PROGRAM

STORMWATER NPDES RELATED MONITORING NEEDS

August 7-12, 1994
Grande Butte Hotel and Conference Center
Mount Crested Butte, Colorado 81225
303-349-7561
Fax: 303-349-6332

Conference Chair:
Ben Urbonas
Urban Drainage and Flood Control District
Denver, Colorado

Conference Co-chairs:
Michael B. Cook
Office of Water and Wastewater Enforcement and Compliance
U.S. Environmental Protection Agency
&
Christine Andersen
APWA Institute for Water Resources
and
Director of Public Works, Eugene, Oregon.

Engineering Foundation Conferences
345 E. 47th Street New York, NY 10017
Telephone: 212-705-7836
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Thursday, August 11, 1994 (continued)

	3. "Monitoring the Effectiveness of Structural BMPs" George Oswald Camp, Dresser & McKee, Inc.; Richard Mattison Kinnetic Laboratories, Inc.
10:00 pm - 11:00 pm	Social Hour (cash bar)

Sunday, August 7, 1994

3:00 pm - 6:00 pm	Registration
6:00 pm - 8:00 pm	Dinner
8:00 pm - 9:00 pm	Opening Reception

Monday, August 8, 1994

7:00 am - 8:30 am	Breakfast Buffet
8:45 am	Welcome Ben Urbonas, Conference Chair and Jonathan Jones, Chair, Urban Water Resources Research Council
9:00 am - Noon	SESSION I: OVERVIEW OF STORMWATER MONITORING NEEDS Moderator: Ben Urbonas **1. "Trends in Monitoring for Stormwater"** Michael B. Cook Director of U.S. EPA Office of Wastewater Management and Conference Co-Chair **2. American Public Works Point of View** Christine Andersen President, APWA Institute for Water Resources and Conference Co-Chair Coffee Break **3. "Overview of Stormwater Monitoring Needs"** Dr. Larry Roesner Chair, Task Force Committee for Preparation of Urban Stormwater Quality Management Manual; Kelly Cave Camp Dresser and McKee, Inc. **4. Non-U.S. Modeler's Point of View** William James University of Guelph, Ontario, Canada
Noon - 1:30 pm	Lunch
1:30 pm - 5:00 pm	*Ad hoc* sessions and/or free time
5:00 pm - 6:00 pm	Social Hour (cash bar)
6:00 pm - 7:30 pm	Dinner
7:30 pm - 10:00 pm	SESSION II: LOCATING ILLICIT CONNECTIONS Co-Chairs: Jon Sorensen and Jim Wulliman, Ch2MHill **1. Locating Inappropriate Discharges to Storm Drains** Robert Pitt & Malinda Lalor University of Alabama at Birmingham; Richard Field U.S. EPA; Edward Thackston Vanderbilt University

Monday, August 8, 1994 (continued)

	2. Finding Illicit Connections and Discharges with P2IL John D. Minor City of Scarborough, Ontario, Canada
	3. Panel of Experts Discussion on Illicit Connections Moderator: Richard Field U.S. EPA, Stormwater Research Group
10:00 pm - 11:00 pm	Social Hour (cash bar)

Tuesday, August 9, 1994

7:00 am - 8:30 am	Breakfast Buffet
9:00 am - 12:00 Noon	**SESSION III: SYSTEM RUNOFF CHARACTERIZATION** Session Chair: Marshall Jennings U.S. Geological Survey **1. NPDES Monitoring - Atlanta, Georgia Region** Michael Thomas Atlanta Regional Commission; Scott McCelland Camp, Dresser & McKee, Inc. **2. NPDES Monitoring - Dallas Ft. Worth, Texas Area** Samuel Brush N. Central Texas COG; Marshall Jennings U.S. Geological Survey; P. Jonathan Young Alan Plummer and Associates, Inc. Coffee Break **3. Stormwater NPDES Monitoring in Santa Clara County** Keith Whitman and David Drury Santa Clara Valley Water District; Peter Mangarella, Terry Cooke, Chow Lee and Revital Katznelson Woodward-Clyde Consultants
Noon - 1:30 pm	Lunch
1:30 pm - 3:00 pm	**POSTER SESSION ON STORMWATER AND ITS MONITORING** Session Chair: Wayne Huber **1. "CDOT Highway Stormwater Runoff Monitoring Results"** Philipp Sieber Colorado DOT **2. "Methods for Assessing Urban Stormwater Pollution"** Chauny Soeur, William Burd, George C. Chang, and Steve Stecher City of Austin **3. "Practical Experience with the Filippi Flow Limiters"** Anders A. Rorholt Tarts-EX SA, Switzerland **4. "Low Cost Automatic Stormwater Sampler"** Lynn A. Dudley Vortox Co., Claremont, California

<u>Tuesday, August 9, 1994 (continued)</u>

5. **"High-Accuracy CSO and Stormwater Flow Monitoring"**
Terrance Burch and Joanna Phillips
ORE International, Inc.

6. **"RCRA-Related Implications of Sediments in BMPs"**
Jonathan Jones
Wright Water Engineers, Inc.;
Scott Anderson
ARCO Coal Company

7. **"Pesticide Concentrations & Fluxes in an Urban Watershed"**
Paul Wotzka
Minnesota Department of Agriculture;
J. Lee
Minnesota Parks & Recreation Board;
P. Capel,
U.S. Geologic Survey
M. Lin
University of Minnesota

8. **"The Use of Special Inlet Devices, Filter Media and Filter Fabrics for the Treatment of Stormwater"**
Robert Pitt and Shirley Clark
University of Alabama at Birmingham

9. **"Treatment of Stormwater from Critical Source Areas Using a Multi-Chambered Treatment Train (MCTT)"**
Robert Pitt, Brian Robertson and Ali Ayyoubi
University of Alabama at Birmingham

10. **"Potential Groundwater Contamination From Stormwater Infiltration"**
Keith Parmer, Robert Pitt and Shirley Clark
University of Alabama at Birmingham;
Richard Field
U.S. Environmental Protection Agency

3:00 - 5:00 pm — *Ad hoc* sessions and/or free time

5:00 pm - 6:00 pm — Social Hour (cash bar)

6:00 pm - 7:30 pm — Dinner

7:30 pm - 10:00 pm — <u>SESSION IV: NPDES COMPLIANCE MONITORING</u>
Session Chair: John Warwick

1. **"Improved Methods for Stormwater Data Collection"**
George C. Chang, William Burd, Thomas Brown, and James E. Lewis
City of Austin

Tuesday, August 9, 1994 (continued)

2. "Biological and Chemical Testing in Stormwater"
William T. Waller, Miguel Acevedo and Eric Morgan
Tennessee Technical University;
Kenneth Dickson, James Kennedy and Larry Ammann
University of Texas at Dallas;
Joel Allen and Paul Keating
University of North Texas

3. "Blackstone River Wet Weather Monitoring Initiative Experience"
Raymond Wright, Roy Chaudhury and Makam S.
University of Rhode Island

10:00 pm - 11:00 pm | Social Hour (cash bar)

Wednesday August 10, 1994

7:00 am - 8:30 am	**SESSION V: POLICY & INSTITUTIONAL ISSUES OF NPDES MONITORING** Session Chair: L. Scott Tucker **1. "An Industry's Perspective on Stormwater Monitoring"** Charles Beck Coors Brewing Company **2. "EPA Use of Stormwater Monitoring Data"** William Swietlik and William Tate US Environmental Protection Agency; Eric Burneson SAIC Coffee Break **3. "Local Municipal Perspective on Stormwater Monitoring"** Doug Harrison Fresno Metropolitan Flood Control District **4. "What Congress Should Do About Stormwater"** Howard Holme Fairfield and Woods, Denver
Noon - 1:30 pm	Lunch
1:30 pm - 5:00 pm	*Ad hoc* sessions and/or free time
5:00 pm - 6:00 pm	Social Hour (cash bar)
6:00 pm - 7:30 pm	Dinner
7:30 pm - 10:00 pm	**SESSION VI: WORK SESSION ON BMP MONITORING FOR DATA TRANSFERABILITY** Session Chair: Ben Urbonas **1. "Parameters to Report with BMP Data"** Ben Urbonas Urban Drainage and Flood Control District, Denver, Co. **2. "Constituents and Methods for Assessing BMPs"** Eric Strecker Woodward-Clyde Consultants **3. Group Brainstorming/Discussion** Conference Participants
10:00 pm - 11:00 pm	Social Hour (cash bar)

Thursday, August 11, 1994

7:00 am - 8:30 am	Breakfast

SESSION VII: MONITORING RECEIVING WATER TRENDS
Session Chair: Richard Horner

1. **"Time-Scale Toxic Effects in Aquatic Ecosystems"**
Edwin Herricks
University of Illinois at Champaign;
Ian Milne and Ian Johnson
Water Research Centre - Medmenham, United Kingdom;

2. **"Use of Sediment and Biological Monitoring"**
Eric H. Livingston, Ellen McCarron, Thomas Seal and Gail Sloane
Florida Department of Environmental Protection

Coffee Break

3. **"Water Quality Trends from Stormwater Controls"**
Robert Pitt
University of Alabama at Birmingham

4. **"Watershed Protection Using an Integrated Approach"**
Earl Shaver, John Maxted and David Carter
State of Delaware DNREC;
Gray Curtis
Madrigal Software Corporation

Noon - 1:30 pm	Lunch
1:30 pm - 5:00 pm	*Ad hoc* sessions and/or free time
5:00 pm - 6:00 pm	Social Hour (cash bar)
6:00 pm - 7:30 pm	Dinner
7:30 pm - 10:00 pm	SESSION VIII: PROTOCOLS FOR MONITORING BMPs FOR EFFECTIVENESS

Session Chair: Eric Strecker

1. **"Monitoring Effectiveness of Non-Structural BMPs"**
Roger Bannerman
Wisconsin Department of Natural Resources

2. **"Monitoring of Wetlands, Wet Ponds & Grass Swales"**
Thomas Grizzard, David Green and Clifford Randall
OCCOQUAN Watershed Monitoring Laboratory

Thursday, August 11, 1994 (continued)

	3. **"Monitoring the Effectiveness of Structural BMPs"** George Oswald Camp, Dresser & McKee, Inc.; Richard Mattison Kinnetic Laboratories, Inc.
10:00 pm - 11:00 pm	Social Hour (cash bar)

Friday, August 12, 1994

7:00 am - 8:30 am	Breakfast Buffet
9:00 am - Noon	**SESSION IX: CLOSING SESSION** Session Chair: Larry A. Roesner **1. "Summary of Session Discussions and Topic Needs"** Harry Torno **2. "What Have We Learned This Week and Yet Need to Learn?"** Michael B. Cook and Christine Andersen **3. Participant Brainstorming on Stormwater Monitoring** Moderator: Larry A. Roesner **4. Closing Comments and Adjournment** Chair: Ben Urbonas
Noon	Lunch

Monday, August 8, 1994

SESSION I: OVERVIEW OF STORMWATER MONITORING NEEDS

1. **"Trends in Monitoring for Stormwater"**
   Michael B. Cook
   Director of U.S. EPA Office of Wastewater Management and Conference Co-Chair

2. **American Public Works Point of View**
   Christine Andersen
   President, APWA Institute for Water Resources and Conference Co-Chair

3. **"Overview of Stormwater Monitoring Needs"**
   Dr. Larry Roesner
   Chair, Task Force Committee for Preparation of Urban Stormwater Quality Management Manual;
   Kelly Cave
   Camp Dresser and McKee, Inc.

