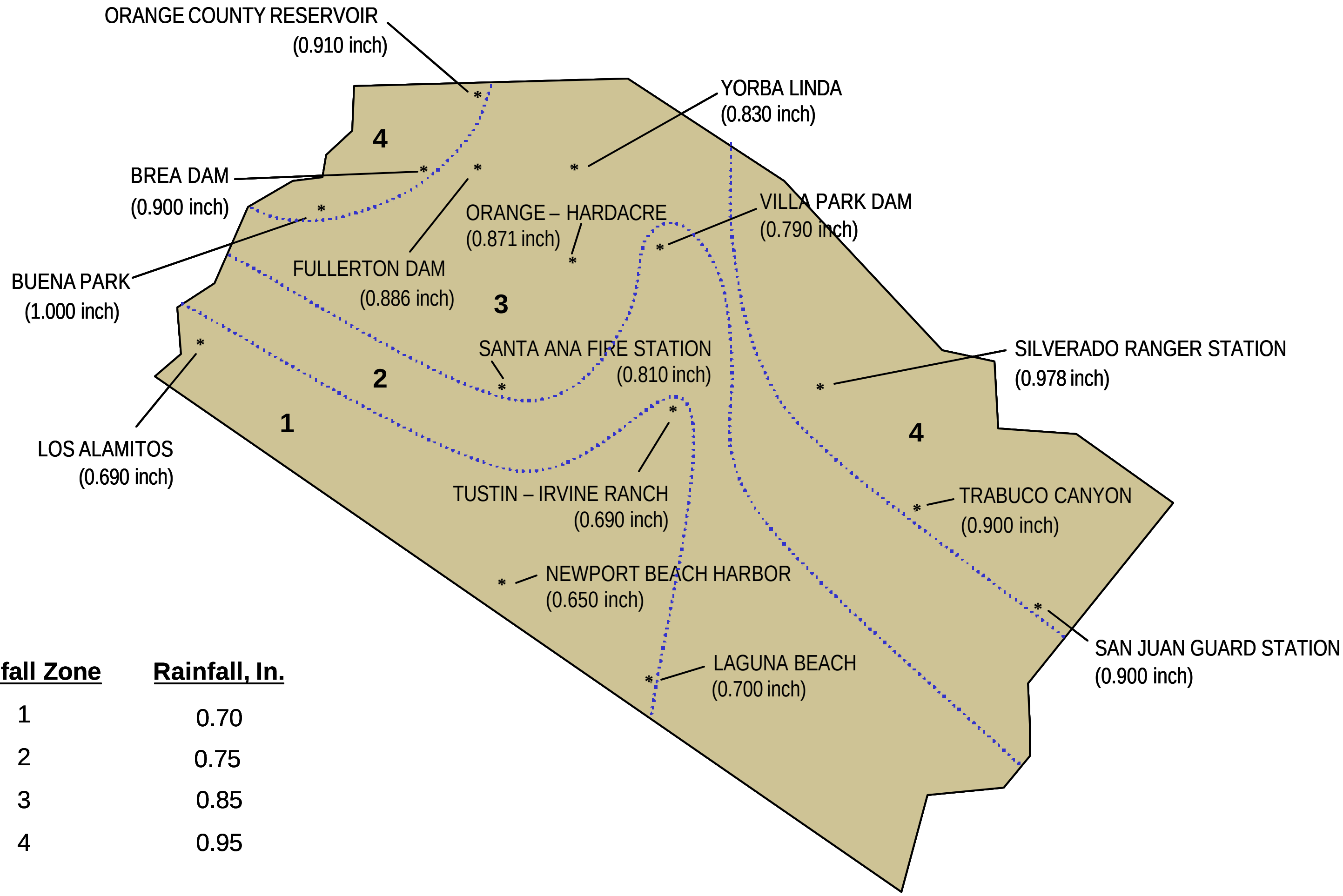
[9] This volume is not a single volume to be applied to all of Orange County. The size of the 85th percentile storm event is different for various parts of the County.

[10] Under this volume criterion, hourly rainfall data may be used to calculate the 85th percentile storm event, where each storm event is identified by its separation from other storm events by at least six hours of no rain. If hourly rainfall data is selected, the Permittees shall describe the method for using hourly rainfall data to calculate the 85th percentile storm event in their local WQMPs.

Individual projects may evaluate and select any of the above approaches. Procedures, data specific to Orange County, and examples for applying approaches (i), (ii), and (iii) are presented herein.

Data and procedures for determining an applicable 85th percentile, 24-hour storm event are presented in **Table A-2** and **Figure A-1**. Rainfall depths for the 85th percentile 24-hour event have been calculated for a number of stations throughout Orange County as shown in **Table A-2**. Approximate contour lines of the 85th percentile depth have been developed based upon the data as shown in **Figure A-1**. Projects should use the 85th percentile value from the rainfall zone in which the project site is located.




| Rainfall Zone | Rainfall, In. |
|---|---|
| 1 | 0.70 |
| 2 | 0.75 |
| 3 | 0.85 |
| 4 | 0.95 |

***Figure A-1***
***Orange County California***
***Precipitation Stations***
***24-hour, 85th percentile rainfall***

The project used to demonstrate the calculations has the following characteristics:

- Located in the City of Irvine
- Total project area, $A_t$, is 10 acres
- Impervious area, $A_i$, is 6 acres

Method (I):
The volume of runoff produced from a 24-hour 85th percentile storm event, as determined from the local historical rainfall record. The procedure is as follows:

1. ***Review the area draining to the proposed BMP***. Determine the percentage of the drainage area that is considered impervious. Impervious area includes paved areas, roofs, and other developed, non-vegetated areas. Non-vegetated, compacted soil areas shall be considered as impervious area.

2. ***Use Table A-1 to determine the Runoff Coefficient "C" for the drainage area***. The runoff coefficients from this table are intended only for use in this procedure for design of volumetric-based stormwater quality BMPs.

3. ***Find the depth of rainfall in inches of the 85th percentile storm event***.
Use 0.75 inch based on the project location and **Figure A-1**.

4. ***Calculate the Water Quality Design Volume of the BMP***. The Water Quality Design Volume of the BMP is then calculated by multiplying the total rainfall by the BMP's drainage area and runoff coefficient. Due to the mixed units that result (e.g., acre-inches, acre-feet) it is recommended that the resulting volume be converted to cubic feet for use during design.

***Example Use of Runoff from 85$^{th}$ Percentile Storm Event for Sizing a Dry Detention Basin***

$(Ai / At) * 100 = (6 / 10) * 100 = 60\%$

From Table A-1, for 60% impervious, C = 0.60

$V_b = C * I * A_t$

$V_b = 0.60 * (0.75 \text{ in}) * (10 \text{ ac}) * (1 \text{ ft} / 12 \text{ in}) * (43{,}560 \text{ ft}^2 / \text{acre})$

**Size the BMP for $V_b$ = 16,335 ft$^3$ and a minimum 48-hr drawdown**

Method (II)

The volume of runoff produced by the 85th percentile 24-hour runoff event, determined as the maximized capture urban runoff volume for the area, from the formula recommended in Urban

Runoff Quality Management, WEF Manual of Practice No. 23 / ASCE Manual and Report on Engineering Practice No. 87, (1998).

From WEF MOP 23 / ASCE MREP 87:

$$P_0 = (a * C) * P_6$$

Where:

$C$ = Runoff Coefficient = $0.858\ i^3 - 0.78\ i^2 + 0.774\ i + 0.04$

$i$ = Watershed imperviousness ratio; namely, percent total imperviousness divided by 100 = 0.60

$P_6$ = mean storm precipitation volume, watershed inches. Using **Figure 5-3** in the manual, P6 = 0.65 inches

$a$ = Regression constant from least-square analysis. Using **Table 5-4** in the manual for 48-hours drain time, a = 1.963

$P_0$ = Maximized detention volume using either the volume capture ratio as its basis, watershed inches

$$C = 0.858\ (0.60)^3 - 0.78\ (0.60)^2 + 0.774\ (0.60) + 0.04 = 0.409$$

$$P_0 = (1.963 * 0.409) * 0.65$$

$$P_0 = 0.522 \text{ inches}$$

$$V_b = 0.522\ (10 \text{ acre})\ (1 \text{ ft} / 12 \text{ in})\ (43{,}560 \text{ ft}^2 / \text{acre})$$

**Size the BMP for $V_b$ = 18,949 ft$^3$ and 48-hour drawdown**

Method (III) – Annual Runoff or Unit Basin Storage Volume Method

1. ***Review the area draining to the proposed BMP***. Determine the percentage of the drainage area that is considered impervious. Impervious area includes paved areas, roofs, and other developed, non-vegetated areas. Non-vegetated, compacted soil areas shall be considered as impervious area.

2. ***Use Table A-1 to determine the Runoff Coefficient "C" for the drainage area.*** The runoff coefficients from this table are intended only for use in this procedure for design of volumetric-based stormwater quality BMPs. Alternately, obtain the Runoff Coefficient from the drainage design calculations for the project.

3. ***Find the Unit Basin Storage Volume***[11].

   Obtain hourly rainfall data for the closest rain gage and develop capture curves using the Unit Basin Storage Volume method. Example storage curves have been developed using data from the Laguna Beach rain gage and the Silverado Ranger Station as shown in Figures A-2 and A-3.

   Enter **Figure A-2** or **A-3** on the vertical axis at 80% Annual Capture for projects in the Santa Ana Regional Board region or 90% Annual Capture for projects in the San Diego Regional Board region.

   Move horizontally to the right across the figure until the curve corresponding to the drainage area's runoff coefficient ("C") determined in Step 2 is intercepted. Interpolation between curves may be necessary. Move vertically down the figure for this point until the horizontal axis is intercepted. Read the Unit Basin Storage Volume along the horizontal axis. Recommended drawdown time for dry detention basins is 48 hours as discussed in the fact sheet.

   OR

   ***Figure A-4*** *provides a direct reading of Unit Basin Storage Volumes required for 80% (Santa Ana Regional Board region) and 90% (San Diego Regional Board region) annual capture of runoff for values of "C" determined in Step 2 for projects using the Laguna Beach rain gage.*

   ***Figure A-5*** *provides a direct reading of Unit Basin Storage Volumes required for 80% (Santa Ana Regional Board region) and 90% (San Diego Regional Board region) annual capture of runoff for values of "C" determined in Step 2 using the Silverado Ranger Station gage.*

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[11] Figures A-1 – A-4 are based on Precipitation Gages 4650 and 8243, located at Laguna Beach and Silverado Ranger Station, respectively. Both of these gages have data records of approximately fifty years of hourly readings and are maintained by the National Weather Service. Figures A-1 through A-4 are for use only in the permit areas specified in Santa Ana Regional Board Order No. R8-2002-0010, NPDES Permit No. CAS618030; and San Diego Regional Board Order No. R9-2002-0001, NPDES CAS0108740.

Enter the vertical axis of **Figure A-4** (or **Figure A–5**) with the "C" value from Step 2. Move horizontally across the figure until the line is intercepted. Move vertically down the figure from this point until the horizontal axis is intercepted. Read the Unit Basin Storage Volume along the horizontal axis.

4. ***Calculate the BMP volume***. The basin volume or basic volume of the BMP is then calculated by multiplying the Unit Basin Storage Volume by the BMP's drainage area. Due to the mixed units that result (e.g., acre-inches, acre-feet) it is recommended that the resulting volume be converted to cubic feet for use during design.

***Example Use of Unit Basin Storage Volume Curves Sizing a Dry Detention Basin***

(Ai / At) * 100 = (6 / 10) * 100 = 60%

From **Table A-1**, for 60% impervious, C = 0.60

Use **Figure A-4**, and the line that provides a direct reading of Unit Basin Storage Volumes required for 80% (Santa Ana Regional Board region) annual capture of runoff for values of "C" determined from **Table A-2**, for the Laguna Beach rain gage.

Enter the vertical axis of **Figure A-4** with C = 0.60. Move horizontally across the figure until the line is intercepted. Move vertically down the figure from this point until the horizontal axis is intercepted. Read the Unit Basin Storage Volume ($V_u$) along the horizontal axis.

$V_u$ = 0.46 inches

The volume of the basin is then $V_u \times A_t$

$V_b = V_u \times A_t$ = (0.46 in) (10ac) (1 ft / 12 in) (43,560 $ft^2$ / ac)

**Size the BMP for $V_b$ = 16,698 $ft^3$ and 48-hour drawdown**

*Figure A-2*
*Volumetric BMP Sizing Curves for*
*Orange County Stormwater Quality Management Program*
*Laguna Beach*

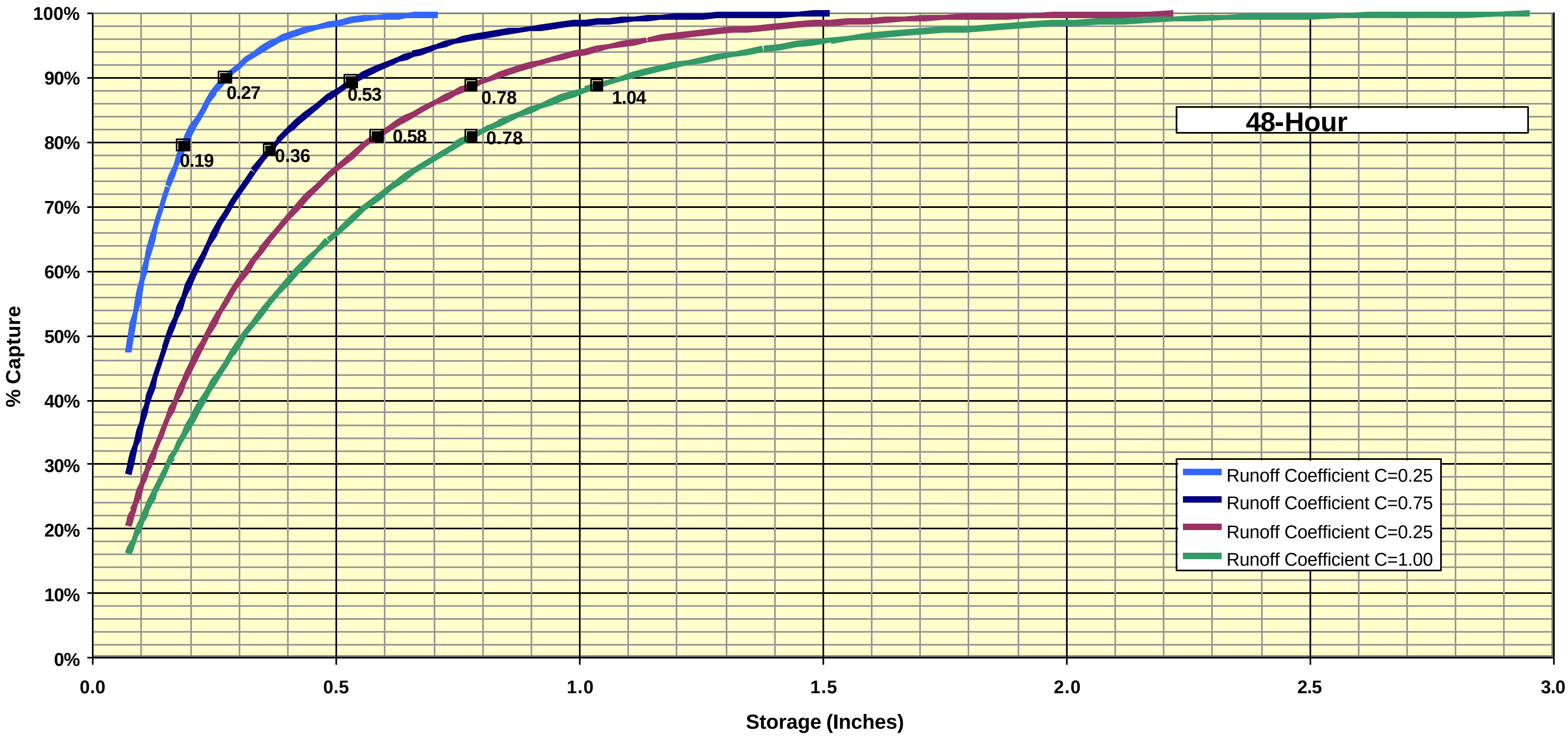


***Figure A-3***
***Volumetric BMP Sizing Curves for***
***Orange County Stormwater Quality Management Program***
***Silverado Ranger Station***