4. **Non-U.S. Modeler's Point of View**
   William James
   University of Guelph, Ontario, Canada

MONITORING NEEDS IN THE NPDES STORM WATER PROGRAM -- EPA'S POINT OF VIEW

June 1994

by

Michael B. Cook[1], Kevin J. Weiss[2], and William F. Swietlik[3]

INTRODUCTION

Traditionally, monitoring requirements under the National Pollutant Discharge Elimination System (NPDES) program have emphasized analyzing pollutants in discharges at the end the end of the pipe. However, EPA anticipates that a number of recent initiatives will be changing the direction of monitoring in general and, when coupled with the evolving needs of the storm water program, will result in more comprehensive, improved and better integrated approaches to monitoring storm water in the future.

OVERVIEW OF NEW INITIATIVES

EPA is participating in a number of initiatives that will shape and improve the Agency's monitoring and data collection efforts. Five initiatives that will directly impact monitoring in the NPDES storm water program include:

- the Intergovernmental Task Force on Monitoring Water Quality (ITFM)
- the EPA- National Goals Project
- the Office of Water- NPDES Watershed Strategy
- the Office of Water environmental indicators project.
- the Office of Wastewater Management storm water environmental indicators project.

Intergovernmental Task Force on Monitoring Water Quality (ITFM):

The ITFM was established in 1992 to develop a strategy to solve a number of problems associated with water-quality monitoring activities[4]. The Task Force grew out of the recognition that environmental programs are moving beyond single-media, technology-based approaches towards holistic programs based on risk reduction and pollution prevention. As environmental programs change to more holistic risk-based approaches, monitoring needs become more complex, with new emphasis on:

- Watershed, ecosystem and geographically based programs,
- Biological resources, ecology and habitat,
- Nonpoint source remediation programs,
- Wetlands and coasts, and
- Sediment quality.

The mission of the ITFM is to develop and implement an integrated, voluntary, nationwide strategic plan that provides recommendations for achieving effective collection, interpretation, and presentation of water-quality data to improve the availability of information for decision making at all levels of the government. The strategy was developed in 1992[5]. The goal of the strategy is to provide water-quality data that meet the following four objectives:

1) define water quality status and trends;

2) identify existing and emerging water quality problems;

3) develop and implement policies and programs for water-resource management and regulation; and

4) evaluate water programs effectiveness.

The strategy includes both a national committee to develop monitoring guidelines and standards, and regional committees to tailor those guidelines to regional needs and to encourage agency participation in the strategy. Tasks planned by the national committee are shown in Table 1. Products that have been or are being developed by the ITMF are shown in Table 2.

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[1] Mr. Cook is the Director of the Office of Wastewater Management (OWM) at the Environmental Protection Agency (EPA).

[2] Mr. Weiss is a Chemical Engineer with the Storm Water Section in OWM at EPA.

[3] Mr. Swietlik in the Chief of the Storm Water Section in OWM at EPA.

[4] The ITFM is a federal/state/tribal partnership with representatives from 20 agencies and organizations. ITMF members include: the Army Corps of Engineers, Department of Energy, National Oceanic and Atmospheric Administration, National Park Service, Office of Management and Budget, Tennessee Valley Authority, U.S. Department of Agriculture, U.S. EPA, U.S. Fish and Wildlife Service/National Biological Survey, U.S. Geological Survey, Arizona, California, Colorado, Delaware River Basin Commission, Florida, New Jersey, Ohio, Potabatomi Community, South Carolina, Washington, and Wisconsin. The ITFM is chaired by EPA, and the USGS is vice chair.

[5] See "Ambient Water-Quality Monitoring in the United States - First Year Review, Evaluation, and Recommendations", ITFM, December 1992.

Table 1 - Tasks of the ITFM National Committee

1. Develop, for each monitoring objective, a set of questions to address issues.
2. Develop QA/QC guidelines for all aspects of the strategy.
3. Develop and update a core list of environmental indicators.
4. Determine the comparability of field and laboratory methods.
5. Develop station selection guidelines.
6. Promote data sharing among major information systems.
7. Identify formatting of ancillary data [illegible]d to interpret water-quality data.
8. Promote the development and standardization of data-analysis techniques.
9. Develop unified formats for reporting water-quality information.
10. Develop and organize training for personnel of participating agencies.

Table 2 - Products Developed or Being Developed by the ITFM

Product	Description
National Charter	A charter for a permanent national body to guide the implementation of the ITFM recommendations and to facilitate further collaboration of the many Federal, State, Tribal, regional, local, private, and voluntary organizations that are involved in monitoring.
Monitoring Framework	A framework for monitoring water quality which defines the components that a monitoring program should consider in order to ensure that it accomplishes its objectives.
Indicator Selection Criteria	Criteria with which to select parameters that measure progress in achieving water-quality goals.
Environmental Indicators Recommendations	ITFM recommendations of indicators to measure whether water-quality uses designated by the State are being met.
Methods and Data Comparability Council Charter	A charter for a Methods and Data Comparability Council to foster the development and use of performance-based methods of collection and analysis in a manner which will result in the acquisition of data of known quality. The Council will address some of the biggest obstacles to sharing data among monitoring agencies and other users.
Use of Ecoregions, Reference Conditions, and Index Calibration	An examination of reference conditions as a tool in biological assessment, and the use of the ecoregions concept as a way to categorize landscapes on which assessments are carried out.

These products are described in more detail in "Water-Quality Monitoring in the United States-1993 Report of the Intergovernmental Task Force on Monitoring Water Quality," ITFM, January 1994.

EPA National Goals Project:

EPA is in the process of developing a set of broad environmental goals for the Agency. The project's goal is to produce, by Earth Day, April 22, 1995, a set of ambitious, realistic and measurable environmental goals to be achieved in the next century. As part of this effort, the Agency has identified three goals which relate to controlling pollutant sources to surface waters: clean surface waters, safe drinking water, and ecological protection. The Agency is in the process of identifying measures that can be used to evaluate progress towards meeting these goals.

In a complementary effort, the Office of Water issued a Strategic Plan to provide a framework for Office of Water goals and measures of success. A key part of this plan are a series of national environmental goals and environmental indicators. The plan also calls for working closely with the States to put together action plans for reporting on these goals and indicators over time.

As part of the plan, the Office of Water has established four major strategic goals for water programs, shown in Figure 1. Each goal contains one or more subgoals:

- ♦ PROTECT AND ENHANCE PUBLIC HEALTH (meet designated uses)
  - Safe Drinking Water
  - Safe Fish and Shellfish Consumption
  - Safe Aquatic Recreation
- ♦ CONSERVE AND ENHANCE ECOSYSTEMS (meet designated uses)
  - Biologically Healthy Water Resources
- ♦ IMPROVE AMBIENT CONDITIONS
  - Improved Surface Water Ambient Concentrations of Toxic and Conventional Pollutants
  - Ground Waters Meet Water Quality Objectives
  - No Net Loss of Wetlands
  - Extent of Contaminated Sediments is Reduced
- ♦ REDUCE POLLUTANT LOADINGS (point and nonpoint sources)
  - Reduced Toxic Pollutant Loadings
  - Reduced Conventional Pollutant Loadings

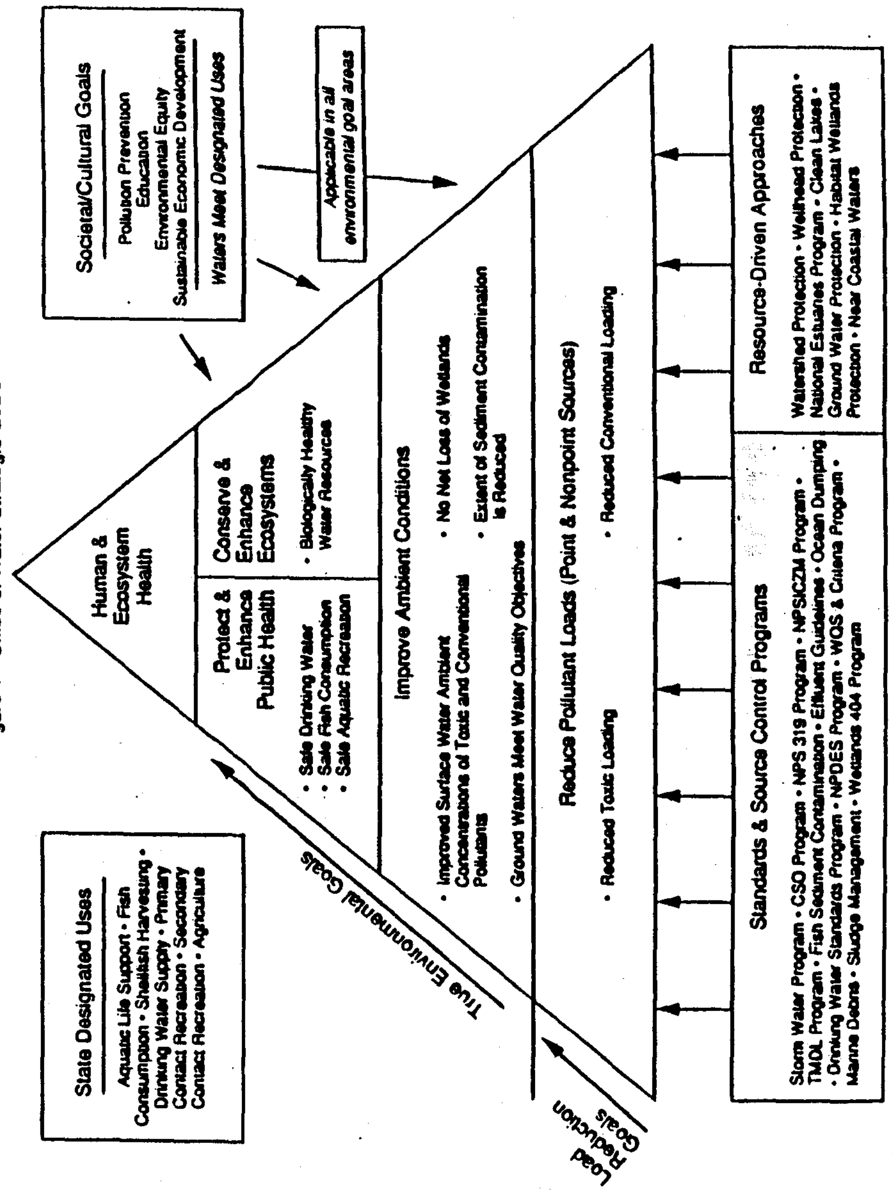

Figure 1 - Office of Water Strategic Goals

NPDES Watershed Strategy:

In March of 1994, EPA issued the NPDES Watershed Strategy. The Strategy is a first step toward the goal of integrating the NPDES program into a comprehensive, multi-program approach to addressing surface water, ground water, and habitat concerns on a watershed basis. The NPDES Watershed Strategy outlines national objectives and implementation activities to (1) integrate NPDES program functions into broader watershed approaches; and (2) support the development of State-wide basin management approaches.