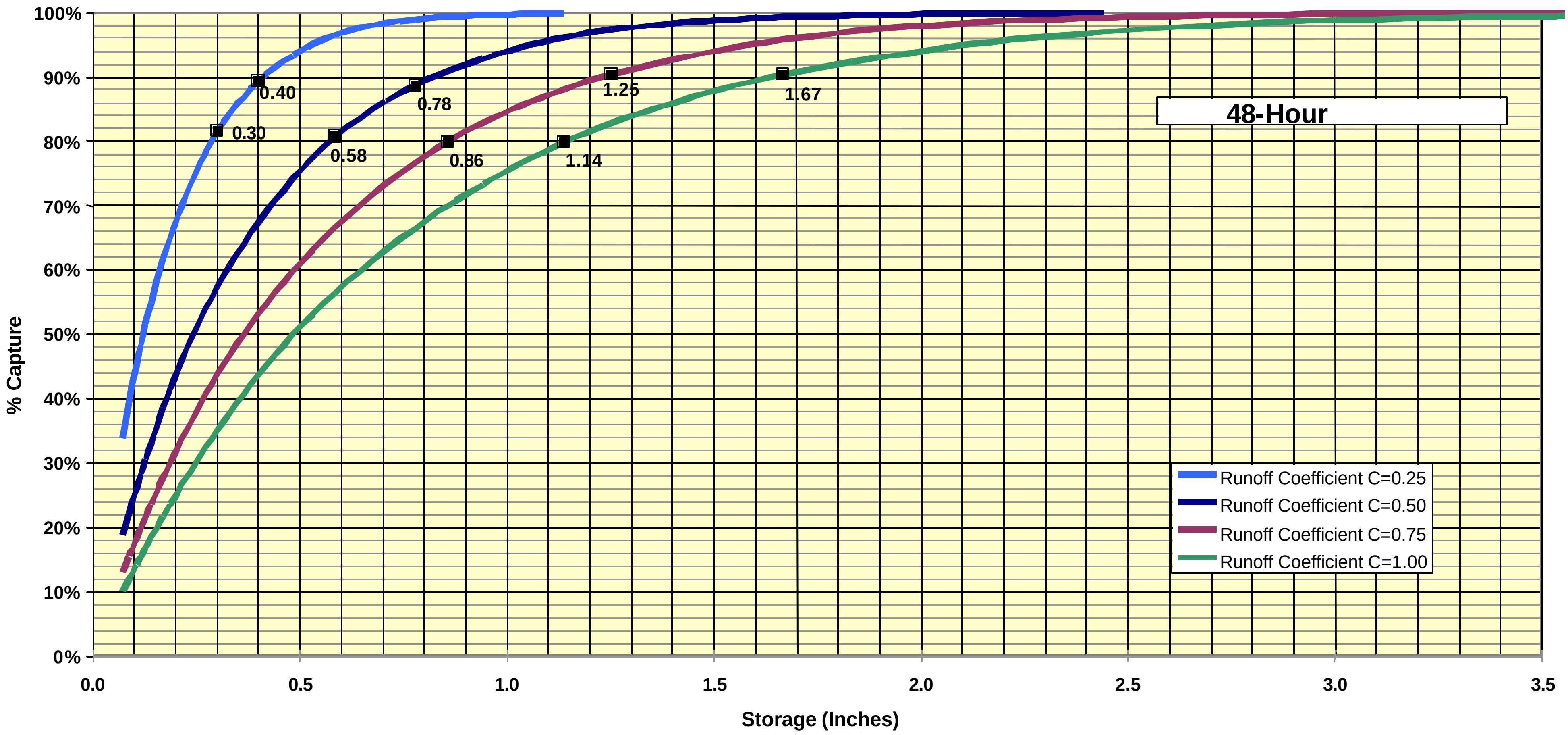


***Figure A-4***
***Volumetric BMP Sizing Curves for***
***Orange County Stormwater Quality Management Program***
***Laguna Beach***

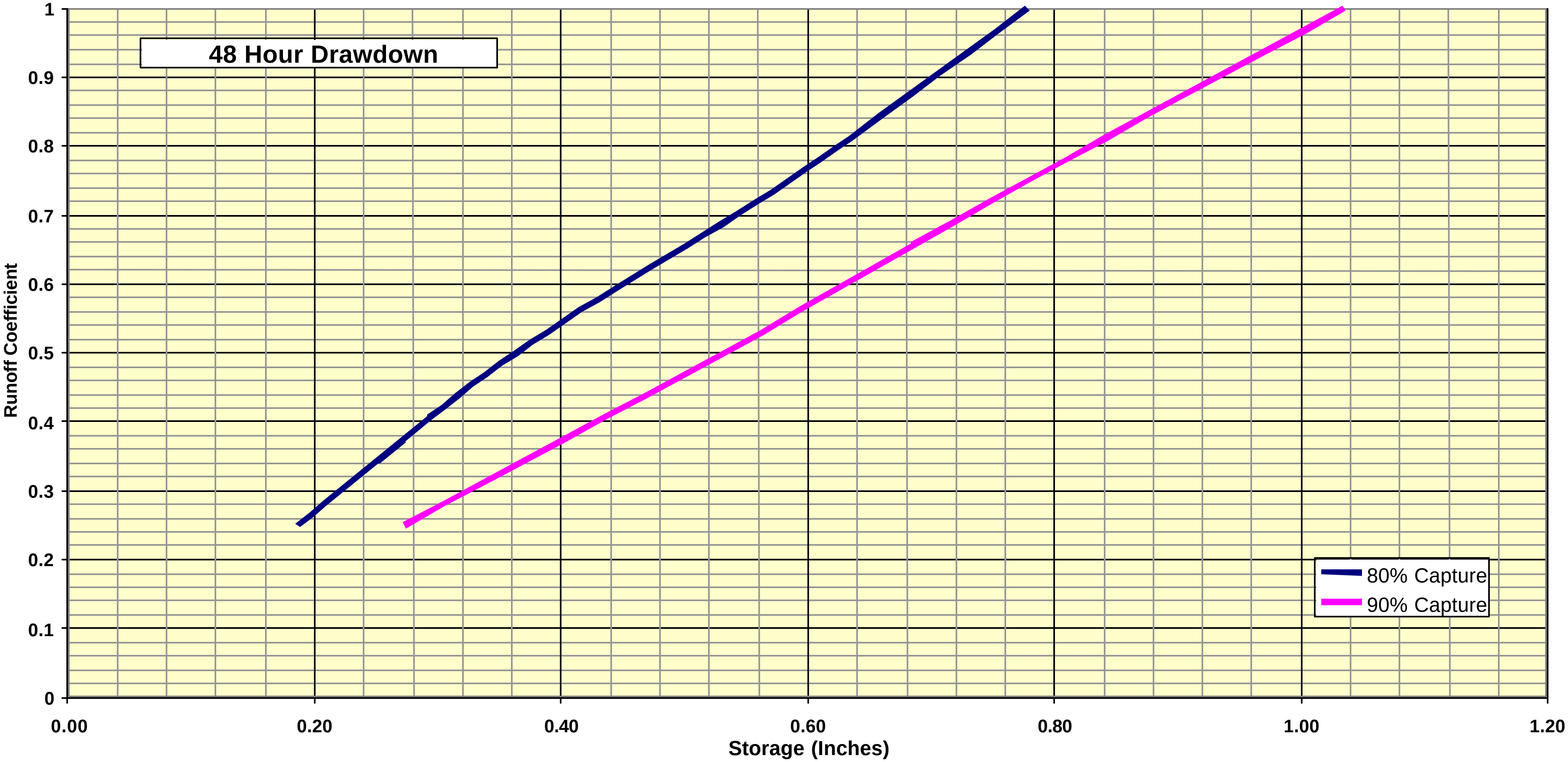
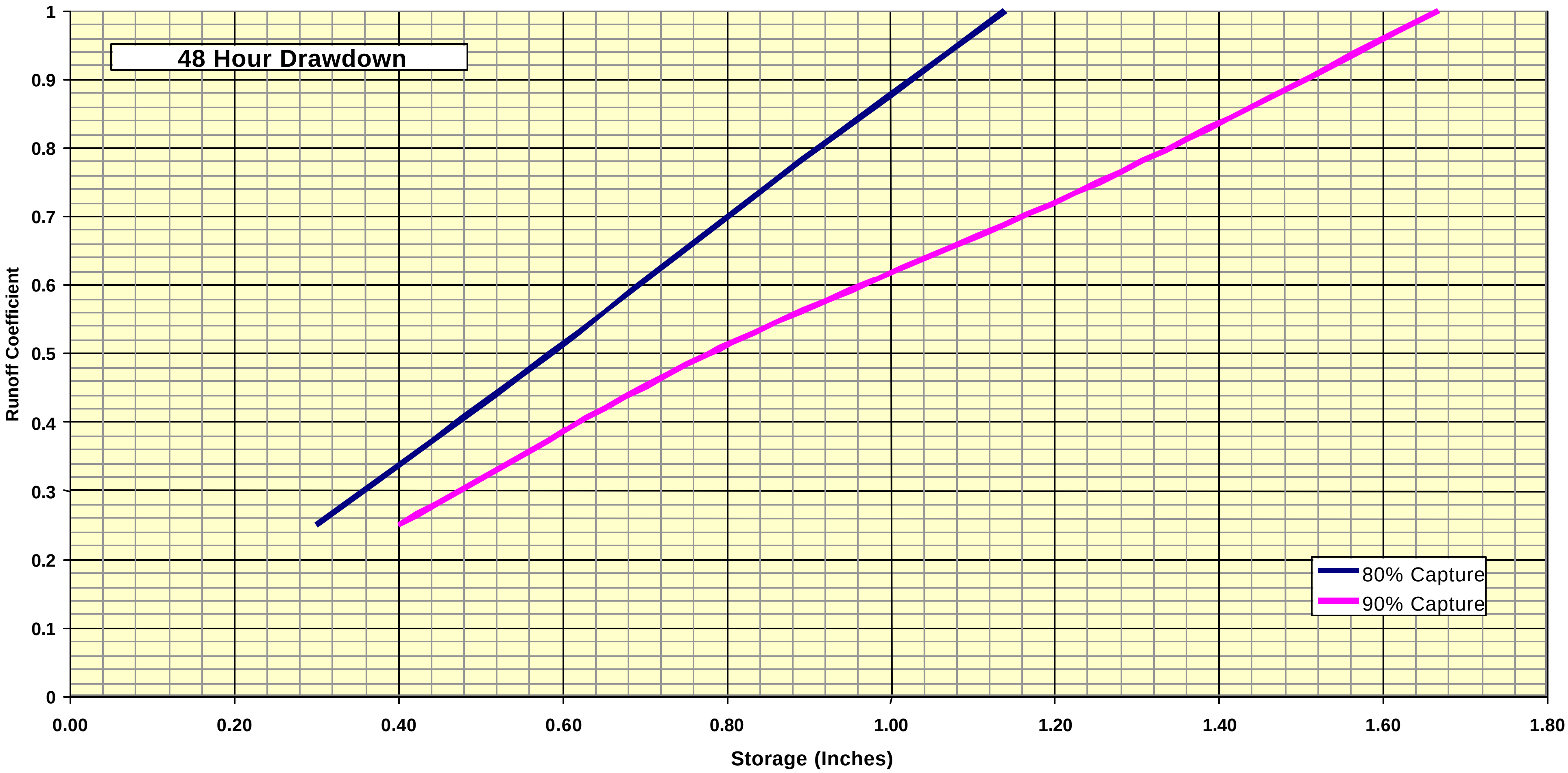


***Figure A-5***

***Volumetric BMP Sizing Curves for Orange County Stormwater Quality Management Program***

***Silverado Ranger Station***



## Peak Design Storm Hydrology

While the treatment control BMPs must be designed to function at full treatment effectiveness up to SQDF or SQDV in accordance with accepted design practices, drainage systems must also be designed to safely pass the peak design storm flows. This can be accomplished either by designing the drainage system such that higher flows or runoff volumes that exceed the SQDF or SQDV bypass the treatment control BMP ("off-line"), or by designing the BMP to safely pass the peak design flow without impacting the treatment effectiveness for the lower flow rates ("in-line").

Hydrologic calculations for determining peak design storm flows in Orange County shall be in accordance with the latest edition of the Orange County Hydrology Manual produced in January 1986, together with the procedure set forth herein. Where jurisdictions within Orange County have approved alternative hydrologic calculation methods, the alternative methods may be utilized if they have been approved by the jurisdiction for use in design of flow rate-based stormwater quality BMPs.

## ATTACHMENT B – Suggested Resources

| SUGGESTED RESOURCES | HOW TO GET A COPY |
|---|---|
| Better Site Design: A Handbook for Changing Development Rules in Your Community (1998)<br><br>Presents guidance for different model development alternatives. | Center for Watershed Protection<br>8391 Main Street<br>Ellicott City, MD 21043<br>410-461-8323<br>www.cwp.org |
| California Urban runoff Best Management Practices Handbooks (1993) for Construction Activity, Municipal, and Industrial/Commercial<br><br>Presents a description of a large variety of Structural BMPs, Treatment Control, BMPs and Source Control BMPs | Los Angeles County Department of Public Works<br>Cashiers Office<br>900 S. Fremont Avenue<br>Alhambra, CA 91803<br>626-458-6959 |
| Caltrans Urban runoff Quality Handbook: Planning and Design Staff Guide (Best Management Practices Handbooks (1998)<br><br>Presents guidance for design of urban runoff BMPs | California Department of Transportation<br>P.O. Box 942874<br>Sacramento, CA 94274-0001<br>916-653-2975 |
| Design and Construction of Urban Stormwater Management Systems, American Society of Civil Engineers (ASCE) Manuals and Reports on Engineering Practice No. 77/ Water Environment Federation (WEF) Manual of Practice FD-20, 1992. | |
| Design Manual for Use of Bioretention in Stormwater Management (1993)<br><br>Presents guidance for designing bioretention facilities. | Prince George's County<br>Watershed Protection Branch<br>9400 Peppercorn Place, Suite 600<br>Landover, MD 20785 |
| Design of Stormwater Filtering Systems (1996) by Richard A. Claytor and Thomas R. Schuler<br><br>Presents detailed engineering guidance on ten different urban runoff-filtering systems. | Center for Watershed Protection<br>8391 Main Street<br>Ellicott City, MD 21043<br>410-461-8323 |
| Development Planning for Stormwater Management, A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), (May 2000) | Los Angeles County<br>Department of Public Works<br>http://dpw.co.la.ca.us/epd/ or<br>http://www.888cleanLA.com |
| Florida Development Manual: A Guide to Sound Land and Water Management (1988)<br><br>Presents detailed guidance for designing BMPs | Florida Department of the Environment 2600 Blairstone Road, Mail Station 3570<br>Tallahassee, FL 32399<br>850-921-9472 |

| SUGGESTED RESOURCES | HOW TO GET A COPY |
|---|---|
| Guidance Manual for On-Site Stormwater Quality Control Measures, Sacramento Stormwater Management Program. | City of Sacramento Department of Utilities and County of Sacramento Water Resources Division. January 2000. |
| Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters (1993) Report No. EPA–840-B-92-002.<br><br>Provides an overview of, planning and design considerations, programmatic and regulatory aspects, maintenance considerations, and costs. | National Technical Information Service U.S. Department of Commerce<br>Springfield, VA 22161<br>800-553-6847 |
| Guide for BMP Selection in Urban Developed Areas (2001) | ASCE Envir. and Water Res. Inst.<br>1801 Alexander Bell Dr.<br>Reston, VA 20191-4400<br>(800) 548-2723 |
| Low-Impact Development Design Strategies -<br>An Integrated Design Approach (June 1999) | Prince George's County, Maryland<br>Department of Environmental Resource<br>Programs and Planning Division<br>9400 Peppercorn Place<br>Largo, Maryland 20774<br>http://www.co.pg.md.us/Government/DER/PPD/pgcounty/lidmain.htm |
| Maryland Stormwater Design Manual (1999)<br><br>Presents guidance for designing urban runoff BMPs | Maryland Department of the Environment<br>2500 Broening Highway<br>Baltimore, MD 21224<br>410-631-3000 |
| Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality, Environmental Protection Agency (EPA-440/5-87-001). | |
| National Stormwater Best Management Practices (BMP) Database, Version 1.0<br><br>Provides data on performance and evaluation of urban runoff BMPs | American Society of Civil Engineers<br>1801 Alexander Bell Drive<br>Reston, VA 20191<br>703-296-6000 |
| National Stormwater Best Management Practices Database (2001) | Urban Water Resources Research Council of ASCE<br>Wright Water Engineers, Inc.<br>(303) 480-1700 |
| Operation, Maintenance and Management of Stormwater Management (1997)<br><br>Provides a thorough look at stormwater practices including, planning and design considerations, programmatic and regulatory aspects, maintenance considerations, and costs. | Watershed Management Institute, Inc.<br>410 White Oak Drive<br>Crawfordville, FL 32327<br>850-926-5310 |
| Potential Groundwater Contamination from Intentional and Non-Intentional Stormwater Infiltration | Report No. EPA/600/R-94/051, USEPA (1994). |

| SUGGESTED RESOURCES | HOW TO GET A COPY |
|---|---|
| Preliminary Data Summary of Urban runoff Best Management Practices (August 1999)<br><br>EPA-821-R-99-012 | http://www.epa.gov/ost/stormwater/ |
| Reference Guide for Stormwater Best Management Practices (July 2000) | City of Los Angeles<br>Urban runoff Management Division<br>650 South Spring Street, 7th Floor<br>Los Angeles, California 90014<br>http://www.lacity.org/san/swmd/ |
| Second Nature: Adapting LA's Landscape for Sustainable Living (1999) by Tree People<br><br>Detailed discussion of BMP designs presented to conserve water, improve water quality, and achieve flood protection. | Tree People<br>12601 Mullholland Drive<br>Beverly Hills, CA 90210<br>(818) 623-4848<br>Fax (818) 753-4625 |
| Site Planning for Urban Stream Protection, Department of Environmental Programs, Metropolitan Washington Council of Governments | |
| Start at the Source (1999)<br><br>Detailed discussion of permeable pavements and alternative driveway designs presented. | Bay Area Stormwater Management Agencies Association<br>2101 Webster Street<br>Suite 500<br>Oakland, CA<br>510-286-1255 |
| Stormwater, Grading and Drainage Control Code, Seattle Municipal Code Section 22.800-22.808, and Director's Rules, Volumes 1-4. (Ordinance 119965, effective July 5, 2000) | City of Seattle<br>Department of Design, Construction & Land Use<br>700 5th Avenue, Suite 1900<br>Seattle, WA 98104-5070<br>(206) 684-8880<br>http://www.ci.seattle.wa.us/dclu/Codes/sgdccode.htm |
| Stormwater Management in Washington State (1999) Vols. 1-5<br><br>Presents detailed guidance on BMP design for new development and construction. | Department of Printing<br>State of Washington Department of Ecology<br>P.O. Box 798<br>Olympia, WA 98507-0798<br>360-407-7529 |
| The Stormwater Manager's Resource Center. This is a comprehensive site with information on BMP design and sizing.<br>http://www.stormwatercenter.com | |
| Stormwater Pollution Control, Municipal, Industrial and Construction NPDES Compliance, Second Edition. Roy D. Dodson, P.E., 1999. | |
| Texas Nonpoint Source Book – Online Module (1998)www.txnpsbook.org<br><br>Presents BMP design and guidance information on-line | Texas Statewide Urban runoff Quality Task Force<br>North Central Texas Council of Governments<br>616 Six Flags Drive<br>Arlington, TX 76005<br>817-695-9150 |

| SUGGESTED RESOURCES | HOW TO GET A COPY |
| --- | --- |
| The Practice of Watershed Protection by Thomas R. Shchuler and Heather K. Holland | Center for Watershed Protection<br>8391 Main Street<br>Ellicott City, MD 21043<br>410-461-8323<br>www.cwp.org |
| Urban Runoff Quality Management, American Society of Civil Engineers (ASCE) Manual and Report on Engineering Practice No. 87/Water Environment Federation (WEF) Manual of Practice No.23, 1998. | |
| Urban Storm Drainage, Criteria Manual – Volume 3, Best Management Practices (1999)<br><br>Presents guidance for des igning BMPs | Urban Drainage and Flood Control District<br>2480 West 26th Avenue, Suite 156-B<br>Denver, CO 80211<br>303-455-6277 |

**ATTACHMENT C**
**Orange County Sanitation District, Guidelines for Preventing Sewer Discharge of Surface Runoff through Wash Pads**

## Purpose and Scope

These guidelines are established pursuant to Section 203 of the Districts' Wastewater Discharge Regulations (Ordinance) as amended February 7, 1992. Section 203 provides that

No person shall discharge groundwater, surface runoff, or subsurface drainage to the Districts' sewerage facilities except as provided herein. Pursuant to section 305, et. Seq., the Districts may approve the discharge of such water only when no alternate method of disposal is reasonably available or to mitigate an environmental risk or health hazard.

The Guidelines presented herein are intended for the implementation of this policy as it applies to preventing surface runoff from entering the Districts' sewerage system through exposed wash pads.

## Application

Two sources from which surface runoff can potentially enter the Districts' sewerage system are the exposed area around the wash pad and the wash pad itself.

Exposed Area Around the Wash Pad: Appropriate measures must be taken to insure that surface runoff from the exposed area around the wash pad (e.g. parking lot, storage areas) does not enter the sewer. Surface runoff must be directed away from the sewer. Appropriate measures include grading the open area to redirect surface runoff to the storm drain; berming around the wash pad; or trenching around the wash pad with grating over the trench, and directing the collected water to a storm drain in accordance with stormwater discharge requirements.

The Wash Pad: Appropriate measures must be taken to insure that surface runoff from the wash pad itself does not enter the sewer. Provided that local regulations are satisfied, roofing will be required for all exposed wash pads, which have a total area exceeding 150 square feet. If the roof structure does not include walls, then the roofs overhang must extend a minimum of 20 percent of the roofs height. All roof drains must be routed to a storm drain.

Where rooting of exposed areas is infeasible or prohibited by local regulations, the Districts may accept the use of an automated surface runoff diversion system. [Note: This diversion system will not substitute for the appropriate measures cited above for surface runoff from the exposed area around the wash pad]. In cases where a diversion system is installed, only the first 0.1-inch of rainwater will be allowed to enter the sewer. After the first 0.1 inch of rainfall, excess rainwater must be diverted to an appropriate drainage system by use of an automated diversion system. The diversion system is subject to acceptance by the Districts. Manual methods of diversion (e.g. manual gates, removable plugs) are not acceptable. Companies are responsible for maintaining the automated diversion system in proper operating condition to ensure that no excess surface runoff from the wash pad is discharged to the sewer.

## ATTACHMENT D

## ASCE/EPA Technical Memorandum titled "Development of Performance Measures"

# Development of Performance Measures

# Task 3.1 – Technical Memorandum

# Determining Urban Stormwater Best Management Practice (BMP) Removal Efficiencies

Prepared by

**URS Greiner Woodward Clyde**
**Urban Drainage and Flood Control District**

and

**Urban Water Resources Research Council (UWRRC) of ASCE**

In cooperation with

**Office of Water**
**US Environmental Protection Agency**
**Washington, DC 20460**

July, 2 1999

## Acknowledgements

The authors, Eric Strecker and Marcus Quigley (URS Greiner Woodward Clyde), would like to thank Ben Urbonas, (Urban Drainage and Flood Control District) and Gene Driscoll for their input and guidance on the content and scope of this memorandum, and Larry Roesner, Bill Snodgrass, Bob Pitt, Terry Cooke, Eric Strassler, Jesse Pritts, and Andrew Earles for their thorough review comments and insightful discussion of the subject matter. The database structure and platform discussed herein were developed by Jonathan Jones, Jane Clary, and John O'Brein from Wright Water Engineers as members of the project team. Finally, the assistance by EPA in funding the work under this grant agreement with ASCE's Urban Water Resources Research Council is acknowledged.

## Scope of Memorandum

This memorandum is intended for use in this cooperative research effort as an outline and description of the methodology for Task 3.0, Data Exploration and Evaluation. Although the memorandum describes, in detail, methods to be used for analysis of stormwater best management practices, the discussion included here is not inclusive of all of the issues relevant to the subject and is not intended as a "guidance manual" of analysis techniques. The application of the approach should be limited to the current scope of this project until the methods and issues described have been further explored and reviewed by the Team, ASCE(UWRRC), and EPA.

# Table of Contents

# ASCE/EPA
# Determining Urban Stormwater Best Management Practice (BMP) Removal Efficiencies
# May, 14 1999

## TECHNICAL MEMORANDUM - TASK 3.1
## Development of Performance Measures

## 1 Overview

The purpose of this cooperative research effort between EPA and the American Society of Civil Engineers (ASCE) is to develop a more useful set of data on the performance and effectiveness of individual best management practices (BMPs), specifically by assessing the relationship between measures of effectiveness and BMP design. BMP monitoring data should not only be useful for a particular site, but should also be useful for comparing data collected in studies of both similar and different types of BMPs in other locations and with different design attributes. Almost all past BMP monitoring studies have provided very limited data that is useful for comparing BMP design and selection. This technical memorandum provides an overview of methods for evaluating the efficiency, performance, and effectiveness of best management practices (BMPs) through analysis of water quality, flow, and precipitation data for monitored storm events as well as BMP design attributes collected and stored in the National Stormwater (NSW) Best Management Practices Database. Furthermore, it provides a specific description of the methods that will be used to conduct the data exploration and evaluation, described under Tasks 3.2-3.4 of this project. These methods provide the basic techniques for analyzing data manually and a preliminary basis for integrated analysis tools to be built into the database in the future.

### 1.1 Definition of Terms

In order to better clarify the terminology used to describe the level of treatment achieved and how well a device, system, or practice meets its goals, definitions of some terms, often used loosely in the literature, are provided here. These terms help to better specify the scope of monitoring studies and related analyses.

- Best Management Practice (BMP) **-** A device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters.
- BMP System **-** A BMP system includes the BMP and any related bypass or overflow. For example, the efficiency (see below) can be determined for a offline retention (Wet) Pond either by itself (as a BMP) or for the BMP system (BMP including bypass)
- Performance **-** measure of how well a BMP meets its goals for stormwater that the BMP is designed to treat.
- Effectiveness **-** measure of how well a BMP system meets its goals in relation to all stormwater flows
- Efficiency **-** measure of how well a BMP or BMP system removes pollutants.

The primary focus of the data exploration and evaluation will be to determine efficiency of BMPs and BMP systems and to elucidate relationships between design and efficiency. In addition, effectiveness and performance will be evaluated, acknowledging the limitations of existing information about the goals of specific BMP projects. Quantification of efficiency only evaluates a portion of the overall performance or effectiveness of a BMP or BMP system. Calculation of the efficiency, however, does help to determine additional measures of performance and effectiveness, for example the ability of a BMP to meet any regulatory goals based on percent removal. A list of typical goals and the current ability of the ASCE/EPA project to help evaluate them is shown in Table 1.1.

Table 1.1 Goals of BMP Projects and the Ability of the National Stormwater BMP Database to Provide Information Useful for Determining Performance and Effectiveness

| **Goals of BMP Projects** | | **Ability to Evaluate Performance and Effectiveness** |
|---|---|---|
| **Category** | | |
| Hydraulics | • Improve flow characteristics upstream and/or downstream of BMP | - |
| Hydrology | • Flood mitigation, improve runoff characteristics (peak shaving) | ✓ |
| Water Quality (Efficiency) | • Reduce downstream pollutant loads and concentrations of pollutants | ✓ |
| | • Improve/minimize downstream temperature impact | ✓ |
| | • Achieves desired pollutant concentration in outflow | ✓ |
| | • Removal of litter and debris | - |
| Toxicity | • Reduce acute toxicity of runoff | ✓[1] |
| | • Reduce chronic toxicity of runoff | ✓[1] |
| Regulatory | • Compliance with NPDES permit | - |
| | • Meet local, state, or federal water quality criteria | ✓[2] |
| Implementation Feasibility | • For non-structural BMPs, ability to function within management and oversight structure | - |
| Cost | • Capital, operation, and maintenance costs | ✓[1] |
| Aesthetic | • Improve appearance of site | - |
| Maintenance | • Operate within maintenance, and repair schedule and requirements | ✓[1] |
| | • Ability of system to be retrofit, modified or expanded | ✓ |
| Longevity | • Long term functionality | ✓[1] |
| Resources | • Improve downstream aquatic environment/erosion control | |
| | • Improve wildlife habitat | - |
| | • Multiple use functionality | - |
| Safety, Risk and Liability | • Function without significant risk or liability | - |
| | • Ability to function with minimal environmental risk downstream | - |
| Public Perception | • Information is available to clarify public understanding of runoff quality, quantity and impacts on receiving waters | ✓ |

✓ can be evaluated using the ASCE/EPA Database as information source
✓[1] will be able to be evaluated using the database as primary source of information after enough studies have been submitted
✓[2] can be evaluated using the database as the primary source of information combined with a secondary source of comparative data
\- can be evaluated only qualitatively through included comments by reviewer or author, or are unable to be evaluated at this time

The term event mean concentration (EMC) is used throughout this memorandum. The EMC is a statistical parameter used to represent the flow-proportional average concentration of a given parameter during a storm event. It is defined as the total constituent mass divided by the total runoff volume. It is often estimated via the collection of multiple flow volume triggered grab samples that are composited for analysis. When combined with flow measurement data, the EMC can be used to estimate the pollutant loading from a given storm.