One of the six essential areas identified in the Watershed Strategy is monitoring and assessment. Action items identified in the Strategy to support monitoring and assessment include:

- Develop a State-wide monitoring strategy to assure the most effective targeting of limited monitoring resources and coordinate collection and analysis of NPDES, nonpoint source, and other watershed data.

- Establish point source ambient monitoring requirements where appropriate to support assessment of watershed conditions; this action may provide opportunities for group monitoring plans for multiple discharges to the same basin.

- Promote comparable data collection, analysis, and utilization by all stakeholders (e.g. NPDES, 303(d), 304(l), and 319) through revisions to information collection and management systems (e.g., permit applications and compliance monitoring, PCS, TMDL development, 305(b), NEP, STORET, and water body systems)

As the NPDES program moves further towards embracing the watershed strategy, monitoring in the NPDES storm water program, as in all NPDES program areas, will need to evolve to be fully supportive.

The Office of Water Environmental Indicators Project:

The Office of Water is proposing to evaluate progress in meeting the goals of the Strategic Plan by using a number of environmental and programmatic indicators. These indicators, when adopted, will have a strong influence on the purpose, direction and types of monitoring employed in Office of Water programs in the future. Recommended preliminary indicators for the strategic goals are outlined in Table 3. To complete this effort a significant amount of work remains, including:

Table 3 - Office of Water List of 33 Recommended Indicators

Goal	Objective	Indicators
Protect and Enhance Public Health	Safe Drinking Water	1. Waters Meet Drinking Water Supply Designated Use 2. Populations Served by Public Water Supply Systems with Wellhead Protection 3.* Populations Served by Public Water Supply Systems (ground and surface water) that Meet Drinking Water Standards 4. Blood Lead Levels in Children 5. Disease Outbreaks from Public Water Supplies
	Safe Aquatic Recreation	6.* Waters Meet Swimming and Secondary Contact Designated Uses 7. Beach Closures: Miles Closed and Organism Levels 8. Disease Outbreaks from Swimming
	Safe Fish & Shellfish Consumption	9.* Waters Meet Fish and Shellfish Consumption Designated Uses 10. Fish Advisories 11.* Waters with Fish Contaminant Levels of Concern to Human Health 12.* Shellfish Bed Closures 13. Disease Outbreaks from Fish and Shellfish Consumption
Conserve and Enhance Ecosystems	Biologically Healthy Water Resources, Including Lakes, Rivers, Streams, Estuaries, Coastal Waters, Wetlands, and Ground Water	14.* Water Meet Aquatic Life Designated Uses (including ground water discharges to surface water) 15. Fish (assemblage) or IBI-like Index 16. Benthic Macroinvertebrates (assemblage) 17. Habitat (physical structure) 18. Plankton and Periphyton Assemblages 19. Floral Composition 20. Faunal Composition
Improve Ambient Conditions	Ground Waters Meet Water Quality Objectives	21.* Ambient Ground Water Quality
	Improved Surface Water Ambient Concentrations of Toxic and Conventional Pollutants	22.* Selected Water Quality Parameters 23.* Water Quality Standards Attainment
	Extent of Contaminated Sediments is Reduced	24.* Extent of Contaminated Sediments
	No Net Loss of Wetlands	25.* Loss or Gain of Wetland Acreage
Reduce Pollutant Loadings	Reduced Conventional Pollutant Loadings	26. Pollutant Loading to Ground Water from Underground Injection Wells 27.* Point Source Toxics 28.* Selected Conventional Pollutants: TSS, BOD, Fecal Coliform, and Nutrients 29. Key Wetweather Conventionals from CSOs
	Reduced Toxics Pollutant Loadings	30. Number of State and Local Governments Requiring Treatment of Stormwater Runoff from Rural, Suburban, and Urban Land Uses 31. Number of NPS Best Management Practices Implemented at State and Local Level 32. Key Wetweather Conventional Pollutants from Nonpoint Sources and Stormwater 33 Marine Debris

* Adequate data exists in the near term to establish baseline information.

- selecting indicators that major participants can agree on,
- establishing a nationwide monitoring and data system that:
  - uses information from various sources to support management systems and report on progress towards national goals,
  - uses comparable collection, reporting and analytical methods,
  - stores data of known quality in systems that can "talk" to each other,
  - has clear roles and responsibilities and focusses use of available resources from many sources (EPA, other Federal agencies, States, utilities, etc.).

In fiscal year 1995, EPA will be taking two major steps towards implementing the Office of Water Strategic Plan. The first step will be funding a series of State pilot projects to test selected environmental indicators. Eight States[6] will be implementing the pilot projects, lasting 18 to 24 months, using indicators from the list of 33 national indicators developed by EPA. The States will use the indicators to measure success towards reaching the goals of protecting human health, conserving and enhancing ecosystems, improving ambient conditions, and reducing pollutant loadings. These pilot projects will be our first real attempt to test "on the ground" whether the necessary steps to implement and track environmental indicators over time can be successful. The pilots will serve another important purpose--to determine if selected environmental indicators can compliment or substitute over time for some of our current programmatic measures of success for State water programs that are activity-based (such as number of permits issued and enforcement actions taken). We are very pleased with the enthusiasm shown by the States for the environmental indicators pilot project.

The Office of Wastewater Management Storm Water Environmental Indicators Project:

As a complement to the Office of Water environmental indicators effort, the Office of Wastewater Management is initiating a project that will identify and implement environmental indicators specific to the NPDES storm water program.

To accomplish this, EPA is issuing a series of grants to support the selection and implementation of storm water environmental indicators that can be used by municipalities and industries to assess the effectiveness of their storm water control efforts and to possibly

[6] The States tentatively selected for the pilots are Maine, Delaware, Maryland, Georgia, South Carolina, Wisconsin, Ohio and possibly Nevada. In addition, EPA is considering a local project under the National Estuary Program in Oregon.

provide data for the national environmental indicators tracking system. The project, which will be implemented for the most part in fiscal year 1995, includes:

- compiling a summary of recent efforts to develop and implement environmental indicators for storm water discharges;
- holding a series of stakeholder meetings around the country to select environmental indicators for the storm water program, including a select list of indicators to be used for national tracking;
- preparing a report on the results of the stakeholder meetings describing the environmental indicators selected and the methodologies and criteria for implementation; and,
- awarding grants for a series of demonstration projects on implementing storm water environmental indicators.

It is the objective of this project that valuable information for selecting and implementing storm water program environmental indicators will be developed which should significantly guide the direction of storm water monitoring in the future.

Upon completion of the storm water environmental indicators demonstration projects, EPA hopes that numerous municipalities and industries will better understand, and be better equipped, to implement effective monitoring strategies for assessing their storm water management programs.

The data that is generated by municipalities, and other sources, if done in a consistent, quality fashion, should be applicable at the national level for tracking and assessing progress of the NPDES storm water program towards accomplishing the Office of Water strategic goals.

SUMMARY

Several national initiatives will directly impact the future of monitoring in the NPDES storm water program. The Intergovernmental Task Force on Monitoring Water Quality (ITFM) will be recommending that monitoring efforts be more holistic in nature and will be developing national and regional guidelines and standards for monitoring.

The EPA National Goals Project will produce a set of realistic and measurable environmental goals to be achieved in the next century. The Goals Project will involve identifying monitoring that can be used to effectively evaluate progress towards meeting the goals.

Under the new NPDES Watershed Strategy, monitoring and assessment have been identified as an essential element to be addressed. Important objectives of the Strategy are the development of State-wide monitoring strategies to assure the more effective targeting of limited monitoring resources and the coordination of the collection and analysis of data, and the use of receiving water monitoring procedures where appropriate to support assessment of watershed conditions.

The EPA Office of Water is proposing to evaluate progress in meeting the goals of the EPA Strategic Plan by using a number of environmental and programmatic indicators. These indicators, when adopted, will have a strong influence on the purpose, direction and types of monitoring employed in water programs in the future.

Finally, the Office of Water, Office of Wastewater Management is planning the development of a set of environmental indicators that can be used specifically by storm water dischargers to evaluate progress towards meeting the goals of the NPDES storm water program and, more broadly, the strategic goals of the Office of Water.

These initiatives will result in a number of changes to monitoring approaches under the NPDES storm water program in the future. As monitoring requirements under the NPDES storm water program change and evolve, storm water professionals will be presented with unique opportunities to provide insight and expertise on innovative approaches to storm water monitoring at national, State and local levels.

American Public Works Point of View

Christine F. Andersen[1], Member ASCE

Abstract

Public works agencies are responsible for implementing the regulations regarding stormwater in the NPDES program. As such they become the agencies responsible for balancing environmental protection, community interests, political interests, financial constraints and the technical skills and resources necessary to carry out the goals of the Clean Water Act. To carry out this implementation role effectively there is a critical need to build the level of technical knowledge and understanding of stormwater quality and promote opportunities for sharing this information. Pressure for funding at the local level is creating tremendous resistance in communities across the country. Gaining community understanding and support requires the ability to clearly articulate environmental benefits and cost effective application of resource to address local problems. Without grassroots support, communities will become the biggest roadblocks to achieving the goals of the Clean Water Act.

Introduction

Since the reauthorization of the Federal Clean Water Act in 1987, the requirement that municipalities with populations greater than 100,000 obtain NPDES permits for separate storm sewer systems has been implemented.

[1]Director, Department of Public Works, City of Eugene, 858 Pearl Street, Eugene, OR 97401

Across the country affected public works agencies responsible for stormwater have been developing stormwater quality programs and seeking permits from state environmental regulatory departments in those NPDES designated states or from EPA. The investment of resource in permit application and the sampling and data base development is significant. The resource requirement for implementation and monitoring of Best Management Practices (BMP's) covered by those permits will require an ongoing commitment.

In the early years following the 1972 adoption of the Federal Water Pollution Control Act when the primary focus of the clean water program was wastewater, up to 90% of the funding required for local agency implementation was provided from federal and state sources. Today, program costs are borne almost entirely at the local level. This fact, along with similar program funding shifts in virtually every area of local government agency programming, has presented real challenges to the implementation of the stormwater NPDES program. Coupled with that challenge is the fact that agencies across the country are scrambling to build stormwater programs based on relatively limited research and experience in the whole area of stormwater monitoring and BMP effectiveness.

Capturing and Sharing Information

Huge data bases of stormwater sampling and BMP monitoring information are being generated across the country through implementation of mandated stormwater programs. It is still uncertain when or how municipalities with populations less than 100,000 will be brought into the stormwater NPDES program. For those 200 or so communities already embarking on their first permit, there is much to learn and share. The focus of this conference is timely and critical to the effective use of the significant resource going into current permit development and implementation. It is essential that communities be able to learn from each other and share information reliably and effectively. In addition, EPA needs to be able to use the information being reported under these permits to base future Clean Water Act changes on improved understanding of stormwater quality problems. The Nationwide Urban Runoff Program (NURP), which served as the basis for the 1987 Clean Water Act amendments covering the stormwater quality program, was relatively limited, covering only 28 cities. The number of communities currently required to be permitted under NPDES and the type of data being generated should result in a far clearer picture of the need for future stormwater program regulatory changes if that data is captured and used effectively.

Not too long ago, it would have been unthinkable to expect communities to take on a research and development role for a problem of this magnitude. Unfortunately, today that is precisely where local communities find themselves. Strategies and techniques are being identified, tested and monitored in the hope that they will result in improved water quality conditions and that it will be feasible to accurately detect environmental improvements.

In many cases, consultants working in partnership with public works agencies are providing the vehicle for technology transfer. Communities are now sharing experiences and information through common consultants, even as the regulatory agencies struggle to develop their own administrative programs. The attendance and participation at this conference reflects both this relationship and the strong common interest in sharing information and learning from other professionals engaged in the development and implementation of stormwater quality programs. This approach has been surprisingly effective but it is not adequate to handle the growing demand and need for transferable information. Authorization and funding of the National Academy of Sciences to evaluate research and development programs and provide an umbrella for better coordination and utilization of colleges and universities in expanding environmental research programs would be important and appropriate steps.

Funding

Program funding is a serious constraint. The issue of unfunded mandates has generated a tremendous local community lobbying effort in Congress and impeded the adoption of the new Clean Water Act. Across the country the demand for funding at the local level to support federal and state mandated programs, as well as those identified by local priorities, is continuing to grow. Revenue limitation initiatives are appearing throughout the states. The strategy used in many communities to implement a stormwater quality program has been the creation of a stormwater utility. That is not a problem-free option and may become even more difficult to initiate and manage over time. As an example, in Oregon there is a statewide initiative measure on the November 1994 ballot that would prohibit any new fees or changes to an existing fee without a public vote. In short, without local support for the implementation of local programs, funding will be more and more at risk. With an eye to the future and the goals of the 1972 Clean Water Act to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters," it is critical to build a foundation of community consensus and support and not rely on the force of federal mandates to achieve these goals.

Building Community Consensus

Gaining community support, particularly where funding is involved,

is becoming more and more difficult as public sentiment regarding government and governmental agencies continues to deteriorate. In testimony before the House Subcommittee on Water Resources and Environment this past May, EPA Administrator Carol Browner described the goal of the reauthorized Clean Water Act as "a better, more flexible clean water act that will result in increased protection for our water resources at a lower cost." Flexibility and cost effectiveness are minimum requirements for the achievement of local support. Better understanding of BMP effectiveness and the ability to shift resource from ineffective strategies to other, more environmentally beneficial ones are basic needs to ensure continued local support. The ability to demonstrate results and contain the otherwise spiraling resource demanded from urban residents are necessities for local program support. The ability to accurately describe the real benefits to a community that are derived from the development, implementation and maintenance of a local stormwater program is critical to gaining and sustaining local support.

Where Do We Go From Here?

The purpose of this conference is to target current needs and future directions. Months and months of work has gone into the drafts of Clean Water Act reauthorization bills that will not make it through Congress this year. Many of the individuals responsible for hammering out language in those bills are at this conference and undoubtedly have perceptions to share about possible next steps. Focusing on common goals for environmental protection and clean water will help to ensure that progress continues to be made as these needs are sorted out.

Overview of Stormwater Monitoring Needs

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Abstract

Runoff pollution studies have attempted to quantify the stormwater pollution load contribution to surface waters since the early 1970s. This paper presents a select summary of what has been learned from previous stormwater monitoring programs and offers recommendations help guide the future direction of such programs.

Introduction

Since the early 1960s, stormwater runoff has been recognized as a significant source of pollution to the nation's waterways. Since the early 1970s, there has been a growing body of runoff pollution research to quantify the stormwater pollution load contribution to surface waters and to characterize stormwater pollutant generation, transport, and fate. Recently, over 100 U.S. cities and numerous industries collected stormwater runoff data under the Phase I National Pollutant Discharge Elimination System (NPDES) stormwater permitting program. Additional stormwater runoff data will be collected as the Phase I NPDES permits are issued and in other stormwater programs around the world. Stormwater runoff data collection is also likely to be required under the Phase II NPDES program which will be defined this fall.

This paper presents a select summary of what has been learned from previous stormwater monitoring programs and offers recommendations help guide the future direction of such programs.

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What We've Learned from the Past

Since the early 1970s, runoff pollution research studies have attempted to quantify the stormwater pollution load contribution to surface waters and to characterize stormwater pollutant generation, transport, and fate. In the late 1970s, the "208 studies" implemented under Section 208 of the Federal Water Pollution Control Act Amendments of 1972 showed that stormwater generally contributed as much as half of the total pollutant load entering U.S. surface waters. This realization led to the U. S. Environmental Protection Agency's (USEPA) development of the Nationwide Urban Runoff Program (NURP) which was initiated to characterize the water quality of urban runoff and the potential for water quality impacts in receiving waters. NURP represents the largest research effort targeting urban stormwater runoff to date. Storm event monitoring was performed at 81 outfalls at 28 cities across the U.S. during the years 1978 through 1983.

The large number of sites monitored under the NURP program represented a wide variety of climatological conditions, land use types, land slopes, and soil types, thereby providing the basis for identifying similarities and differences among sites. Approximately 2,300 storm events were monitored, which corresponds to an average of 28 storms per outfall site. At a particular site, the monitoring was typically conducted over a 12-month period. Urban land uses monitored during the study included: residential, commercial, and limited light industrial. Several of the NURP cities also monitored receiving waters to characterize impacts of urban runoff on receiving water quality. A variety of receiving waters were monitored, including rivers, lakes and estuaries.

The NURP sampling program included a wide range of water quality constituents. For all of the 2,300 storms events monitored, constituents analyzed included total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total phosphorus, dissolved phosphorus, total Kjeldahl nitrogen (TKN), nitrite + nitrate nitrogen, fecal coliforms, lead, zinc and copper. In addition, a limited number of grab samples were collected during 121 storms and were subsequently analyzed for priority pollutants. At the time, the priority pollutant list included 129 constituents.

The event mean concentration (EMC), which is defined as the total constituent mass in runoff divided by the volume of runoff during a given storm event, was established as the primary water quality statistic in the NURP study. EMCs were estimated at monitoring sites for individual storm events by collecting and analyzing flow-weighted composite samples of runoff generated by each event. At other sites, however, the monitoring consisted of a set of sequential discrete samples collected during a storm event. For these sites, EMCs were calculated by analyzing the hydrographs (flow vs. time) and pollutographs (concentration vs. time) from each storm.

USEPA analysis of the pooled national database from all of the project sites could not explain the variability of the pooled national EMC values by any single factor such as land use, soil type, land slope, climatology or geographic location. These and other transferability evaluations led to the development of a general characterization of urban runoff which can be used nationwide for estimating stormwater pollutant loadings from un-monitored areas. The pooled national NURP urban runoff characterization was recommended for use in planning level water quality studies, unless more localized water quality data are available. Another product of the NURP study was the development of standard monitoring and data analysis approaches which have been used by most subsequent stormwater pollution studies.

Since the NURP study, other stormwater monitoring studies have continued to quantify the pollution load contribution to surface waters and to characterize stormwater pollutant generation, transport, and fate. The U.S. Geological Survey (USGS), for example, has developed an urban storm runoff database consisting of data for 1,123 storms for 98 urban stations in 20 metropolitan areas. The Federal Highway Administration (FHWA) investigated stormwater runoff loadings from highways by analyzing storm event monitoring data at 31 highway runoff monitoring sites in 11 states during the 1970s and 1980s.

NPDES Stormwater Monitoring

Recently, over 100 U.S. cities and numerous industries were required to collect stormwater runoff data under the Phase I National Pollutant Discharge Elimination System (NPDES) stormwater permitting program. Each Phase I municipality was required to characterize stormwater runoff by monitoring a minimum of 5 "representative" sites during a minimum of 3 storm events. The monitored sites were chosen to characterize discharges representative of commercial, residential, and industrial land use activities of the drainage area contributing to the system. The NPDES sampling protocols were derived from the NURP study. A composite sample from each storm event was analyzed for conventional pollutants (including nutrients, solids, oxygen demand, fecal bacteria) and for priority pollutants (toxic organic and inorganic compounds). Stormwater quality characterization data was based on estimating the EMC from a single flow-weighted composite sample prepared by combining discrete samples collected over the duration of the storm event. The intent of this permit application requirement was to ensure that the system discharges can be appropriately represented by the various existing data bases and to provide a basis for developing a monitoring plan to be implemented as a permit condition.

Use of Existing Data

A comprehensive analysis of all available storm event water quality data collected over the past 15-20 years has not been performed. A comparison of NURP data collected in the early 1980s with the NPDES data collected in 1991 - 1993 in the

State of Michigan is presented below. Three of the NURP studies were located in Michigan (Washtenaw County, Oakland County, and the City of Lansing) with approximately 100 storm events monitored at eleven stations. As part of the NPDES stormwater permit application process, representative outfalls were recently monitored in the Michigan Cities of Warren, Flint, Ann Arbor, and Grand Rapids and at the University of Michigan. The Michigan NPDES data includes EMCs for approximately 75 storm events that were monitored at 27 stations.

The stormwater monitoring data comparisons presented below are based on the lognormal means of the data reported for each site. When data are characterized by infrequent extreme observations, as often happens in water quality monitoring, it is appropriate to apply a lognormal distribution. Studies such as the NURP and FHWA programs described previously have shown that stormwater quality data are best represented by the lognormal distribution. The appropriate statistic to employ for comparisons between individual sites or groups of sites is the median value, because it is less influenced by the small number of large values typical of lognormally distributed data. However, for comparisons with other published data which usually report average values, the mean value is more appropriate.

Table 1 compares the Michigan NPDES EMCs for residential, commercial, and industrial land uses with the Michigan NURP and national NURP EMCs. It should be noted that the NURP sites did not represent any heavy industrial land uses, but rather light industrial park land use. In general, the mean Michigan NPDES EMCs are within the range of EMCs reported under the earlier studies with the exception of lead. For oxygen demand (biochemical oxygen demand (BOD) and chemical oxygen demand (COD)), Michigan NPDES concentrations are generally higher than NURP EMCs for residential and industrial land uses while Michigan NPDES concentrations are lower than NURP for commercial land uses. For total suspended solids (TSS), EMCs reported for the residential and commercial Michigan NPDES sites are as much as 40% lower than NURP EMCs while those for industrial land uses are similar to NURP EMCs. Nutrient (phosphorus and nitrogen) NPDES concentrations are very similar to national NURP EMCs for all three land use categories. However, lead EMCs reported for the Michigan NPDES sites which were monitored during 1991 through 1993 are an order of magnitude lower than those reported in the NURP and other earlier studies which include data collected during the mid-1970s through early 1980s. The primary reason for the decrease in lead EMCs is probably the increased usage of unleaded gasoline.