## 1.3 BMPs Types and Implications for Calculation of Efficiency

The issues involved in selection of methods for quantifying efficiency, performance, and effectiveness are complex. It would be difficult, at best, to find one method that would cover the data analysis requirements for the widely varied collection of BMP types and designs found in the NSW Database. When analyzing efficiency, it is convenient to classify BMPs according to one of the following four distinct categories:

- BMPs with well-defined inlets and outlets whose primary treatment depends upon extended detention storage of stormwater, (e.g., wet and dry ponds, wetland basins, underground vaults)
- BMPs with well-defined inlets and outlets that do not depend upon significant storage of water, (e.g., sand filters, swales, buffers, structural "flow-through" systems)
- BMPs that do not have a well defined inlet and/or outlet (e.g., retention, infiltration, porous pavement)
- Widely distributed BMPs that use reference watersheds to evaluate effectiveness, (e.g., catch basin retrofits; education programs)

Any of the above can also include evaluations where the BMP's efficiency was measured using before and after or paired watershed comparisons of water quality.

The difficulty in selection of measures of efficiency stems not only from the desire to compare a wide range of BMPs, but also from the large number of methods currently in use. There is much variation and disagreement in the literature about what measure of efficiency is best applied.

## 1.4 Relationship Between Monitoring Study Objective and Data Analysis

In developing a method for quantifying BMP performance of effectiveness, it is helpful to look at the objectives of previous studies seeking such a goal. BMP studies usually are conducted to obtain information regarding one or more of the following objectives:

- What degree of pollution control does the BMP provide under typical operating conditions?
- How does efficiency vary from pollutant to pollutant?
- How does efficiency vary with various input concentrations?
- How does efficiency vary with storm characteristics such as rainfall amount, rainfall density, antecedent weather conditions?
- How do design variables affect performance?
- How does efficiency vary with different operational and/or maintenance approaches?
- Does efficiency improve, decay, or remain the stable over time?
- How does the BMP's efficiency, performance, and effectiveness compare relative to other BMPs?
- Does the BMP reduce toxicity to acceptable levels?
- Does the BMP cause an improvement or protect in downstream biotic communities?
- Does the BMP have potential downstream negative impacts?

The monitoring efforts implemented most typically seek to answer a small subset of the above questions. This often leaves larger questions about the efficiency, performance and effectiveness of the BMP, and the relationship between design and efficiency, unanswered. The goal of this document is develop a recommended approach to utilize the National Stormwater BMP Database to evaluate BMP data that have been entered such that some of or all of the above questions about BMP efficiency can be assessed where sufficient data is available.

## 1.5 Physical Layout and Its Effect on Efficiency and Its Measure

The estimation of the efficiency of BMPs is often approached in different ways based on the goals of the researcher. A BMP can be evaluated by itself or as part of an overall BMP system. The efficiency of a BMP not including bypass or overflow may be dramatically different than the efficiency of an overall system. Bypasses and overflows can have significant effects on the ability of a BMP to remove constituents and appreciably reduce the efficiency of the system as a whole. Researchers who are interested in comparing the efficiency of an offline wet pond and an offline wetland may not be concerned with the effects of bypass on a receiving water. On the other hand, another researcher who is comparing offline wet ponds with online wet ponds would be very interested in the effects of the bypass. Often detailed information about the bypass of the BMP is not available for analysis. In some cases, comprehensive inflow and outflow measurements allow for the calculation of a mass balance that can be used to estimate bypass flow volumes. Estimations of efficiency of a BMP system can be based on these mass balance calculations coupled with sampling data.

The efficiency of a BMP system or a BMP can be directly effected by the way in which an operator chooses to manage the system. This is the case where parameters of a design can be adjusted, (e.g., adjustments to the height of an overflow/bypass weir or gate). These adjustments can vary the efficiency considerably. In order to analyze a BMP or BMP system thoroughly, all static and state variables of the system must be known.

## 1.6 Relevant Period of Impact

The period of analysis used in an efficiency calculation is important. The period used should take into account how the parameter of interest varies with time. This allows for observation of relevant changes in the efficiency of the BMP on the time scale in which these changes occur. For example, in a wetland it is often observed that during the growing season removal efficiency increases for nutrients. The opposite effect may be observed during the winter months or during any period where decaying litter and plant material may contribute significantly to export of nutrients and, potentially, other contaminants. Therefore, the efficiency calculations may need to be made based on data collected over a few months or seasonally. This variation of efficiency on a temporal scale is extremely important in understanding how BMPs function.

In addition to observing how factors, such as climate, affect efficiency as a function of time, it is important to relate the calculation period to the potential impact a given constituent would have on the receiving water. For example, it may not be useful to study the removal of a chlorinated organic for a short period of record when the negative impacts of such a contaminant are generally expressed over a long time scale. Likewise, some parameters (e.g., temperature, BOD, DO, pH, TSS and metals) may have a significant impact in the near term.

Toxicity plays a major role in evaluating what time period should be used to analyze efficiency. Specific constituents that are acutely toxic require a short-term analysis on an "intra-storm" basis. Where dilution is significant and/or a constituent is toxic on a chronic basis, long-term analysis that demonstrates removal of materials on a sum of loads or average EMC basis may be more appropriate. Many contaminants may have both acute and chronic effects in the aquatic environment. These contaminants should be evaluated over both periods of time. Similarly, hydraulic conditions merit both short and long term examination. Event peak flows are examples of short-term data, while seasonal variations of the hydrologic budget due to the weather patterns are examples of long-term data. Examples of water quality parameters and their relationship to the time scale over which they act are given in Table 1.2.

Table 1.2

| **Time Scale for Analysis** | **Water Quality Parameter** |
|---|---|
| Short Term | BOD, DO |
| Long Term | Organics, Carcinogens |
| Both Short and Long Term | Metals, TSS, Nitrogen, Phosphorous, Temperature, pH, Pesticides |

# 2 Example Study for Examination of Efficiency Calculation Methods

In order to discus and contrast the various methods that have been employed for estimating the efficiency of BMPs, an example data set was utilized. The examples taken from this data set are based upon data from *Three Design Alternatives for Stormwater Detention Ponds*, (Rushton, Miller, Hull and Cunningham, 1997). The study was conducted by the Southwest Florida Water Management District (SWFWMD). The single pond studied with different design attributes was located at the SWFWMD Service office in Tampa. The following quote from the executive summary of the report describes the site:

> *The drainage basin is 6.5 acres with about 30 percent of the watershed covered by roof tops and asphalt parking lots, 6 percent by a crushed limestone storage compound and the remaining 64 percent as a grassed storage area. The impervious surfaces discharge to ditches which provide some pre-treatment before stormwater enters the pond. During the first year of the study (1990), the pond was shallow and completely vegetated with a permanent pool less than one foot deep and an average wet season residence time of two days. In the second year (1993), the vegetated littoral zone covered 35 % of the pond area and the volume of the permanent pool was increased to include a five-day residence time by excavating the pond to five feet. For the final year (1994), the vegetated littoral zone was planted with desirable species, the depth of the pond was kept at five feet and the area of the permanent pool was enlarged for a calculated wet season residence time of 14 days.*

This example study was chosen due its comprehensive data set and its ability to demonstrate the effects of changes in efficiency based on design variations. The pond study also demonstrates the potential effects of average wet season residence time on the calculated performance of the BMP. All calculations included in this memorandum are based on the raw data provided in the report as stored in the National Stormwater Best Management Practices Database at this time. The values reported in the SWFWMD report are given in Table 2.1 for comparison. Two methods were used by SWFWMD to enumerate effectiveness, 1) the *Summation of Loads* and, 2) the *Efficiency Ratio*. Both of these methods are described in more detail in Section 3 of this memorandum.

Table 2.1

| | TSS Percent Removal Reported by SWFWMD | | |
|---|---|---|---|
| **Method** | **1990** | **1993-1994** | **1994-1995** |
| Efficiency Ratio (EMC) | 61 | 69 | 95 |
| Summation of Loads | 71 | 67 | 94 |
| **Other Information** | | | |
| Number of Rain Events (>0.05 in) | 53 | 60 | 83 |
| Percent Monitored | 43 | 50 | 56 |
| Average Depth of Monitored Storms | 0.53 inch | 0.57 inch | 0.53 inch |
| Total Rainfall During Monitoring Period | 28 inch | 34 inch | 44 inch |

Differences between the values calculated for the examples given in this memo and the values reported in the SWFWMD report were checked thoroughly and it was determined that the cause for the difference in reported efficiencies is due to rounding of each flow weighted sample value in the SWFWMD report. All of the calculations in this memo were based on the digital data provided by SWFWMD, which were not rounded. SWFWMD also excluded some of the values in their final analysis of the BMP during the 1993-1994 water year due to a leaking water main and problems with the rain collector used on site. This change to the data set used for calculating performance had no net effect on the efficiency reported for TSS. The examples in this document use the entire data set.

# 3 Review of Commonly Used Efficiency Calculation Methods

A variety of pollutant removal methods have been utilized in BMP monitoring studies to evaluate efficiency. This section describes and gives examples of methods employed by different investigators. One of five methods are typically used by investigators for the calculation of BMP efficiency:

- Efficiency ratio
- Summation of loads
- Regression of loads
- Mean concentration
- Efficiency of individual storm loads
- Reference watersheds and before/after studies

Although these methods do present a summary of efficiency, they do not look at removal statistically, and thus, do not provide enough information to determine if the differences in inflow and outflow water quality measures are statistically significant. Previous studies comparing BMP efficiency for a number of BMPs statistically examined reported removal efficiencies that were based upon various efficiency calculation methods. The National Stormwater Best Management Practices Database allows for the consistent calculation of efficiencies for each of the BMPs based on event data. Calculating efficiency on this basis makes detailed statistical analysis possible. Section 4 of this memorandum describes and gives examples of the methodology that will be used in Tasks 3.2-3.4 of the project. This selected methodology, the Lognormal Statistical Efficiency (LSE) is an expansion of the efficiency ratio method (ER). The LSE method fully describes the statistical distribution of water quality upstream and downstream of BMPs and determines if differences in water quality are statistically significant.

## 3.1 Efficiency Ratio

### Definition

The efficiency ratio is defined in terms of the average event mean concentration (EMC) of pollutants over some time period:

$$ER = 1 - \frac{\text{average outlet EMC}}{\text{average inlet EMC}} = \frac{\text{average inlet EMC - average outlet EMC}}{\text{average inlet EMC}}$$

EMCs can be either collected as flow weighted composite samples in the field or calculated from discrete measurements. The EMC for an individual event or set of field measurements, where discrete samples have been collected, is defined as:

$$EMC = \frac{\sum_{i=1}^{n} V_i C_i}{\sum_{i=1}^{n} V_i}$$

where,

| | |
|---|---|
| V: | volume of flow during period i |
| C: | average concentration associated with period i |
| n: | total number of measurements taken during event |

The arithmetic average EMC is defined as,

$$\text{average EMC} = \frac{\sum_{j=1}^{m} EMC_j}{m}$$

where,

m: number of events measured

In addition, the log mean EMC can be calculated using the logarithmic transformation of each EMC. This transformation allows for normalization of the data for statistical purposes.

$$\text{Mean of the Log EMCs} = \frac{\sum_{j=1}^{m} Log\left(EMC_j\right)}{m}$$

Estimates of the arithmetic summary statistics of the population (mean, median, standard deviation, and coefficient of variation) should be based on their theoretical relationships (Appendix A) with the mean and standard deviation of the transformed data. Computing the mean and standard deviation of log transforms of the sample EMC data and then converting them to an arithmetic estimate often obtains a better estimate of the mean of the population due to the more typical distributional characteristics of water quality data. This value will not match that produced by the simple arithmetic average of the data. Both provide an estimate of the population mean, but the approach utilizing the log-transformed data tends to provide a better estimator, as it has been shown in various investigations that pollutant, contaminant and constituent concentration levels have a log-normal distribution (NURP, 1983). As the sample size increases, the two values converge.

## Assumptions

This method

- Weights EMCs from all storms equally regardless of relative magnitude of storm. For example a high concentration/high volume event has equal weight in the average EMC as a low concentration/low volume event. The logarithmic approach tends to minimize the difference between the EMC and mass balance calculations.

- Is most useful when loads are directly proportional to storm volume. For work conducted on nonpoint pollution (i.e., inflows), the EMC has been shown to not vary significantly with storm volume. This lends credence to using the average EMC value for the inflow but does not provide sufficient evidence that outflows are well represented by average EMC. Accuracy of this method will vary based on the BMP type.

- Minimizes the impacts of smaller/cleaner storm events on actual performance calculations. For example, in a storm by storm efficiency approach, a low removal value for such an event is weighted equally to a larger value.

- Allows for the use of data where portions of the inflow or outflow data are missing, based on the assumption that the inclusion of the missing data points would not significantly impact the calculated average EMC.

## Comments

This method

- Is taken directly from non-point pollution studies and does a good job characterizing inflows to BMPs but fails to take into account some of the complexities of BMP design. For example, some BMPs may not have outflow EMCs that are normally distributed (e.g., a media filter that treats to a relatively constant level that is independent on inflow concentrations).

- Assumes that if all storms at the site had been monitored, the average inlet and outlet EMCs would be similar to those that were monitored.

## Example

The example calculations given below are for the Tampa Office Pond using arithmetic average EMCs in the efficiency ratio method.

| Period of Record | Average EMC In | Average EMC Out | Efficiency Ratio |
|---|---|---|---|
| 1990 | 27.60 | 11.18 | 0.59 |
| 1993-1994 | 34.48 | 12.24 | 0.64 |
| 1994-1995 | 131.43 | 6.79 | 0.95 |

## 3.2 Summation of Loads

### Definition

The summation of loads method defines the efficiency based on the ratio of the summation of all incoming loads to the summation of all outlet loads, or:

$$\mathrm{SOL} = 1 - \frac{\text{sum of outlet loads}}{\text{sum of inlet loads}}$$

The sum of outlet loads are calculated as follows:

$$\text{sum of loads} = \sum_{j=1}^{m}\left(\sum_{i=1}^{n} C_i V_i\right) = \sum_{j=1}^{m} EMC_j \cdot V_j$$

### Assumptions

- Removal of material is most relevant over entire period of analysis.
- Monitoring data accurately represents the actual entire total loads in and out of the BMP for a period long enough to overshadow any temporary storage or export of pollutants.
- Any significant storms that were not monitored had a ratio of inlet to outlet loads similar to the storms that were monitored.
- No materials were exported during dry periods, or if they were, the ratio of inlet to outlet loads during these periods is similar to the ratio of the loads during the monitored storms.

### Comments

- A small number of large storms typically dominate efficiency.
- If toxics are a concern then this method does not account for day to day releases, unless dry weather loads in and out are also accounted for.
- Based on mass balance.

### Example of Summation of Loads for TSS Using the Tampa Office Pond

| Period of Record | Sum of Loads In (kg) | Sum of Loads Out (kg) | SOL Efficiency |
|---|---|---|---|
| 1990 | 134.60 | 39.67 | 0.71 |
| 1993-1994 | 404.19 | 138.44 | 0.66 |
| 1994-1995 | 2060.51 | 130.20 | 0.94 |

## 3.3 Regression of Loads (ROL), Martin and Smoot (1986)

### Definition

The regression of loads method defines the regression efficiency as the slope of a least squares linear regression of inlet loads and outlet loads of pollutants, with the intercept constrained to zero. The equation for the ROL efficiency is:

$$\text{Loads out} = b \bullet \text{Loads in} = b - \frac{\text{Loads out}}{\text{Loads in}}$$

The percent reduction in loads across the BMP is estimated as:

$$\text{Percent Removal} = 1 - b = 1 - \frac{\text{Loads out}}{\text{Loads in}}$$

### Assumptions

- The assumptions for this method are identical to the assumptions for the *Summation of Loa*ds method.

### Comments

- A few data points often control the slope of line due to clustering of loads about the mean storm size. Regressions are best used where data is equally populous through the range to be examined. This is readily observed in the examples that follow (See Figures 3.1 and 3.3).

- The process of constraining the intercept of the regression line to the origin is questionable and in some cases could significantly misrepresent the data. It may be more useful to apply the *Regression of Loads* method over some subset of the data without requiring that the intercept be constrained to the origin. The problem with this alternative approach is that a large number of data points are required in order to get a good fit of the data. Often (See Figure 3.1) a meaningful regression cannot be made using the data that was collected. This is well illustrated by the very low $R^2$ values in the table below. Forcing the line though the origin, in these cases, provides a regression line even where no useful trend is present.

- There is sufficient evidence that this first order polynomial (straight line) fit is not appropriate over a large range of loadings. Very small events are much more likely to demonstrate low efficiency where larger events may demonstrate better overall efficiency depending on the design of the BMP.

### Example of ROL Efficiency Results for TSS in the Tampa Office Pond

| **Period of Record** | **Slope of Regression Line** | **$R^2$** | **Percent Removal** |
|---|---|---|---|
| 1990 | 0.21 | 0.06 | 0.79 |
| 1993-1994 | 0.18 | -0.06 | 0.82 |
| 1994-1995 | 0.05 | 0.46 | 0.95 |

The regressions used to arrive at the above slopes are given in Figures 3.1-3.3.

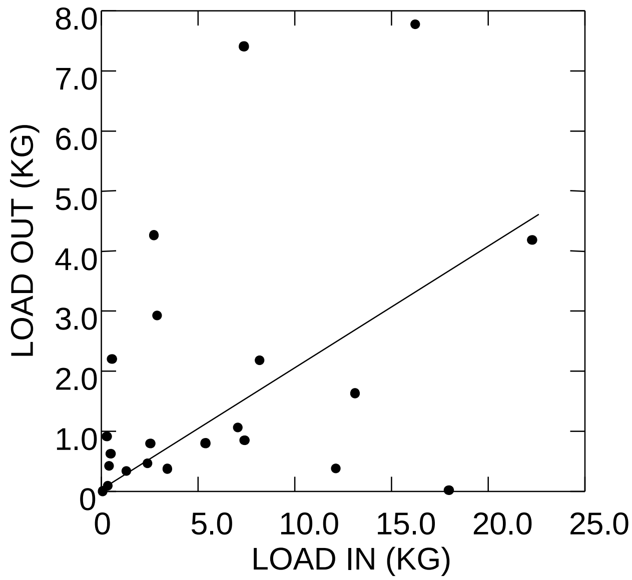



Figure 3.1 ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1990) (Slope = 0.2135, $R^2$ = 0.0563, Standard Error in Estimate = 2.176, one point is considered an outlier with a Studentized Residual of 3.304). All points were used for regression.

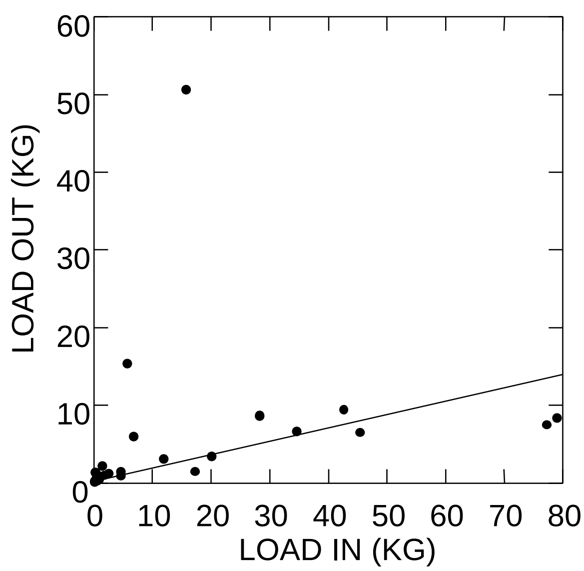



Figure 3.2 ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1993-1994) (Slope = 0.1801, $R^2$ = -0.0562, Standard Error in Estimate = 10.440, One point is considered an outlier with a Studentized Residual of 13.206 and one point has a high Leverage of 0.323). All points were used for regression.

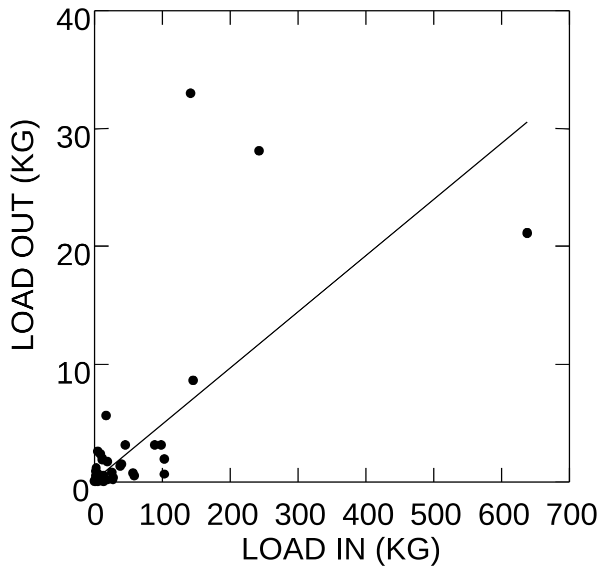



Figure 3.3 ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1994-1995) (Slope = 0.0492, $R^2$ = 0.4581, Standard Error in Estimate = 5.260, three points are considered outliers (Studentized Residuals of 3.724, 8.074, and –4.505, The point to the far right on the graph has large Leverage (0.724) and Influence, Cook Distance = 36.144). All points were used for regression.

## 3.4 Mean Concentration

### Definition

The mean concentration method defines the efficiency as unity minus the ratio of the average outlet to average inlet concentrations. The equation using this method is, thus:

$$MC = 1 - \frac{\text{average outlet concentration}}{\text{average inlet concentration}}$$

This method does not require that concentrations be flow weighted. This method might have some value for evaluating grab samples where no flow weighted data is available or where the period of record does not include the storm volume.

### Assumptions

- The flows from which the samples were taken are indicative of the overall event.

### Comments

- This method may be useful for calculating BMP's effectiveness in reducing acute toxicity immediately downstream of the BMP. This is due to the fact that acute toxicity is measured as a threshold concentration value of a specific constituent in the effluent at or near the point of discharge. If more than one sample per event is analyzed, this method would result in more information on potential toxicity reduction.

- Weights individual samples equally. Biases could occur due to variations in sampling protocols or sporadic sampling (i.e., collectively many samples close in time and others less frequently. The sample collection program specifics are not accounted for in the method and estimated efficiencies are often not comparable between studies.

- This method does not account for storage capacity. Typically BMP's will have an equal or lesser volume of outflow than of inflow, on a mass basis this affects removal, since volume (or flow) is used with concentration to determine mass for a storm event,

$$1 - \frac{C_{out}V_{out}}{C_{in}V_{in}} \geq 1 - \frac{\text{average outlet concentration}}{\text{average inlet concentration}}$$

where:

$C_{in}$: Concentration In
$C_{out}$: Concentration Out
$V_{in}$: Volume In
$V_{out}$: Volume Out

In this respect, it is often more conservative (i.e., lower removal efficiency stated) to use concentration rather than mass-based removal.

## 3.5 Efficiency of Individual Storm Loads

### Definition

The Efficiency of Individual Storm Loads (ISL) method calculates a BMP's efficiency for each storm event based on the loads in and the loads out. The mean value of these individual efficiencies can be taken as the overall efficiency of the BMP. The efficiency of the BMP for a single storm is given by:

$$\text{Storm Efficiency} = 1 - \frac{Load_{out}}{Load_{in}}$$

The average efficiency for all monitored storms is thus:

$$\text{Average Efficiency} = \frac{\sum_{j=1}^{m} \text{Storm Efficiency}_{j}}{m}$$

where,

m: number of storms

### Assumptions

- Storm size or other storm factors do not play central roles in the computation of average efficiency of a BMP.
- Storage and later release of constituents from one storm to the next is negligible.
- The selection of storms monitored does not significantly skew the performance calculation.

### Comments

- The weight of all storms is equal. Large storms do not dominate the efficiency in this scenario. The efficiency is viewed as an average performance regardless of storm size.
- Some data points are not able to be used due to the fact that there is not a corresponding measurement at either the inflow or the outflow for a particular storm, and thus an efficiency cannot always be calculated on a storm by storm basis. This is not true for the ER method, however it is a limitation of the Summation of Load Method.
- Storm by storm analysis neglects the fact that the outflow being measured may have a limited relationship to inflow in BMPs that have a permanent pool. For example, if a permanent pool is sized to store a volume equal to the average storm, about 60 to 70 percent of storms would be less than this volume [from studies conducted using SYNOP (EPA, 1989)].

## Example of Efficiency of Individual Storm Loads for TSS in the Tampa Office Pond

| Period of Record | Efficiency |
|---|---|
| 1990 | 0.29 |
| 1993-1994 | -0.02 |
| 1994-1995 | 0.89 |

## 3.6 Reference Watershed Methods

## Discussion

Many BMPs do not allow for comparison between inlet and outlet water quality parameters. In addition it is often difficult or costly, where there are many BMPs being installed in a watershed (e.g., retrofit of all catch basins), to monitor a large number of specific locations. Often a reference watershed is used to evaluate the effectiveness of a given BMP or multiple BMPs of the same type. The database allows for a watershed and all associated data to be identified for use as a reference watershed. One of the primary reasons for using a reference watershed is that there is no clearly defined inlet or outlet point at which to monitor water quality. Such is the case with many non-structural BMPs, porous pavements, and infiltration practices.

The difficulty in determining the effectiveness of a BMPs using reference watersheds stems from the large number of variables typically involved. When setting up a BMP monitoring study, it is advantageous to keep the watershed characteristics of the reference watershed and the test watershed as similar as possible. Unfortunately, finding two watersheds that are similar is often quite difficult and the usefulness of the data can be compromised as a result. In order to attempt to determine the effectiveness of a BMP based on a reference watershed, an accurate accounting of the variations between the watersheds, operational, and environmental conditions is needed. The database explicitly stores some of the key parameters required for normalization of watershed and environmental conditions.

The most obvious parameter used to normalize watershed characteristics is area. If the ratio of land uses and activities within each watershed is identical in both watersheds then the watershed area can be scaled linearly. Additionally, the loads found at each downstream monitoring station, for each event, can be scaled linearly with area as well. Difficulty arises when land use in the reference watershed is not found in the same ratio. In this case, either the effects of land use must be ignored or a portion of the load found for each event must be allocated to a land use and then scaled linearly as a function of the area covered by that land use. In many cases, the differences in land use can be ignored, (e.g., between parking lots with relatively small, but different unpaved areas). The effect of the total impervious area is relevant and provided in the database in all cases and can be used to normalize the water quality data collected. The ratio of the total impervious areas can be used to scale event loads. Scaling the loads based on impervious areas would be best used where it is determined that the majority of pollutants are from runoff from the impervious areas (e.g., parking lots), or the contaminant of interest primarily results from deposition on impervious surfaces, (e.g., TSS in a highly urban area). Methods that attempt to determine BMP performance from poorly matched watersheds yield poor results at best. As the characteristics of the two watersheds diverge, the effect of the BMP is masked by the large number of variables in the system; the noise in the data becomes greater than the signal.

The analysis of BMPs utilizing reference watersheds also requires incorporation of operational details of the system, (e.g., frequency of street sweeping, type of device used, device setup). The database asks users to provide the frequency, extent, and other operational parameters for nonstructural BMPs. If the BMP is an alteration of the frequency of a certain practice, the system can be viewed in two ways, (1) as a control/test system, or (2) as a series of data aimed at quantifying the continuous effect of increasing or decreasing BMP frequency. In the first case the BMP can be analyzed in a manner similar to other BMPs with reference watersheds. In the second case, the loads realized at the monitoring stations need to be correlated with the frequency using some model for the effectiveness of the practice per occurrence.

### 3.7 Summary and Comparison of Methods from the Examples

The table below shows the results of the various methods shown above for calculation of efficiency for the Tampa Office Pond. It can be seen that the four methods demonstrated (mean concentration method was not applicable to data available from the Tampa Office Pond study) vary widely in their estimates of percent removal depending on the assumptions of each method as discussed above.

| | Method | | | |
|---|---|---|---|---|
| Design | Efficiency Ratio (ER) | Summation of Loads (SOL) | Regression of Loads (ROL) | Efficiency of Individual Storms |
| 1990 | 0.59 | 0.71 | 0.79 | 0.29 |
| 1993-1994 | 0.64 | 0.66 | 0.82 | -0.02 |
| 1994-1995 | 0.95 | 0.94 | 0.95 | 0.89 |

## 4 Proposed Methods for Calculation of Efficiency

This section describes methods that will be used in Task 3.2 of the project to quantify efficiency of each BMP currently stored in the database. In order assess efficiency, water quality data needs to be analyzed in a consistent manner. Background information on data preparation is provided in Section 4.1, procedures and techniques that will be used for graphical exploration of the data are demonstrated in Section 4.2, the proposed primary method for quantification of efficiency (the Lognormal Statistical Efficiency, LSE) is outlined in Section 4.3, and Section 4.4 describes an alternative method (the Relative Outflow Efficiency) for quantification of efficiency where outflow EMCs do not vary with respect to inflow concentrations.

### 4.1 Data Preparation

There are a number of types of water quality data stored in the database due to the varying methods used conduct monitoring studies. In order to analyze the data, some degree of preparation of the data is required.

The water quality data stored in the database can be broken down into two principal types.

1. Event Mean Concentration Data
    - Discrete (manual or automatic) Sample Flow Weighted Composite EMCs
    - Discrete Sample Time Weighted Composite EMCs
    - Discrete Sample Composite EMCs Without Flow or Time Weighting

2. Discrete Water Sample Data
    - Grab Samples

The approach described and demonstrated in Sections 4.2 and 4.3 is based on EMC monitoring data. The use of grab samples for the calculation of removal efficiencies requires additional preparation of water quality sampling data. On a study by study basis, grab sampling programs will be examined. Numerical methods will be used to approximate EMCs for certain constituents (based on flow and/or time weighting), where this is possible. If EMCs cannot be calculated for a particular study, then estimations of efficiency will be based on the grab samples themselves (i.e., a statistical analysis of concentration data will be conducted to the extent possible). For some constituents and field parameters, a discrete sample approach is required. In calculating the ability for a BMP to improve field parameters such as temperature, a "grab" sample approach will need to be utilized even where EMCs were collected in a flow or time weighted manner.