The previous monitoring studies such as the NURP and the recent NPDES monitoring programs provide stormwater pollution loading data on which to base estimates of stormwater pollutant loadings from a given area. In the case of the Michigan NPDES programs and other programs reviewed, the recent monitoring data compares well with that collected during previous studies. Therefore, continued emphasis on single land use "end-of-pipe" monitoring programs is

TABLE 1
COMPARISON OF SELECTED STATE OF MICHIGAN MUNICIPAL NPDES MONITORING DATA
TO NATIONAL RUNOFF DATA FOR RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL LAND USE

		EVENT MEAN CONCENTRATIONS (1, 2)							
		Michigan NPDES				Michigan NURP (6)		National NURP (7)	
Constituent	Units	N	MAX	MIN	MEAN	N	MEAN	N	MEAN
RESIDENTIAL LAND USE (3)									
BOD	mg/L	43	125	2	26	58	16	134	11
COD	mg/L	43	316	27	102	71	85	913	83
TSS	mg/L	42	380	2	84	97	125	1,102	140
Total-P	mg/L	34	1.23	0.07	0.38	95	0.32	1,029	0.47
Dissolved-P	mg/L	34	0.98	0.02	0.18	88	0.07	344	0.16
TKN	mg/L	31	4.90	0.03	2.24	96	1.62	904	2.35
NO2 + NO3	mg/L	31	2.80	0.03	1.98	94	0.83	593	0.96
Lead, total	ug/L	43	200.0	3.5	48.7	71	116.8	802	180.0
Copper, total	ug/L	43	97.0	10.0	29.6	44	18.2	468	50.0
Zinc, total	ug/L	43	600.0	10.0	189.5	45	154.0	797	180.0
COMMERCIAL LAND USE (4)									
BOD	mg/L	19	140	1	21	8	52	171	14
COD	mg/L	19	150	26	80	9	99	243	92
TSS	mg/L	19	280	5	77	10	149	309	186
Total-P	mg/L	16	0.96	0.05	0.33	10	0.16	307	0.29
Dissolved-P	mg/L	16	0.90	0.02	0.17	10	0.07	62	0.17
TKN	mg/L	14	4.00	0.57	1.74	10	1.25	223	1.61
NO2 + NO3	mg/L	13	1.50	0.03	1.23	9	0.74	209	0.89
Lead, total	ug/L	19	150.0	1.5	49.3	10	56.9	291	235.5
Copper, total	ug/L	19	130.0	10.0	37.0	10	14.0	152	61.8
Zinc, total	ug/L	18	380.0	48.0	156.3	8	69.3	221	399.5
INDUSTRIAL LAND USE (5)									
BOD	mg/L	11	73	5	24	17	7	25	10
COD	mg/L	10	150	41	85	23	64	39	61
TSS	mg/L	11	271	5	149	38	143	61	123
Total-P	mg/L	7	1.14	0.06	0.32	35	0.49	56	0.49
Dissolved-P	mg/L	7	0.69	0.02	0.11	30	0.09	51	0.17
TKN	mg/L	7	3.60	1.00	2.08	36	1.49	53	1.53
NO2 + NO3	mg/L	7	3.60	1.30	1.89	35	0.71	40	0.79
Lead, total	ug/L	11	130.0	3.0	72.4	26	115.5	26	115.5
Copper, total	ug/L	9	172.0	12.5	58.0	13	30.1	18	31.7
Zinc, total	ug/L	11	1,230.0	140.0	670.8	14	233.5	20	979.8

NOTES:

(1) Values below the detection limit were analyzed at 50% of the detection limit.
(2) Event mean concentrations assume that the data are lognormally distributed.
(3) Values reported for the Michigan NPDES sites were calculated for 29 single family storm events and 14 multi-family storm events from sites located in the Cities of Ann Arbor, Flint, Grand Rapids, and Warren, and at the University of Michigan during 1992 - 93. Values reported are the averages of the single family and multi-family lognormal means.
(4) Values reported for the Michigan NPDES sites were calculated for 19 commercial storm events from sites located in the Cities of Ann Arbor, Flint, Grand Rapids, and Warren, and at the University of Michigan during 1992 - 1993.
(5) Values reported for the Michigan NPDES sites were calculated for 11 industrial storm events from sites located in the Cities of Flint, Warren, and Grand Rapids during 1992.
(6) "Final Report of the Nationwide Urban Runoff Program," (NURP) USEPA 1983, Tables 6-1 through 6-10 for the Pitt AA-N, Grace N, Grand R. Ot., and Waverly sites and "SEMCOG/Oakland County NURP Project: Final Report," SEMCOG, 1983, Table 3 for the combined Beaver Trail and Sylvan Glen sites.
(7) NURP, USEPA 1983, adapted from Table 6-12.

probably not warranted. However, many of the Phase I NPDES cities are proposing to continue this type of program for the 5-year permit term.

As mentioned previously, a comprehensive analysis of all appropriate storm event water quality data collected over the past 15-20 years has not been performed. We recommend that such analysis be completed to aid in the development of future monitoring programs. For example, the variability in EMCs among NURP sites was greater than any observable variability among geographic regions which made development of land-use specific or regionalized EMC estimates infeasible. Analyses of the NURP data for seasonal differences among EMCs were either not performed or not reported by the NURP team. Clearly these analyses, particularly investigation of regional, geographic, or seasonal differences among EMCs, need to be performed on the larger database of monitoring data available today to guide the direction of future stormwater pollution research.

Objectives of Future Monitoring Programs

Monitoring data collected under the existing Phase I NPDES stormwater permitting program has further supported the premise that stormwater runoff is a significant source of pollution to the nation's waterways. Data collected during development of the Phase I permit programs has been and will be used to aid municipalities and industries in the development and refinement of management programs to reduce stormwater pollutant loadings to U.S. surface waters. Most stormwater management specialists nationwide recognize, however, that effective management programs for protecting our nation's water resources should be based on a watershed basis instead of a jurisdictional basis. This sentiment is also reflected in the recent drafts of the upcoming Clean Water Act (CWA) Reauthorization; both the House and Senate CWA reauthorization bills include language to this effect.

It is our recommendation that nonpoint pollution management plans and the monitoring programs which support their development and implementation should include all nonpoint sources of pollution within a watershed. Many of the NPDES stormwater programs focus exclusively on characterizing stormwater pollution from an industry or a municipality. In urban areas, pollutants from other sources such as atmospheric deposition and contaminated river bottom sediments may also be significant and should be characterized to support a comprehensive management plan.

The current NPDES program relies on "end of pipe" monitoring data to assess the effectiveness of management programs implemented to reduce nonpoint pollution loadings to a receiving water. This approach does not provide local decision-makers with information regarding the performance of individual management measures and programs. We recommend that NPDES monitoring programs also characterize the performance of individual management measures such as detention ponds or source control activities within the watershed investigated. This action will provide local data to guide the development and refinement of management programs tailored to the characteristics of the local community. In addition, local data on the benefits of requiring costly management measures will aid local decision-makers in the implementation of stormwater management programs.

The overall objective of a nonpoint pollution monitoring program such as those required for NPDES permitting should be to support watershed management decisions by local decision-makers. Specific objectives should be:

1) to refine land use nonpoint pollution loading relationships within a watershed,

2) to provide quantitative information regarding the pollutant removal efficiencies that are achieved by structural and nonstructural best management practices (BMPs),

3) to provide sufficient field data to calibrate and verify pollutant loading estimates, and

4) to conduct special studies to characterize other sources of pollution (e.g., atmospheric deposition, contaminated sediments, biological/habitat assessment) to the extent possible.

Approach for Future Monitoring Programs

The Phase I NPDES stormwater permitting program required collection of monitoring data during the permit application process according to specific protocols outlined in the regulations. During the term of the permit, stormwater quality monitoring is also required but a municipality has more flexibility in devising the monitoring program. The time frame and costs associated with collecting an adequate urban stormwater database for planning, implementing, and evaluating stormwater management plans may, however, exceed the resources available. Consequently, it is recommended that all available existing data from local and regional studies be used. Additional data collection should be carefully planned to ensure that it does not duplicate previous efforts and can be used to augment the existing data. Data collected merely to meet permit requirements may be wasted if it does not support stormwater planning and management needs.

USEPA did not specify minimum standards for the monitoring program to be completed by Phase I municipalities and industries during the 5-year term of the permit but allowed the permitees to design their own programs. A review of monitoring programs proposed by a number of Phase I municipalities revealed that most programs specified continued characterization of land use nonpoint pollution loading relationships within their community by monitoring/sampling at most of the same sites monitored during the permit application process. The number of parameters analyzed, however, is typically substantially reduced from the number

required during the permit application process. Further, most proposed programs reviewed specified on the order of 4 storm events sampled per site per year.

Most of the proposed permit term stormwater monitoring programs proposed to date do not include provisions for estimating the pollutant reductions achieved by the structural and nonstructural BMPs (objective 2 above) which already exist in the municipality or which may be implemented as part of a stormwater management plan. For structural BMPs, available pollutant removal performance data shows that pollutant removal efficiencies achieved by BMPs will vary from one storm to the next. After very large storm events or during wet periods, BMPs may exhibit low or negative efficiencies due to insufficient detention times, scour, or resuspension of sediments. Conversely, higher efficiencies may be achieved after smaller storms or during storms that occur after extended dry periods. For nonstructural BMPs, little pollutant removal performance data is available in the literature. For example, few stormwater quality monitoring programs have attempted to document the effectiveness of public education programs aimed at preventing such pollutants as used motor oil and lawn care products from entering receiving waters. Many of the management programs proposed as part of the Phase I NPDES municipal stormwater permit applications submitted to date, however, rely heavily on the use of nonstructural BMPs to reduce stormwater pollutant discharges to the "maximum extent practicable" (MEP) as required in the regulations. Future NPDES monitoring programs should therefore include provisions for defining the effectiveness of management programs implemented and for defining the MEP pollutant reductions for the municipality.

Stormwater monitoring programs to support NPDES stormwater permit programs should be designed to provide a reasonable level of statistical significance on an annual basis as well as over the 5-year permit term. This program design is necessary if regulatory agencies use annual and cumulative data for assessments of the effectiveness of management programs. For many pollutants found in urban runoff, the efficiencies of structural and nonstructural BMP program elements are likely to be on the order of 5% - 10% (nonstructural) up to 50% - 90% (structural). Citywide pollutant loading reductions for typical NPDES stormwater management programs developed to date are likely to be less than 25% for many pollutants under full implementation. In order to demonstrate the progress of local management programs over the 5-year permit term, the estimated mean EMCs from the municipal monitoring database should have a level of accuracy which will reflect reductions due to BMP programs. If the loading reductions achieved by the BMP programs are on the order of 5% - 50%, it will be difficult to draw any meaningful conclusions from the monitoring data if the estimated mean EMCs have a relative error which is much greater than the BMP efficiencies.

Those monitoring programs designed to provide a reasonable level of statistical significance on an annual basis as well as over the 5-year permit term will also demonstrate local benefits of the management program on an annual basis to local decision-makers and the public. Investigations of receiving water quality impacts may also be warranted to aid in management program assessments. The monitoring program should also allow for investigations of seasonal and other bias in the collected data over the 5-year permit term. A monitoring program designed around these recommendations should satisfy both objective 1 above, characterization of land use nonpoint loading relationships within a municipality, and objective 3 above, provide sufficient field data to calibrate and verify pollutant loading estimates as necessary.

In some urban areas, other nonpoint sources of pollution may cause water quality impacts equal to or exceeding those resulting from stormwater pollution loadings. For example, bottom sediments in receiving waters may be heavily contaminated and may introduce significant pollutant loads to the water column. Nonpoint source pollution monitoring programs should investigate such sources to provide data to guide the development of cost-effective watershed management plans. Guidelines for monitoring programs to characterize other nonpoint sources of pollution (objective 4 above) must be developed in accordance with the local situation.