In many of the BMPs currently stored in the database, the number of inflows does not necessarily equal the number of outflows. Although many BMPs have one inflow and one outflow, many do not, and in some cases, the layout of the BMP system is quite complicated. Best management practice designs containing multiple, inflows, outflows, bypasses, and BMPs in series and/or parallel are common and all analyses of BMPs and BMP systems should take these important design details into account.

For cases where more than one inlet and outlet are present, the concentration data will be composited based on flow weighting This will be conducted by calculating a single EMC based on the total mass flowing into or away from the BMP and the associated total flow.

In some cases the flow into or out of a BMP is not directly measured, but can be calculated from the flows that are recorded. In these cases, mass balance equations will be used and checked against work conducted by the original author. In addition, total flow volumes can be estimated from runoff coefficients and the available rainfall data, where available.

## 4.2 Exploratory Data Assessment

An initial exploratory data analysis will be conducted to provide a common starting point for quantification of efficiency, effectiveness and performance. Three initial sets of graphs will be produced for each BMP and constituent monitored as shown below:

1. A normal probability plot showing the log transform of both inflow and out flow EMCs for all storms for the BMP. If the log transformed data deviates significantly from normality, other transformations will be explored to determine if a better transformation exists. Examples for TSS for the three designs examined in Tampa Office Pond Study are shown in Figures 4.1-4.3

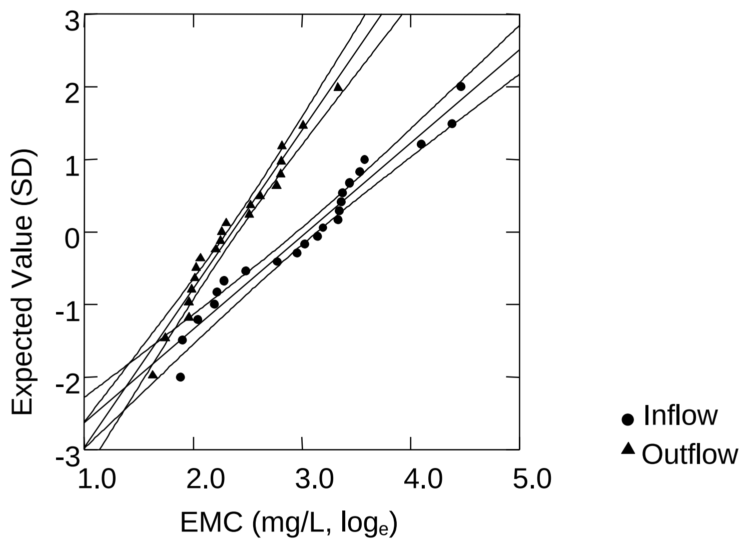



Figure 4.1 Normal Probability Plot for Log Transformed Inflow and Outflow Data for TSS for the Tampa Office Pond (1990), (0.95 confidence interval on the regression lines)

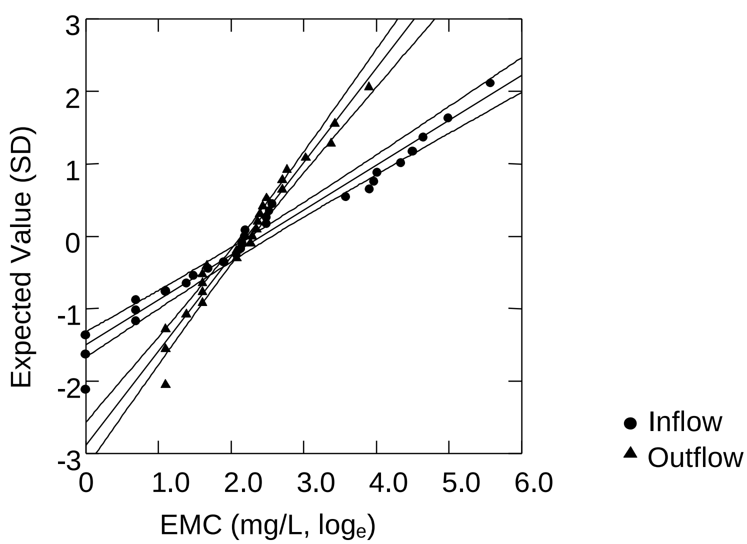



Figure 4.2 Normal Probability Plot for Log Transformed Inflow and Outflow Data for TSS for the Tampa Office Pond (1993-1994) , (0.95 confidence interval on the regression lines)

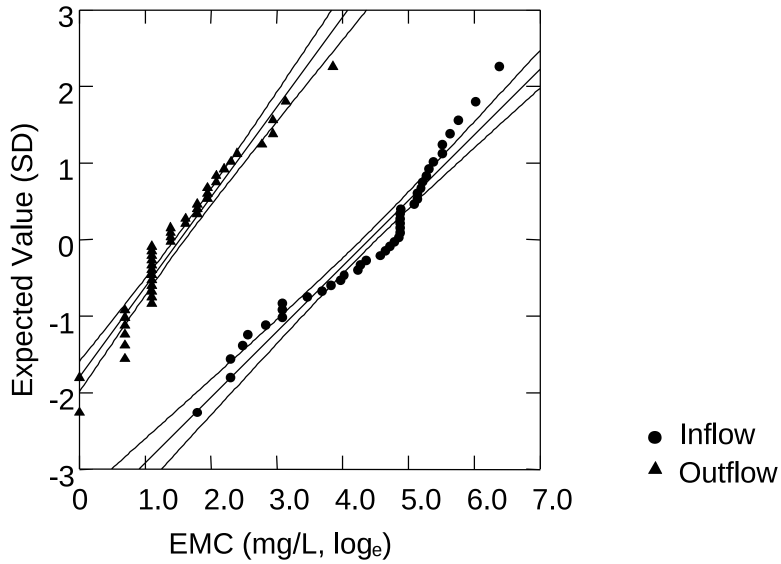



Figure 4.3 Normal Probability Plot for Log Transformed Inflow and Outflow Data for TSS for the Tampa Office Pond (1994-1995), (0.95 confidence interval on the regression lines)

2. A notched grouped box plot will be generated showing both inflow and outflow on the same plot. One plot will be generated based on transformed EMCs or grab sample concentrations and one will be generated based on transformed loads. Each box plot will include the standard deviation and selected percentiles and/or confidence intervals. Examples for TSS for the three designs examined in Tampa Office Pond Study are shown in Figure 4.4.

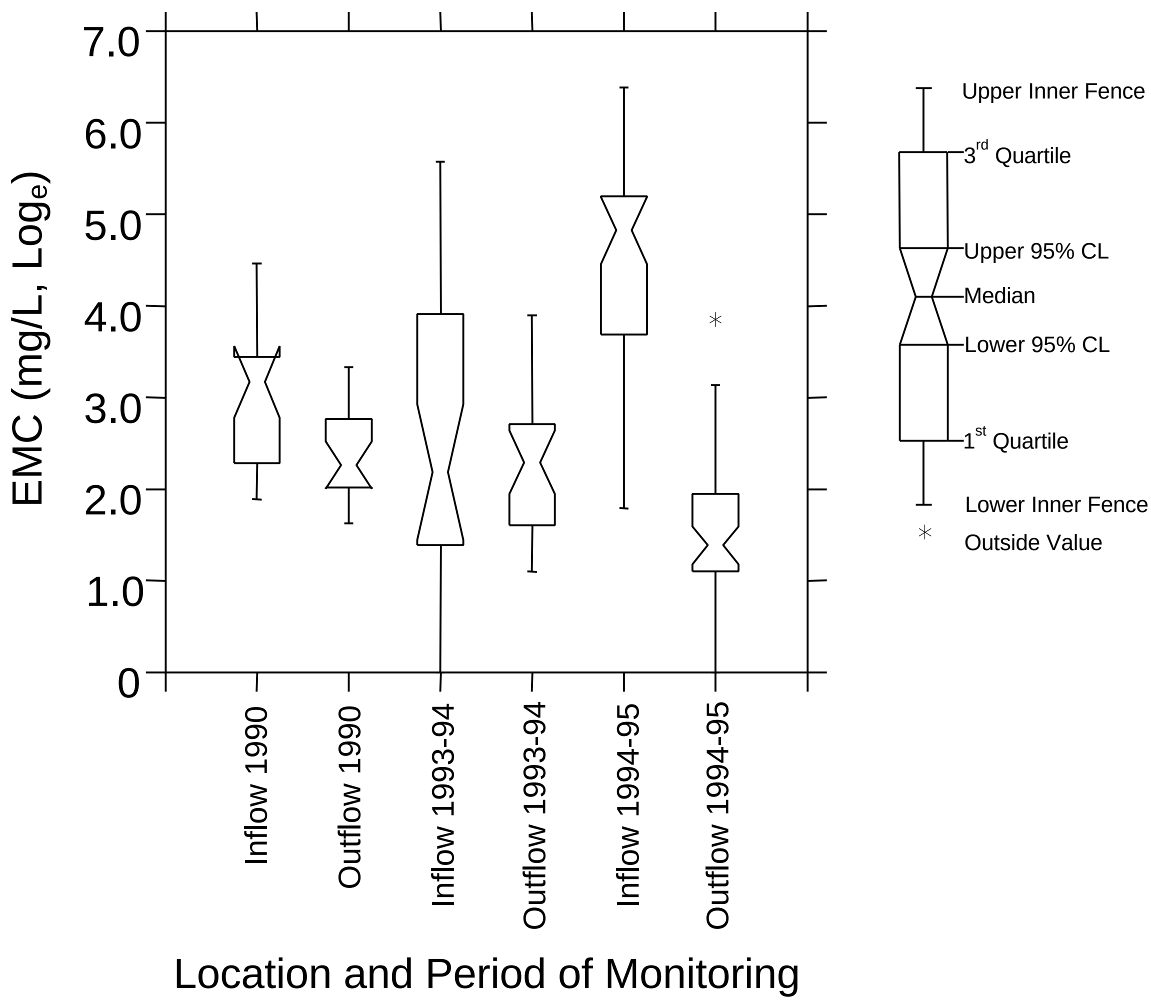
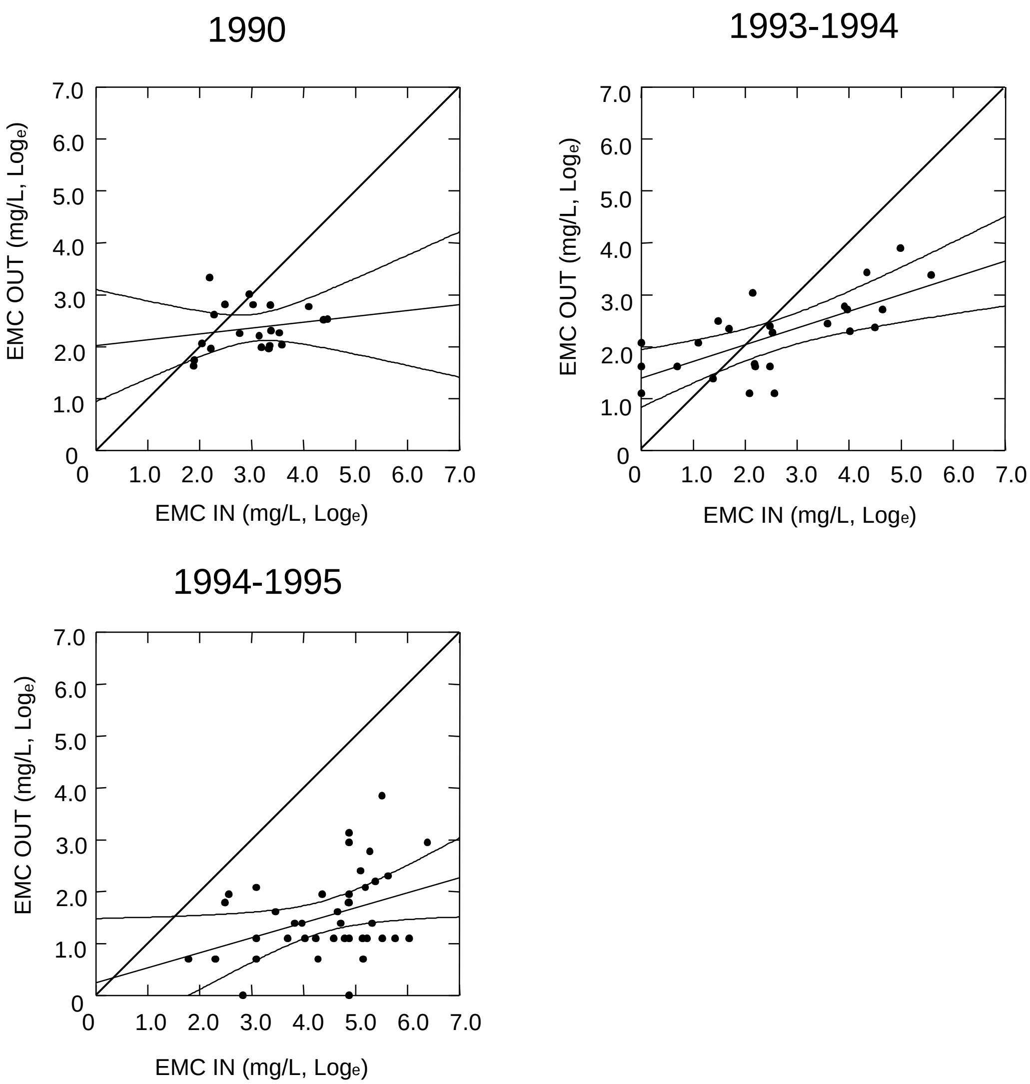



Figure 4.4 Notched Box Plot for Log Transformed Inflow and Outflow Data for TSS for the Tampa Office Pond (Boxes are narrow at the median and are full width at the lower and upper 95% confidence interval. The limits of the box show the range within which the central 50% of the values lie (also called the lower and upper hinge). The whiskers represent the upper and lower inner fences defined as: hinge $\pm$ (1.5 * (median- hinge)). Outside values are labed as an asterix and are defined as being between the inner and outer fence.

3. A scatter plot will be generated showing EMC out as a function of EMC in. This plot will allow for the visual inspection of the degree of "pairing" of EMCs at the inflow and outflow. The scatter plot will be produced with transformed data on both axes. If appropriate, a best-fit line will be plotted.




Figures 4.5-4.7 Scatter Plot for Log Transformed Inflow and Outflow Data for TSS for the Tampa Office Pond (0.95 confidence interval on the regression lines).

After an analysis of the graphical output for each of the above methods, decisions will be made about the best way to further analyze the data on a case by case basis. The paired t-test will be used and other paired and non-paired non-parametric tests will be explored as appropriate.

## 4.3 Data Analysis: Lognormal Statistical Efficiency

The graphical methods shown in Section 4.2 allow for the data to be explored. These methods help determine if a statistical approach to the data is appropriate and if any transformations of the data would improve interpretation. After data for a particular BMP are deemed appropriate for further analysis (i.e., there are enough data points available for a particular study and constituent to lend statistical significance to further analysis) the water quality data will be analyzed as described in this section.

The lognormal statistical efficiency (LSE) defines efficiency, not as a single value, but as a summary of the statistical characteristics of the inflow and outflow. An example of a full analysis using this method is shown in Table 4.1.

The test of statistical significance of the results takes as its hypothesis that the inflow and outflow values are derived from the same population. This null hypothesis allows the efficiency of the BMP to be evaluated by the probability that the BMP has no statistically relevant effect on the distribution of EMCs downstream of the BMP compared to upstream values. This hypothesis is best evaluated using the results of the one-way analysis of variance (ANOVA) test. The effect of the BMP will be considered significant if the probability (P-value) that the resulting F-ratio from the ANOVA could have been generated by chance is less than a chosen significance level (to be chosen after results are examined, typically 0.05). The overall efficiency will be summarized by reporting: the P-value, the percent difference between the arithmetic estimate of the mean log transformed EMCs at the outflow and the inflow along with the related confidence limit of the means, and the percent difference between specific percentile ranges (most likely the $10^{th}$ and $90^{th}$). Note that using only the difference in the mean is identical to the Efficiency Ratio method described in Section 3.1, using the log transform of the data. Additional tests of the statistical relevance of the differences in population characteristics at the inflow and outflow will also be examined depending on the usefulness of parametric methods.

If the assumptions of the parametric ANOVA cannot be met or if the proportion of non-detects in the data set exceeds 15%, a Kruskal-Wallis nonparametric ANOVA (analogous to the parametric one-way analysis of variance) will be used to examine the hypothesis regarding significant differences in constituent concentrations at the inflow and the outflow. The nonparametric ANOVA evaluates the ranks of the observed concentrations at each location. Non-detects will be treated as tied values and are assigned an average rank. The two-sample Kolmogorov-Smirnov test will also be explored. In general, nonparametric methods are less powerful than their parametric counterparts, for distributions that are approximately log normal, reducing the likelihood that a "true" significant difference between treatments will be detected.

### Example of the Lognormal Statistical Efficiency for TSS in the Tampa Office Pond

All supporting graphs for the NSE method are shown in Section 4.2 of the memorandum. Table 4.1 given below shows what typical results will be presented to define efficiency of each BMP in the database.

Table 4.1 Summary of Preliminary Analysis of Tampa Office Pond Using LSE Method

| BMP Name | Constituent | Location | Mean (Log EMC), [Upper CL, Lower CL] | SD | Estimate of Arithmetic Mean EMC Based on Appendix A | | 10th Percentile EMC[1] | | 90th Percentile EMC[1] | | Analysis of Variance (ANOVA) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Value | Diff., [%] | Value | Diff. [%] | Value | Diff. [%] | |
| Tampa Office Pond 1990 | TSS | Inflow | 3.046 [3.382, 2.711] | 0.757 | 28.009 | 16.282 [58.1] | 7.82 | 0.72 [9.2] | 57.15 | 40.45 [70.8] | N: 43<br>Multiple R: 0.488<br>Squared Multiple R: 0.239<br>Sum of Squares: 5.028<br>Mean-Square: 5.028<br>F-ratio: 12.850<br>**P-value: 0.001**<br>Durbin-Watson D Statistic: 1.976<br>First Order Auto Correlation : -1.034 |
| | | Outflow | 2.362 [2.566, 2.159] | 0.447 | 11.727 | | 7.10 | | 16.7 | | |
| Tampa Office Pond 1993-1994 | TSS | Inflow | 2.413 [3.012, 1.814] | 1.575 | 38.602 | 26.386 [68.4] | 1.74 | -1.26 [-72.4] | 108.91 | 90.24 [82.9] | N: 54<br>Multiple R: 0.077<br>Squared Multiple R: 0.006<br>Sum of Squares: .500<br>Mean-Square: 0.500<br>F-ratio: 0.314<br>**P-value: 0.578**<br>Durbin-Watson D Statistic: 0.712<br>First Order Auto Correlation : 0.629 |
| | | Outflow | 2.220 [2.530, 1.909] | 0.752 | 12.216 | | 3.00 | | 18.67 | | |
| Tampa Office Pond 1994-1995 | TSS | Inflow | 4.401 [4.753, 4.050] | 1.128 | 154.037 | 147.591 [95.8] | 12.69 | 10.69 [15.8] | 248.60 | 231.75 [93.2] | N: 84<br>Multiple R: 0.828<br>Squared Multiple R: 0.685<br>Sum of Squares: 173.832<br>Mean-Square: 173.832<br>F-ratio: 178.207<br>**P-value: 0.000**<br>Durbin-Watson D Statistic: 1.820<br>First Order Auto Correlation : 0.088 |
| | | Outflow | 1.524 [1.781, 1.268] | 0.824 | 6.446 | | 2.00 | | 16.85 | | |

1. Calculated based on the difference between the EXP ( 10th percentile of the Log transformed data) for the inflow minus the outflow.

In looking at the results of the ANOVA test the criteria for the P-value (<0.05) is met in two of the three cases (1990 and 1994-1995). C inherent to the ANOVA test, the null hypothesis has been rejected, (i.e., there is less than a 5% chance that the two data sets were taken population). In addition the two non-parametric tests (i.e., the Kruskal-Wallis test and the Two Sample Kolmolgorov-Smirnov test) con ANOVA test (the probability for both the 1990 and 1994-1995 data are below 0.05). When looking at the 1993-1994 data (the P-value the criteria for all three tests), it is apparent that even though the percent difference in the estimates of the mean values is quite large (68 information is not statistically relevant and therefore should be identified such. Although the analysis of the difference in the mean EM relevant, the statistically insignificant differences provide the best estimate of the efficiency of the BMP, though there is little confiden records should be flagged to prevent misinterpretation of any resulting "percent removal" values. The 1990 and 1994-1995 results provi significant approximation of the efficiency of the BMP (for TSS), where the 1993-1994 data fail to do so.

### 4.4 Relative Outflow Concentration

In addition to exploring the LSE, the relative outflow concentration will be examined as an alternative method for quantification of effectiveness where outflow EMCs do not vary significantly with respect to inflow concentrations. The relative outflow concentration examines the relationship between outflow EMCs for a number of separate BMPs, and explores the parameters that affect outflow water quality. The logarithmic transform of the EMC data will be used to statistically characterize the outflow. Descriptive statistics, identical to those methods used in Section 4.2, can be utilized to examine the relationship between outflow concentrations at a number of different BMPs of the same type. In this method, influent EMCs are viewed as one of the design parameters, along with environmental, and design factors. This focuses attention on the actual water quality levels the BMP is theoretically designed to provide and explicitly assumes that there may not be a functional, or at least an overriding, relationship between influent and effluent EMCs. Both multiple regression analysis and population testing can be used to determine the effects of each design parameter, including influent EMCs (see Section 11)

Due to the fact that the method relies on data from multiple BMPs of the same type, the data and studies used to establish the baseline information must be numerous enough to establish a reliable nationwide trend. The inflow concentration may not be the primary factor affecting the performance of a BMP. In some specific cases it is expected that outflow concentrations are independent of or only partially dependent on inflow concentrations (i.e., outflow EMCs often do not parallel inflow EMCs). Therefore, there should be less emphasis on the difference between inflow and outflow EMCs and measures, such as percent removal, when judging BMP effectiveness. In addition, the type of constituent and its associated removal mechanism are important when considering if influent EMCs have an effect on effluent EMCs.

## 5 Analysis of Rainfall Events

Analysis of rainfall data can often shed light on the factors that contribute to the performance of a given BMP. In order for the impact of non-structural BMPs and BMPs that lack an upstream gauging station to be properly evaluated, the rainfall for a particular event must be available for analysis. In most cases, it is sufficient to quantify the relationship between total flow at some downstream monitoring station and total rainfall depth in the BMP's tributary watershed. This can help quantify any effects the BMP may have on reducing the quantity of water that reaches the downstream monitoring location. This information is essential for comparing porous pavements, minimization of directly connected impervious areas, and many non-structural BMPs. In all cases where reference watersheds and/or temporal variation of BMP design are employed, rainfall is one of the key normalization parameters.

Analysis of storm rainfall data can also be very useful for quantifying the effects of bypass of the overall performance of a BMP. In some cases monitoring of bypass and overflows has not been conducted. In these cases, rainfall data provides the only potential means for determining the performance of the overall BMP system, where one is evaluating not only the effect on water quality of flow that pass through a BMP, but also how much the BMP can "treat". In some cases a theoretical hydrograph (which would introduce error) would be required in order to use the data stored in the database to approximate bypass or overflow for a particular event.

## 6 Number of Storms and Number of Samples

The number of storms used for any of the above analyses in Sections 3 and 4 directly impact the statistical relevance of the calculated performance, as evidenced in the ANOVA and confidence interval of the mean log-transformed value at a particular monitoring station. An analysis of the number of storms monitored in comparison to the number required to obtain statistically relevant results will be conducted.

## 7 Characteristics of Storms Monitored

In addition to confirming that the number of storms monitored is sufficient to yield statistically useful results, the types of storms monitored have a major impact on extrapolating the results obtained to determine the overall long-term performance. The relationship between storm size and storm frequency in most locations ensures that smaller storms are more prevalent in most stormwater flow records. This often presents a particular challenge. It must be ensured that the methods inherent to the data collection effort do not unduly skew the results of the performance analysis or that this bias is taken into account or at least recognized. For many of the methods presented in Section 3 and 4, this requires restraint in extrapolation of results to areas of the record that are less populated by data. For example, the presence of a small number of large storms can dominate a summation of loads calculation.

# 8 Toxicity Determinations

The concentrations of both inflow and outflow EMCs can be utilized to evaluate the potential toxicity reduction of BMPs. Although instantaneous grab samples provide a more accurate picture of toxicity at any given time, the EMC comparison will provide a measure of the average concentration during an event versus criterion values. In this effort we will utilize both EMC data and grab sample data (separately) to assess a BMP's potential to reduce toxicity, comparing the frequency and magnitude of the number of both EMCs and grab samples that exceed EPA published values.

# 9 Net Export of Contaminants (Negative Removal Efficiencies)

In some cases, the performance of a given BMP is masked by the introduction of contaminants from within the BMP. This may be caused by significant levels of sorbed or particulate contaminants in the soil matrix, decaying matter within the BMP that exports significant quantities of nutrients, or sources such as ground water, rainwater, or airborne contaminants. If negative removal efficiencies are regularly observed during data analysis, for a contaminant, the causes for such a net export will be sought. Often net export of contaminants is observed where concentrations of the contaminant in the inflow to the BMP are quite low. When concentrations are very low, a slight shift in the quantity of contaminants could greatly affect the calculated efficiency.

# 10 Information Stored in the Database

For each BMP type, and indeed each BMP, there exists an intimate and complex relationship between the environmental and design parameters and the mechanism for removal. An analysis of the relationship between environmental, design, and operational parameters requires an examination of factors that are most likely to observably influence the performance of particular type of BMP. We will explore both individual design attributes and carefully selected "groups" of design attributes to look for potential factors that affect performance. In order to define what information is available through the database, a list of each BMP type along with related design, environmental, and watershed parameters are shown in Table 10. A list of the types and number of BMPs that will be part of the initial data set contained in the database is shown in Table 10.1.

Table 10.1 Parameters to Report with Water Quality Data for Various BMPs

| Parameter Type | Parameter | Ret. (Wet) Pond | Extended Detention (Dry) Basin | Wetland Pond Basin | Grass Swale/ Wetland Channel | Media Filter | Oil & Sand Trap/ Hydrodyn. Device | Infilt. Basins and Trenches |
|---|---|---|---|---|---|---|---|---|
| Tributary Watershed | Area, average slope, average runoff coeff., length, soil types, veg. types | • | • | • | • | • | • | • |
| | Imperv. % and % hyd. connected | • | • | • | • | • | • | • |
| | Details about gutter, sewer, swale, ditches, parking, roads in watershed | • | • | • | • | • | • | • |
| | Land use types (res., com. ind. open) | • | • | • | • | • | • | • |
| General Hydrology | Date and times for monitored storms | • | • | • | • | • | • | • |
| | Runoff volumes for monitored storms Peak 1-hr intensity | • | • | • | • | • | • | • |
| | Design storm/flood recurrence intervals and magnitude | • | • | • | • | • | • | • |
| | Peak flow rate, depth, and Manning's roughness coeff. for the 2-year storm | | | | • | | | |
| | Depth to seasonal high groundwater/impermeable layer | | • | | • | | | • |
| | Saturated hydraulic conductivity, infiltration rate, soil group | | | | • | | | • |
| | Average annual values for number of storms, precipitation, snowfall, min./max. temp. | • | • | • | • | • | • | • |
| Water | Pollutant and constituent EMCs, and alkalinity, hardness and pH by event | • | • | • | • | • | • | • |
| | Water temperature | • | • | • | • | • | • | • |
| | Sediment settling velocity dist. | • | • | • | • | • | • | • |
| | Facility on- or off-line? | • | • | • | • | • | • | • |
| | Bypassed flows during events | • | • | • | • | • | • | • |
| General Facility | Facility Location (Lat./Long.), address, city, state, country, age of BMP, etc. | • | • | • | • | • | • | • |
| | Type and frequency of maintenance | • | • | • | • | • | • | • |
| | Types and location of instruments | • | • | • | • | • | • | • |
| | Inlet and outlet details, and number | • | • | • | • | • | • | • |
| Wet Pool | Media or granular material depth, type, storage volume, and porosity | | | | | • | | • |
| | Volume, surface area, length of permanent pool | • | | • | | • | • | |
| | Littoral zone surface area | • | | | | | | |
| Detention Volume | Solar radiation, days of sunshine, wind speed, pan evaporation | • | • | • | • | | | • |
| | Detention (or surcharge) and flood control volumes | • | • | • | | • | • | • |
| | Basin's surface area and length | • | • | • | | • | • | • |
| | Brimful and half-brimful empty time | • | • | • | | • | • | • |
| Pre-Treatment | Bottom stage/infil. surface area, type | | | • | • | | | • |
| | Forebay volume, surface area | • | • | • | | • | • | • |
| Wetland Plant | Relationship to other BMPs upstream | • | • | • | • | • | • | • |
| | Wetland/swale type, surface area, and length, side slope, bottom width | | | • | • | | | |
| | Percent of wetland surface between 0-12", 12"-24", and 24"-48" | | | • | • | | | |
| | Plant species and age of facility | • | • | • | • | | | |

Based on Urbonas (1994,1995) and NSW database tables

# 11 Parameter Evaluation

This section discusses the selection process for parameters used to evaluate the relationship between, design and environmental conditions, and efficiency. Two methods are presented. The first of these methods is multiple regression analysis. The second is BMP group testing.

## 11.1 Selection of Parameters and Scalability

Parameters that are selected for evaluation must be present or consistently and reliably derivable from the data in the majority of BMP reports. Parameters that relate to sizing of a BMP that are selected as indicative of performance must be scalable. This scalability allows the results obtained from one set of BMPs to be compared with results from another set. As was mentioned in the Section 3, the correlation of the results from two different locations having varied conditions cannot be compared if all significant variables that are related to sizing are not scaled appropriately. Where conditions are significantly dissimilar or a small number of data points are available, scaling can introduce significant errors in analysis.

Parameters that can be calculated from a combination of database fields will be utilized for evaluating the relationship between static and state variables and efficiency. Parameters that correlate well with efficiency should be directly linked to the removal mechanism for that particular BMP type.