Alternative Approaches for Future Monitoring Programs

There are alternative approaches in addition to monitoring the chemical quality of stormwater which can also be used to generate environmentally relevant information to guide the stormwater control plan for a municipal area. Biological and chemical monitoring of receiving waters enable both the evaluation of receiving water impacts and potential identification of stormwater pollutant sources, although these tools can be most effective when used in conjunction with traditional chemical analysis of stormwater (e.g., end-of-pipe monitoring). One advantage of including receiving water and biological monitoring in a stormwater monitoring program is that stream health can be directly assessed without relying solely on chemical surrogates and highly variable stormwater outfall data. In addition, use of biological monitoring may help address concerns about the aggregate affect of stormwater pollutants as well as the bioavailability of those pollutants. Another benefit of including chemical, biological and receiving water components in a stormwater monitoring program is that it may provide more cost-effective information to guide the direction of local stormwater management plans.

Data Analysis

A critical component of a stormwater monitoring program to support stormwater management plans is effectively utilizing the data collected in order to achieve the program's information goals and monitoring objectives. The conversion of data into information should begin with specified data handling procedures including adherence to quality assurance and quality control protocols. Statistical procedures for analyzing the collected data should be established to ensure that the information generated both matches the ability of the data to yield such information with confidence and matches the needs and expectations of decision makers. Finally, for NPDES permit monitoring programs, the results of the monitoring program should not be reported independently but as part of the overall report of the progress of the management program. Other information such as how much of the system was served by BMPs and how the results guided management program decisions should be part of the overall management program report to the regulatory agency.

Conclusions

A stormwater monitoring program to support a management plan to protect water resources such as is required under the NPDES stormwater permitting program should be developed on a watershed basis and should be tailored to address as many local sources of nonpoint pollution as possible. The development of the monitoring program should be based on an inventory of all local sources of NPS pollution (e.g., urban runoff, contaminated river bottom sediments) and available local, regional, and national data to characterize those sources. In addition, provision for assessing the success of the management program should be made in the monitoring program. Local data on the pollutant removal efficiencies of preferred structural and nonstructural management practices should be collected to aid local decision-makers in the development, implementation, and refinement of the management program. Investigations of receiving water impacts or biological assessments may also provide valuable data to guide local nonpoint pollution management policies. Most of the recent NPDES monitoring data reviewed compares well with that collected during previous studies. Therefore, continued emphasis on single land use "end-of-pipe" monitoring programs is probably not warranted.

Stormwater monitoring programs to support NPDES stormwater permit programs should be designed to offer a reasonable level of statistical significance on an annual basis and over the entire permit term. This program design is necessary if regulatory agencies use annual and cumulative data for assessments of progress of management programs. This design will also demonstrate local benefits of the management program on an annual basis to local policy-makers and the public. The monitoring program should also allow for investigations of seasonal and other bias in the collected data. A critical component of a stormwater monitoring program to support stormwater management plans is the effective handling and use of the data collected.

Continuing research is also needed in the area of stormwater pollutant generation, transport, and fate. The authors recognize that such research is beyond the scope of the NPDES stormwater permitting program. This research is necessary, however, to develop new management practices in the continuing quest to restore and protect the nation's water resources.

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KEYWORDS

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nonpoint source pollution
National Pollutant Discharge Elimination System (NPDES)
Nationwide Urban Runoff Program (NURP)
storm event monitoring
stormwater
water quality

Monday, August 8, 1994

SESSION II: LOCATING ILLICIT CONNECTIONS

1. **Locating Inappropriate Discharges to Storm Drains**
   Robert Pitt & Malinda Lalor
   University of Alabama at Birmingham;
   Richard Field
   U.S. EPA;
   Edward Thackston
   Vanderbilt University

2. **Finding Illicit Connections and Discharges with P2IL**
   John D. Minor
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Locating Inappropriate Discharges to Storm Drains

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Abstract

This article describes the results of a series of research tasks to develop a procedure to investigate non-stormwater (dry-weather) entries into storm drainage systems (Field et al. 1993a, Field et al. 1993b). Dry-weather flows discharging from storm drainage systems contribute significant pollutant loadings to receiving waters and although they can originate from many sources, the most significant include sanitary wastewater, industrial and commercial pollutant entries, failing septic tank systems, and vehicle maintenance activities. Protocols are discussed to: characterize the drainage area; locate and identify polluted outfalls; estimate the magnitudes of non-stormwater entries; and locate and correct the non-stormwater entries into the storm drainage system. If these loadings are ignored (e.g., by only considering wet-weather stormwater runoff), only limited improvement in receiving water conditions may occur with stormwater pollution control programs.

Introduction

Current interest in illicit or inappropriate connections to storm drainage systems is an outgrowth of investigations into the larger problem of determining the role urban stormwater runoff plays as a contributor to receiving water

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quality problems. The EPA's Storm & Combined Sewer Overflow Pollution Control Research and Nationwide Urban Runoff Programs, respectively helped highlight the problem with data confirming pollution found in urban storm drainage systems. Regulatory requirements such as the National Pollution Discharge Elimination System (NPDES) require certain classes of stormwater discharges to be permitted. Presently, the NPDES requires certain industries (*Federal* 1990) and municipalities with populations of 100,000 or more to conduct investigations to determine the locations of inappropriate dry-weather entries into storm drainage systems.

Waters discharged from stormwater drainage systems often include waters from many non-stormwater sources. A study in Sacramento, California (Montoya 1987) found that slightly less than half the volume of water discharged from a stormwater drainage system was not directly attributable to runoff. Illicit and/or inappropriate entries to the storm drainage system are likely sources of this discharge and can account for a significant amount of the pollutants discharged from storm drainage systems.

The methods described in this paper were developed specifically for detection of pollution sources in dry-weather flow, but are applicable to wet-weather flows as well. It must be noted that during wet-weather flow conditions there will be additional pollutant sources (e.g., roads, roofs, exposed materials storage, etc.).

Origins of Contamination

Common non-stormwater entries include: sanitary wastewater; automobile maintenance and operation waste products; laundry wastewater; household toxic substances and pollutants; accident and spill waste streams; runoff from excessive irrigation; and industrial cooling water, rinse water, and other process wastewater. Although these sources can enter the storm drainage system a variety of ways, they generally result from: (1) direct connections, such as wastewater piping either mistakenly or deliberately connected to the storm drains; or (2) indirect connections, which include infiltration into the storm drainage system and spills received by drain inlets (Field et al. 1993a).

Direct connections may be defined as physical connections of sanitary, commercial, or industrial piping that carry untreated or partially treated wastewaters to a separate storm drainage system. Usually unauthorized, whether mistaken or intentional, they represent the most common source of entries to storm drains by industry.

Indirect connections may be defined as infiltration into storm drainage systems and non-storm related discharges to storm catchbasins and inlets. Infiltration most commonly occurs through leaking pipe joints and connections to manholes and catchbasins, as well as pipes damaged by overburden and subsidence. Groundwater and percolating waters may or may not be contaminated and will be variable in nature since their levels and amounts can be dependent upon rainfall events.

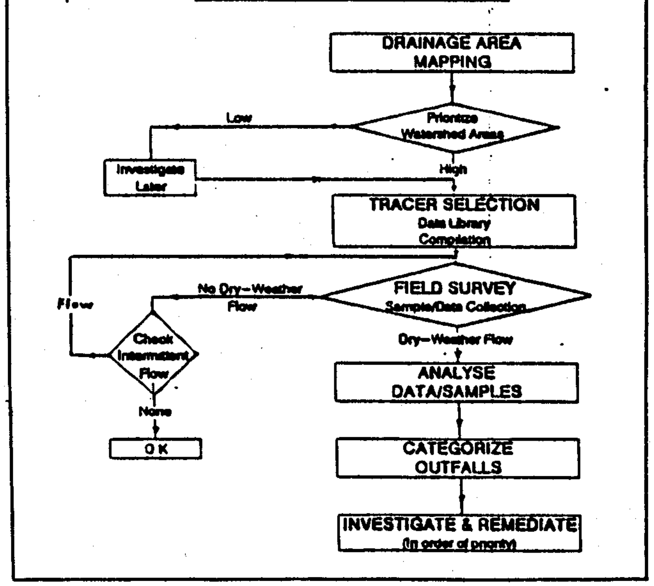
The procedures described in this paper provide an investigative procedure that will allow a user to first determine whether significant non-stormwater entries are present in a storm drain, and then identify the potential source category as an aid to ultimately locating the source.

It is important to emphasize that the removal of inappropriate entries is only one aspect of a comprehensive pollution prevention program required for an effective improvement in receiving water quality.

Procedures

The sequence of "Typical Investigation Steps" is illustrated in Figure 1 and briefly described below.

FIGURE 1. Typical Investigation Steps



A) Drainage Area Mapping

The mapping exercise is carried out as a desktop operation using existing data/information and field visits to collect additional data/information and/or confirm existing information. It must contain complete descriptions of the drainage areas including: outfall locations, drainage system layout, subcatchment boundaries for each outfall, critical land-use areas, permitted discharges to the storm drainage system, city limits, major streets, streams, etc. Possible sources of information include:

- City records and drainage maps.
- Previous surveys, e.g., sanitary sewer infiltration/inflow and sewer evaluation survey studies.
- Topographic maps.
- Existing GIS (Geographic Information System) data.
- Pre-development stream locations.
- Pre-development site investigations indicating groundwater and water table information.
- Drainage department personnel with knowledge of the area.
- Aerial surveys.

From mapping activities, possible pollutant sources are identified (e.g., industries, landfill sites, areas with septic tank systems, vehicle service stations, industrial sites, etc.) and drainage areas with the highest potential for non-stormwater entry sources are determined. This can assist in setting priorities for field investigation of the outfalls (Field et al. 1993a). However, all outfalls will require investigation eventually.

B) Tracer Selection

To detect and identify non-stormwater entries, the dry-weather outfall discharge is analyzed for selected tracers. An ideal tracer should exhibit the following properties:

- Significant difference in concentrations between polluting and non-polluting sources;
- Small variations in concentrations within each likely pollutant source category;
- A conservative behavior (i.e., no significant concentration change due to physical, chemical, and/or biological processes); and
- Ease of measurement with adequate detection limits, good sensitivity and repeatability.

A review of case studies and literature characterizing potential inappropriate entries (e.g., sanitary wastewater, septic tank effluent, laundry wastewater, vehicle wash wastewater, irrigation runoff, etc.) led to the following recommended tracers to identify common pollutant sources in residential/commercial land use areas :

- Specific conductivity;
- Fluoride and/or hardness;
- Ammonia and/or potassium;
- Detergents and/or fluorescence; and
- Temperature, chlorine, and pH.

The last three parameters do not fit the previously stated criteria, but can indicate extreme instances of pollution. Further details on the recommended tracers are given in Appendix II. If specific chemicals used by industries in the watershed are known, it may be possible to include them as tracers also.

In addition to the parameters described above, relative toxicity can be an important outfall screening parameter. Short-term toxicity tests, (e.g., the Microtox™ test from Microbics, Inc.), are valuable for quickly and cheaply assessing the relative toxicity (to a selected test organism) of different dry-weather flows. These tests can be used to identify outfalls that contain toxic flows which may warrant immediate investigation.