For example, in all BMPs that utilize settling as a primary removal mechanism, storm detention time is a key factor. The average detention time for a BMP during a given event is dependent on the design of the BMP and flow conditions during the event. For the general case, average detention time for an event can be calculated based on the average storage volume of the BMP and flows in and out, neglecting other losses; each of these may vary with time as shown in Equations 11.1-11.4.

The volume in the BMP, $V(t)$, at time t is given by:

$$V(t) = V_o + \int_{t_0}^{t} \left[ Q_{in}(t) - Q_{out}(t) \right] \cdot dt \qquad \text{Equation 11.1}$$

where,

| | |
|---|---|
| t: | time |
| $V_0$: | permanent pool storage volume of BMP |
| $Q_{in}$: | volume flow rate into BMP |
| $Q_{out}$: | volume flow rate out of BMP |

In most cases, detention time is outflow dominated and thus can be approximated using the average volume flow rate at the outflow and the average total volume in the BMP.

The average volume flow rate, $\overline{Q_{out}(t)}$, on $[t_0, t]$ is given by:

$$\overline{Q_{out}(t)} = \frac{1}{(t - t_0)} \int_{t_0}^{t} Q_{out}(t) \cdot dt \qquad \text{Equation 11.2}$$

The average value of the total volume in the BMP, $\overline{V(t)}$, on $[t_0, t]$ is:

$$\overline{V(t)} = \frac{1}{t - t_0} \int_{t_0}^{t} V(t) \cdot dt \qquad \text{Equation 11.3}$$

Finally, an average detention time, $\overline{t_{\text{det}}}$, for the BMP on [$t_0$, t], can be found from Equation 11.4:

$$\overline{t_{\text{det}}} = \frac{\overline{V(t)}}{Q_{out}(t)} \qquad \text{Equation 11.4}$$

For locations that do not have a significant change in detention volume with time during events (e.g., ponds with a large permanent pool and little surcharge detention volume) the volume of the pond can be assumed to be constant ($V(t) = V_0$, or $Q_{in}(t) = Q_{out}(t)$) and the storm average detention time can be approximated as:

$$\overline{t_{\text{det}}} = \frac{V_0}{\left( V_{out} / t \right)} \qquad \text{Equation 11.5}$$

If "intra-storm" flow rate data is not available, (the database does not currently support "raw" flow data, although it can be stored in generic attached data tables) and the storage volume in the BMP changes significantly over the course of an event, either an approximate average storage volume would need to be selected based on more detailed information about the system, or some theoretical hydrograph would need to be used based on rainfall and runoff characteristics, BMP design, and design of the outflow structure.

In addition to calculating the detention time for each storm event, an average detention time can be calculated for the BMP based on the historic average wet season rainfall rate for the area (Rushton et al, 1997). This method is applicable to BMPs that have effluent flows that continue for periods well in excess of the duration of the storm event and locations that have fairly steady rainfall rates over some specified wet season. Although the actual storm detention time calculated using this alternative method is not based on data from the monitoring period, it does provide a uniform means of comparing BMP design over a wide variety of locations based on average rainfall characteristics.

It is expected that detention time will be one of the primary parameters of interest for detention based BMPs. In addition to calculating the detention time for each storm event that was monitored, it will be useful to calculate a mean detention time, and a detention time for the mean storm based on the synoptic rainfall data stored in the database. Each of these factors will be assessed to determine if there is a correlation between these factors and the efficiency of removal.

In addition to examining design parameters that are directly stored in the database (e.g., surcharge detention volume), and standard calculated parameters (e.g., detention time), additional ratios composed of more than one factor will be examined. These "treatment factors" allow for examination of other possibly important ratios between design parameters. For example, a "treatment volume factor", which can be defined for BMPs that use storage as the primary treatment process, is shown in Equation 11.6.

$$\frac{f(\text{design volume})}{f(\text{runoff volume})} \qquad \text{Equation 11.6}$$

For BMPs that are "flow-through" in nature, a "treatment flow factor" (Equation 11.7), will be examined.

$$\frac{f\,(treatment\ flow\ rate)}{f\,(runoff\ flow\ rate)} \qquad \text{Equation 11.7}$$

These two "factors" are examples taken from a larger set of combinations of parameters that will be examined. The methods outlined in Sections 11.2 and 11.3 will be used for determining the usefulness of the parameters and factors described in this section.

## 11.2 Multiple Linear Regression

Multiple regression analysis systematically allows for examination of any relationships between the outcome of the performance measurements discussed in Section 3 of the memorandum and some design parameter or "factor" for a type of BMP.

For example, for dry detention ponds, the relationship between the design parameters length, depth, and draw down rate could be evaluated against the efficiency of the BMP for removing TSS.

Multiple linear regression can be used to see if there is a linear relationship between the parameters or "factors" of interest and efficiency. Multiple linear regression attempts to define a continuous linear relationship between the set of parameters and the resulting efficiency of the BMP. The method first assumes that each of the variables of interest are independent. In the example we can assume, for the sake of analysis, that length and depth meet this criteria. Multiple linear regression also assumes that a linear correlation exists between each independent variable and the dependent variable. It is always advisable to plot the dependent variable as a function of each independent variable in order to determine if there may be some transformation of the independent data that may allow for a linear relationship.

After linear regression is conducted, the correlation coefficient gives a measure of the goodness of fit for the regression line. In addition the F statistic can be used to determine if the results occurred by chance and the t-statistics can be used to determine the relative usefulness of each variable in the regression equation.

## 11.3 BMP Group Test Methods

Group testing methods use a "cutoff" value for a design or environmental parameter and report the effects of exclusion of BMPs based on this "cutoff". Most likely, this would be done with a set of factors; a BMP to make the "cutoff" might have to meet 4 of 6 "good" design factors. This approach does not require that a continuous relationship between some parameter and performance exists. This method can therefore be applied to yes/no factors, (e.g., forebay volume >10% of the total volume of a wet pond; length to width ratio of 3:1, etc.) or factors that have a small set of discrete values. In addition, the group testing method follows the design process, where often a required value is specified in order to meet a certain performance goal. The group testing method will probably be a more successful approach, compared to multiple regression, due to the small number of data points available for any given BMP type.

# APPENDIX A

Table A.1

| | |
|---|---|
| T=EXP(U) | S=M * CV |
| M = EXP(U + 0.5 * $W^2$) | W = SQRT(LN(1 + $CV^2$) |
| M = T * SQRT(1 + $CV^2$) | U = LN(M / EXP(0.5 * WP) |
| CV = SQRT(EXP($W^2$) – 1) | U = LN(M/SQRT(1 + $CV^2$) |

| | Arithmetic | Logarithmic (ln) |
|---|---|---|
| Mean | M | U |
| Standard Deviation | S | W |
| Coefficient of Variation | CV | |
| Median | T | |

Table A.1 presents transformations between logarithmic transformed population statistics and estimates of arithmetic population statistics.

## ATTACHMENT E – DEFINITIONS

***"Attached Residential Development"*** means any development that provides 10 or more residential units that share an interior/exterior wall. This category includes, but is not limited to: dormitories, condominiums and apartments.

***"Automotive Repair Shop"*** means a facility that is categorized in any one of the following Standard Industrial Classification (SIC) codes: 5013, 5014, 5541, 7532-7534, or 7536-7539.

***"Commercial and Industrial Development"*** means any development on private land that is not exclusively heavy industrial or residential uses. The category includes, but is not limited to: mini-malls and other business complexes, shopping malls, hotels, office buildings, public warehouses, hospitals, laboratories and other medical facilities, educational institutions, recreational facilities, plant nurseries, car wash facilities, automotive dealerships, commercial airfields, and other light and heavy industrial complexes or facilities.

**"Commercial and Industrial Development greater than 100,000 square feet"** means any commercial or industrial development with a project footprint of at least 100,000 square feet.

***"Detached Residential Development"*** means any development that provides 10 or more freestanding residential units. This category includes, but is not limited to: detached homes, such as single-family homes and detached condominiums.

***"Directly Connected Impervious Area (DCIA)"*** means the area covered by a building, impermeable pavement, and/ or other impervious surfaces, which drains directly into the storm drain without first flowing across permeable vegetated land area (e.g., lawns).

***"Environmentally Sensitive Areas"*** means areas that include, but are not limited to, all Clean Water Act 303(d) impaired water bodies ("303[d] water bodies"); areas designated as an "Area of Special Biological Significance" (ASBS) by the State Water Resources Control Board (1990 Water Quality Control Plan for Ocean Waters of California [Ocean Plan] and Water Quality Control Plan for the San Diego Basin (1994) and amendments); water bodies designated as having a RARE beneficial use by the State Water Resources Control Board (Water Quality Control Plan for the San Diego Basin (1994) and amendments), or areas designated as preserves or their equivalent under the Multiple Species Conservation Program (MSCP) within the Cities and County of Orange. The limits of Areas of Special Biological Significance are those defined in the 1990 Water Quality Control Plan for Ocean Waters of California (Ocean Plan) and the Water Quality Control Plan for the San Diego Basin (1994 and amendments). Environmentally sensitive area is defined for the purposes of implementing WQMP requirements, and does not replace or supplement other environmental resource-based terms, such as "Environmentally Sensitive Lands," employed by Permittees in their land development review processes. As appropriate, Permittees should distinguish between environmentally sensitive area and other similar terms in their local WQMP's.

***"Hillside"*** means lands that have a natural gradient of 25 percent (4 feet of horizontal distance for every 1 foot of vertical distance) or greater and a minimum elevation differential of 50 feet, or a natural gradient of 200 percent (1 foot of horizontal distance for every 2 feet of vertical distance) or greater and a minimum elevation differential of 10 feet.

***"Hillside development greater than 5,000 square feet"*** means any development that would create more than 5,000 square feet of impervious surfaces in hillsides with known erosive soil conditions.

***"Infeasibility Waivers"*** means a Permittee-issued waiver from requirements for Treatment BMPs. The waiver requires a project proponent demonstrate Treatment BMP infeasibility and the Permittee to notify the Executive Officer of the applicable Regional Board of the waiver.

***"Infiltration"*** means the downward entry of water into the surface of the soil.
***"Municipal Storm Drain System"*** means public drainage facilities by which stormwater may be conveyed to Receiving Waters, such as: natural drainages, ditches, roads, streets, constructed channels, aqueducts, storm drains, pipes, street gutters, or catch basins.

***"Natural Flow Regime"*** means the pre-development hydrologic conditions within a stream.

***"New Development"*** means land disturbing activities; structural development, including construction or installation of a building or structure, the creation of impervious surfaces; and land subdivision.

***"Parking Lot"*** means land area or facility for the temporary parking or storage of motor vehicles used personally, or for business or commerce.

***"Projects Discharging to Receiving Waters within Environmentally Sensitive Areas"*** means all development and significant redevelopment that would create 2,500 square feet of impervious surfaces or increase the area of imperviousness of a project site to 10% or more of its naturally occurring condition, and either discharge urban runoff to a receiving water within an environmentally sensitive area (where any portion of the project footprint is located within 200 feet of the environmentally sensitive area), or discharge to a receiving water within an environmentally sensitive area without mixing with flows from adjacent lands (where the project footprint is located more than 200 feet from the environmentally sensitive area).

***"Project Feature"*** means a project component or subpart that in and of itself, meets Priority Project criteria. For example, a greater than 5000 sq. ft. parking lot within a non-Priority Project.

***"Project Footprint"*** means the limits of all grading and ground disturbance, including landscaping, associated with a project.

***"Receiving Waters"*** means surface bodies of water, that receive discharges from new development and redevelopment projects, either directly, or indirectly through municipal storm drain systems or otherwise. Surface bodies of water include naturally occurring wetlands, streams (perennial, intermittent and ephemeral [exhibiting bed, bank, and ordinary high water mark]), creeks, rivers, reservoirs, lakes, lagoons, estuaries, harbors, bays and the Pacific Ocean and such other waters as are considered waters of the United States and/or the State of California under applicable definitions. The Permittee shall determine the definition for wetlands and the limits thereof for the purposes of this definition, provided the Permittee definition is as protective as the definition utilized by the United States Army Corps of Engineers (US COE), the United States Environmental Protection Agency (US EPA) and/or the State of California. In some instances, constructed wetlands or other constructed BMPs may not be considered wetlands or receiving waters under this definition particularly if they are constructed outside of receiving waters, not for mitigation purposes, and are routinely maintained.

***"Residential Development"*** means any development on private land that provides living accommodations for one or more persons. This category includes, but is not limited to: single-family homes, multi-family homes, condominiums, and apartments.

***"Restaurant"*** means a stand-alone facility that sells prepared foods and drinks for consumption, including stationary lunch counters and refreshment stands selling prepared foods and drinks for immediate consumption (SIC code 5812).

***"Significant Redevelopment"*** means development that would add 5,000 or more square feet of impervious surface on an already developed site. Significant redevelopment includes, but is not limited to: Expansion of a building footprint; Addition of a building and/or structure; Addition of an impervious surface that is not part of a routine maintenance activity such as construction of a new parking lot; Replacement of impervious surfaces, buildings and/or structures when 5000 or more square feet of soil is exposed during replacement construction. Replacement does not include routine maintenance activities, trenching and resurfacing associated with utility work, resurfacing and reconfiguring the surface of parking lots (unless 5000 or more square feet of impervious surface is added to the existing parking lot area) or reconfiguration of pedestrian ramps and replacement of damaged pavement.

***"Site Design BMP"*** means any project design feature that reduces the creation or severity of potential pollutant sources or reduces the alteration of the project site's natural flow regime. Redevelopment projects that are undertaken to remove pollutant sources (such as existing surface parking lots and other impervious surfaces) or to reduce the need for new roads and other impervious surfaces (as compared to conventional or low-density new development) by incorporating higher densities and/or mixed land uses into the project design, are also considered Site Design BMPs.

***"Source Control BMP (both structural and non-structural)"*** means land use or site planning practices, or structures that aim to prevent urban runoff and stormwater pollution by reducing the potential for contamination at the source of pollution. Source Control BMPs minimize the contact between pollutants and urban runoff. Examples include roof structures over trash or material storage areas, and berms around fuel dispensing areas.

***"Stormwater Best Management Practice (BMP)"*** means any schedules of activities, prohibitions of practices, general good house keeping practices, pollution prevention and educational practices, maintenance procedures, structural treatment BMPs, and other management practices to prevent or reduce to the maximum extent practicable the discharge of pollutants directly or indirectly to receiving waters. Stormwater BMPs also include treatment requirements, operating procedures and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. This Model WQMP groups stormwater BMPs into the following categories: Site Design, Source Control, and Treatment Control (pollutant removal) BMPs.

***"Streets, Roads, Highways, and Freeways"*** means any project that is not part of a routine maintenance activity, and would create a new paved surface that is 5,000 square feet or greater used for the transportation of automobiles, trucks, motorcycles, and other vehicles. For the purposes of WQMP requirements, Streets, Roads, Highways, and Freeways do not include trenching and resurfacing associated with utility work; applying asphalt overlay to existing pavement; new sidewalk, pedestrian ramps, or bike lane construction on existing roads; and replacement of damaged pavement.

***"Treatment Control (Structural) BMP"*** means any engineered system designed and constructed to remove pollutants from urban runoff. Pollutant removal is achieved by simple gravity settling of particulate pollutants, filtration, biological uptake, media adsorption or any other physical, biological, or chemical process.