Potential sources of dry weather flows commonly identified within commercial and residential land use areas include spring water, infiltrating shallow ground water, tap water, irrigation runoff from landscaped areas and golf courses, sewage, septic tank discharge, commercial laundry waters, commercial carwash waters, radiator flushing wastes and metal plating bath waters. Obviously, some of these sources would contribute to pollution problems, and some would not. However, all have the potential for showing up in dry-weather flows. Therefore a chemical understanding of each, with respect to the selected tracers, is needed to build a "library" to which outfall dry-weather flows can be compared. To obtain the background information needed to construct such a library, samples are collected directly from the potential sources identified. To the extent possible, samples should come from sources within the study area. For each tracer, the concentration means and standard deviations for all the potential source flows, is calculated. Without this information the likelihood of identifying the pollutant sources is greatly reduced. The selection of a suitable analytical method is discussed later under the "Analysis of Data/Samples" section.

C) Field Survey

Field investigations are used to locate and record all outfalls, and involve physically wadding, boating, etc. the receiving waters in search of all known and unknown outfalls. At each outfall the inspection and sampling should at least include:

- Accurate location of outfall and assignment of ID number;
- Photographs of outfall;
- Outfall discharge flow rate estimate (and note whether continuous or intermittent discharge);
- Physical inspection and record of outfall characteristics including odor, color, turbidity, floatable matter (fecal matter, sanitary discards, solids, oil sheen, etc.), deposits, stains, vegetation effected by pollutants, damage to outfall structure, and discharge water temperature; and
- Collection of dry-weather discharge samples for tracer analyses in the laboratory (specific conductivity and temperature can be field measured).

Intermittent flows will be more difficult to confirm and sample. Additional field visits, use of automatic samplers, and/or flow damming or screening techniques must be utilized for detecting and obtaining samples of intermittent flows.

D) Analyses of Data/Samples

The recommended analytical procedures and associated equipment in Appendix III have been selected based on laboratory and field testing of analytical methods using the following criteria:

- Appropriate detection limits;
- Freedom from interferences;
- Good analytical precision (repeatability);
- Low cost and good durability; and
- Minimal operator training.

For consistent results the analyses should be carried out in the laboratory and not in the field, except for temperature and specific conductivity. Field analyses may be conducted for pH by using portable pH meters or litmus paper depending upon the degree of accuracy required and time constraints. Note that pH is a support tracer and not a primary parameter (see Appendix II for further detail).

The analysis methods selected must provide adequate detection limits (i.e., measurement of the lowest required concentration) and precision (i.e., consistent results). Methods found suitable for residential/commercial land use areas are recommended in Appendix III. These, methods should be checked for suitability at the proposed study site. In order to estimate the required detection limit, it is necessary to know or estimate the tracer mean concentration and standard deviation. The median multiplier values given below, when used in conjunction with the median and coefficient of variation (COV = standard deviation/mean) of the tracer in the more dilute flow, provide a quick and conservative estimate of the detection limit required. These median multipliers were derived from the assessment of a large number of probability calculations. This method is illustrated below:

COV Value	Median Multiplier For Detection Limit
Low (<0.5)	0.80
Medium (0.5 to 1.25)	0.23
High (>1.25)	0.12

Example: COV <0.5

median concentration = 0.5 mg/L

detection limit required = 0.5 x 0.8 = 0.4 mg/L

The analytical precision, defined as the repeatability of the analytical method, is also an important consideration. It is determined by repeated analyses of a stable standard, conducting replicate analyses on the samples, or by analyzing known standard additions to samples. Precision is expressed as the standard deviation of the multiple analysis results.

E) Categorize Outfalls

Outfalls must be categorized and subsequently prioritized so that a plan of action can be developed. Naturally, the most toxic and dangerous outfalls need to be eliminated first, especially considering the limited availability of funds in today's strained economic climate. The above analysis of the dry-weather flows provides data to help categorize the outfalls into three groups: 1) pathogenic or toxic pollution, 2) nuisance or aquatic life threatening pollution, 3) unpolluted.

The pathogenic and toxic pollutants can cause illness upon water contact or consumption and significant water treatment problems for downstream consumers, especially if the pollutants are soluble metal and organic toxicants. These pollutants may originate from sanitary, commercial, and/or industrial wastewater non-stormwater entries. Additional residential area activities with a pollution potential include, household toxicant disposal, automobile engine degreasing and oil disposal, and excessive use of chemical pesticides.

Nuisance and aquatic life threatening pollutants include laundry wastewaters, irrigation runoff carrying heavy loads of fertilizers, vehicle washwaters, construction site dewatering, washing of concrete ready-mix trucks, etc. These pollutants can cause: excessive algal growths; tastes and odors in downstream water supplies; offensive coarse solids and floatables; and noticeably colored, turbid, or odorous waters.

Unpolluted discharge from stormwater outfalls can originate from natural springs feeding urban creeks that have been converted to storm drains, infiltrating groundwater, infiltrating domestic waterline leakage, etc.

Outfalls must be visited, observations made, and all dry-weather flows sampled and tested in order to correlate flows with potential sources. Five methods for analyzing outfall dry-weather flow data/observations have been tested. These methods range from relatively simple reviews of physical

indicators for outfall contamination, to more sophisticated methods requiring computer modeling for evaluation. Methods 1 and 2 attempt only to distinguish between contaminated and uncontaminated flows, while methods 3 through 5 are useful in identifying the likely sources from which dry-weather flows are originating.

Physical Indicators of Contamination

Indicators of contamination (negative indicators) are clearly apparent visual or physical parameters indicating obvious problems that are readily observable at the outfall during the field screening activities. The direct examination of outfall characteristics for unusual conditions of flow, odor, color, turbidity, floatables, deposits/stains, vegetation conditions, and damage to drainage structures is the simplest method of identifying grossly contaminated dry-weather outfall flows. While this procedure doesn't necessarily identify the flow source, some sources may be identifiable based on recognizable odors or floatables, for example. Pearson Correlation results indicated that high turbidity (lack of clarity) and odors appeared to be the most useful physical indicators of contamination when contamination was defined by toxicity and the presence of detergents. Observable parameters cannot be relied upon as a sole method for the evaluation of outfalls. A contaminated discharge may not be visible and can only be determined by other methods (Lalor 1993, Field et al. 1993a).

Detergents as Indicators of Contamination

Results from Mann-Whitney U tests during method development indicated that pure streams from any of the dry-weather flow sources investigated in this research could be correctly classified as clean or contaminated based only on the measured value of any one of the following parameters: detergents, color, or conductivity. Color and conductivity were present in samples from clean sources as well as contaminated sources, but their levels of occurrence were significantly different between the two groups (Lalor 1993). If pure streams from only one source were expected to make up outfall flows, the level of color or conductivity measured could be used to distinguish contaminated form clean outfalls. However, since this is commonly not the case, measured levels in outfalls with multiple sources could fall within acceptable levels even though a contaminating source was contributing to the flow. etergents, on the other hand, can be used to distinguish between clean and contaminated outfalls simply by their presence or absence. "Presence" translates to the lower limit of detection for the HACH detergent test kit, which is 3.29 times the standard deviation, or 0.06 mg/L of detergents. This reduces the probability of a false nondetection or a false detection to 5% (Standard Methods 1989).

Flow Chart for Most Significant Flow Component Identification

Figure 2 is a flow chart describing an analysis strategy which may be used to identify the major component of dry-weather flow samples in residential and commercial areas. This method does not attempt to distinguish among all potential sources of dry-weather flow identified earlier, but rather the following four groups of flow are identified: (1) tap waters (tap water, irrigation water and rinse water), (2) natural waters (spring water and shallow ground water), (3) sanitary wastewaters (sanitary sewage and septic tank discharge), and (4) wash waters (commercial laundry waters, commercial car wash waters, radiator flushing wastes, and plating bath wastewaters).

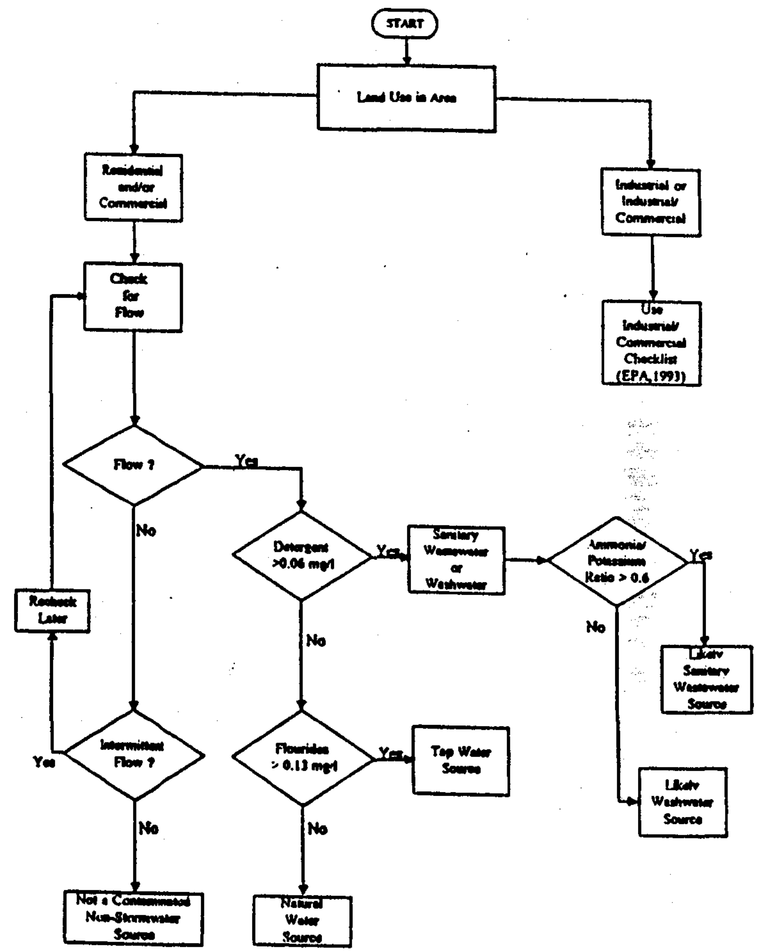
The use of this method would not only allow outfall flows to be categorized as contaminated or uncontaminated, but would allow outfalls carrying sanitary wastewaters to be identified as such. These outfalls could then receive highest priority for further investigation leading to source control.

This flow chart was designed for use in residential and /or commercial areas only. Investigations in industrial or industrial/commercial land use areas must be approached in an entirely different manner (EPA 1993).

In residential and/or commercial areas, all outfalls should be located and examined. The first indicator is the presence or absence of dry-weather flow. If no dry-weather flow exists at an outfall, then indications of intermittent flows must be investigated. Specifically, stains, deposits, odors, unusual stream-side vegetation conditions, and damage to outfall structures can all indicate intermittent non-stormwater flows. However, frequent visits to outfalls over long time periods, or the use of other monitoring techniques, may be needed to confirm that only stormwater flows occur (Field et al. 1993a). If intermittent flow is not indicated, then the outfall probably does no have a contaminated non-stormwater source. The other points on the flow chart serve to indicate if a major contaminating source is present, or if the water is uncontaminated (Lalor 1993). Component contributions cannot be quantified using this method, and only the "most contaminated" type of source present will be identified. Sources are ranked from lowest to highest based on their contamination potential in the following way: (1) Natural water sources, (2) Tap water sources, (3) Wash water sources, (4) Sanitary wastewater sources. Numerical values presented in the flow chart were developed from source flow data collected during method development in Birmingham, Alabama (Lalor 1993). Values should be verified for other locales.

If more specific source information is desired, a more complex approach is necessary. Algorithms based on the simultaneous solution of a series of chemical mass balance equations have been developed to predict the most likely flow source, or sources, making up an outfall sample, and are discussed in the following paragraphs. The degree of accuracy achievable will depend greatly

Figure 2



upon the extent of local tracer data gathered to describe potential source flows.

Chemical Mass Balance at Outfalls: Matrix Algebra Solution

Flow contributions from various sources may be estimated by using a 'receptor model' based on a set of chemical mass balance equation. Such models, which assess the contributions from various sources based on observations at sampling sites (the 'receptors'), have been applied to the investigation of air pollution sources for over 20 years. The characteristic "signatures" of the different types of sources, as identified in the library of source flow data developed in the study area, allows the development of a set of mass balance equations. These equations describe the measured concentrations in an outfall's flow as a linear combination of the contributions from the different potential sources. A major requirement for this method is the physical and chemical characterization of waters collected directly from potential sources of dry-weather flow. This allows concentration patterns for the parameters of interest to be established for each type of source. If these patterns are different for each source, the observed concentrations at the outfall will be a linear combination of the concentration patterns from the different component sources, each weighted by a source strength term (m_n). This source strength term would indicate the fraction of outfall flow originating from each likely source. By measuring a number of parameters equal to, or greater than, the number of potential source types, the source strength term could be obtained by solving a set of chemical mass balance equations of the type:

$$C_p = \sum_n m_n x_{pn}$$

where C_p is the concentration of parameter p in the outfall flow and x_{pn} is the concentration of parameter p in source type n. As noted above, the m_n term represents the fraction contribution of flow from source type n affecting the outfall dry weather flow. The selection of parameters for measurement should reflect evaluated parameter usefulness.

Chemical Mass Balance at Outfalls with Monte Carlo Sampling

The Monte Carlo method goes one step further than the matrix algebra solution by allowing the variation within the library values for each source type to be considered. Instead of using a single value (i.e. mean value) to represent the parameter concentration (C_p) for each likely type of source flow, a Monte Carlo simulation is used to randomly select values from a statistical distribution. Monte Carlo sampling is a traditional method of sampling randomly across an entire input variable distribution. Any value across the range of the distribution is possible, although the sampling is influenced by the relative probability assigned to each value. The more probable values will have a greater chance of

being selected. (Lalor 1993).

Based on samples collected from known sources, probability distributions are calculated, for each parameter (conductivity, fluoride, hardness, etc.), within each potential source flow. Distributions considered in this procedure include normal, log-normal, and uniform. Local source flow quality monitoring is necessary to obtain this information, as discussed previously.

Monte Carlo simulation generates sets of concentration values based on the mean, coefficient of variation, and distribution of each parameter within each source. A set of equations is established for each set of sampled concentration values generated by the Monte Carlo simulation. The fraction of flow from each potential source is calculated by solving each set of equations. These flow values are then stored. Multiple trials are used to calculate the most probable sources of contaminants for each outfall.

F. Investigation and Remediation

The investigation of pollutant sources involves upstream surveys to progressively narrow the drainage area(s) of concern and locate the pollutant source(s). Upstream surveys can take a number of forms including:

1) Analysis of dry-weather flow at strategically designated upstream manholes and/or access points which includes all or some of the methods and parameters measured at the outfall;
2) In-depth watershed evaluation of potential sources, achieved by developing on information gained during mapping and tracer data collection; and
3) Localized surveys by visual inspection, TV camera survey, and smoke and dye tests.

In some of the case studies investigated, correcting problems only at the most contaminated outfalls resulted in insufficient receiving water quality improvements. Therefore after the contaminated outfalls have been identified, most of them are likely to require correction if receiving water quality recovery is to be affected. However, categorizing the outfalls allows the most serious outfalls to be recognized and corrective action to be initially concentrated in the most cost-effective manner.

For an effective improvement in receiving water quality (assuming a problem exists), the investigation and correction of only illicit stormwater entries is unlikely to solve the problem. Dry-weather flows are only one source of pollutants and an effective improvement may require a comprehensive investigation and remediation program covering wet-weather induced flows as well.

Discussion and Conclusions

The main purpose of the research from which this paper emanated was to develop and test an effective screening methodology to identify storm sewer outfalls which are contaminated by illicit discharges in residential and commercial land use areas. Stormwater outfall screening methods presented here were tested in residential and commercial land use areas only. Techniques appropriate for industrial land use areas are discussed in *Investigation of Inappropriate Pollutant Entries into Storm Drainage Systems* (EPA 1993).

Each of the screening methodologies evaluated is based on the location and investigation of stormwater outfalls with dry-weather flows. Consideration must be given to the potential of outfalls to carry intermittent discharges. Intermittent discharges are not inconsequential, and are likely to be missed during infrequent outfall screening visits. Care should be taken to note evidence of intermittent discharges, such as unusual sediments, stains, odors, or abnormal vegetative growth around outfalls.

Additionally, field work associated with this research confirms the importance of investigating all storm water outfalls and direct discharge pipes encountered, not just those within a specific size range. Some of the most contaminated flows encountered were issuing from small pipes (Lalor 1993).

The use of negative physical indicators of contamination alone, such as color, odor, lack of clarity, and the presence of floatables or deposits, resulted in a high false negative rate of 20%, and a false positive rate of 10%. Examination of outfalls for negative indicators of contamination identified only the most grossly contaminated commercial outfalls. Outfalls carrying sanitary wastewaters in mixtures with uncontaminated waters, one of the most serious concerns, were frequently missed using this method.

Testing dry-weather flows in residential and commercial areas for only the parameters identified by EPA as minimum requirements, (pH, chlorine, copper, phenols and detergents), can be used to accurately categorize outfalls as contaminated or uncontaminated. This determination in fact can be based simply on the presence or absence of detergents (lower limit of detection 0.06 mg/L as MBAS). During this research effort in Birmingham, Alabama, all flows from contaminated outfalls contained detergents, while all flows from uncontaminated outfalls did not. No false positives or false negatives resulted from the use of this method. No further prioritization of outfalls was possible using only the parameters identified by EPA. However, in residential and commercial areas, pH, total chlorine, total copper, and total phenols could be useful in identifying industrial discharges not previously known to exist within the drainage area (EPA 1993).

Testing for fluoride, ammonia, and potassium, in addition to detergents, allowed for further prioritization of outfalls, by identifying the outfalls most likely to be contaminated by sanitary wastewaters, wash waters, or relatively

clean tap water sources. Using the flow chart presented in Figure 2, the most serious contaminating source can usually be identified for each outfall, whether or not the flow is a mixture originating from several sources. In flows issuing from a single source, the sole flow component can be identified. n multiple source flows which include at least one contaminating source, a contaminated source can be identified as long as it comprises at least approximately 10% of the flow. In mixed flows, contaminating sanitary wastewaters may be incorrectly identified as wash water when they contribute less than about 25% of the flow. This depends on the ratio of ammonia to potassium in both the sanitary wastewater and the other flow sources. The use of the flow chart in this research resulted in no false negatives, no false positives, and further, the correct identification of the most contaminated source contributing to each outfall analyzed (Lalor 1993).

The use of chemical mass balance equations as a means of identifying all sources contributing to flow at a given outfall is appealing in theory. However, this research indicated that the amount of variation present within potential sources of dry-weather flow, as well as the likelihood of unexpected and thus uncharacterized flows, especially in commercial areas, made this method ineffective for use in this application. Possible additional modification to the chemical masss balance program, such as allowing for the inclusion of more equations than unknowns, variable weighting, and the linking of variables with relatively high correlation coefficients, could improve its effectiveness (Wilson 1958). However, these modifications are not likely to fully compensate for the highly variable character of many of the potential dry-weather flows which will be encountered in this application. The amount of time and effort required to adequately identify and characterize potential sources also decreases the economic advantage of this method over wide-scales dye testing. Use of the chemical mass balance method in this research, with no threshold for program noise, resulted in a false positive rate of 40%, and no false negatives. Further, the most contaminated contributor to flow was incorrectly identified 70% of the time.

Defining a threshold level, based on analysis of many samples from known sources, and disregarding identified flow contributors below this level, reduced the false positive rate to zero while maintaining a false negatives rate of zero. However, the most contaminated contributor to flow was still incorrectly identified 50% of the time, making this method less useful for prioritizing outfalls than the simpler flow chart approach.

In summary, the following screening methodology is suggested. All stormwater outfalls and direct discharge pipes should be located. All dry-weather flows should be sampled, regardless of the size of the pipe. Evidence of intermittent flows should be noted, and the affected outfalls should be visited again. The flow chart in Figure 2 should be used as a guide for interpreting screening data. It is extremely important to determine the fluoride, ammonia, and potassium values for ground, surface, and tap waters in the local study area, if outfall screening data is to be interpreted with confidence. Outfall samples collected should be tested first for detergents. If desired, samples testing negative for detergents could be tested for fluoride, to identify flows from relatively clean tap water sources. Samples testing positive for detergents should be tested for ammonia and potassium. A high ammonia-to-potassium ratio indicates those outfalls most likely to carry flows from sanitary wastewater sources. These outfalls sources receive the highest priority for source correction measures.

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Appendix II: Recommended Tracer Parameters

Specific Conductivity- Specific conductivity can be used as an indicator of dissolved solids (i.e., ions). The variation between water and wastewater sources can be substantial enough to indicate the source of a dry-weather flow, and because the measurement is easy, quick, and cheap it is a suggested tracer.

Fluoride- Fluoride concentration should be a reliable indicator of potable water where fluoride levels in the raw water supply are adjusted to consistent levels and where groundwater has low natural fluoride levels.

Hardness- Hardness may be useful in distinguishing between natural and treated waters (like fluoride), as well as between clean treated waters and waters that have been subjected to domestic use. It should be noted that hardness of waters varies considerably from place to place, with groundwaters generally being harder than surface waters.

Ammonia/Ammonium- The presence or absence of ammonia (NH_3), or ammonium ion (NH_4+), has been commonly used as a chemical indicator for prioritizing sanitary wastewater cross-connection drainage problems. Ammonia should be useful in identifying sanitary wastes and distinguishing them from commercial water sources.

Potassium- Greater potassium concentrations have been noted for sanitary wastewater compared to potable water during studies reviewed. These potassium increases following domestic water usage reveal its potential as a tracer parameter.

Surfactants and Fluorescence- Surfactants from detergents used in household and industrial laundering and other cleaning operations results in high concentrations in wastewater. Anionic surfactants account for approximately two thirds of the total surfactants used in detergents in the U.S., and are commonly measured as Methylene Blue Active Substances (MBAS).

Water fluorescence is also an indicator of detergent residue in waters. Most detergents contain fabric whiteners which cause substantial fluorescence.

pH- The pH of most dry-weather flow sources is close to neutral (pH = 7). However, pH values may be extreme (below 6 and above 9) in certain inappropriate commercial and industrial flows or where groundwaters contain dissolved minerals. If unusual pH values are observed, then the drainage system needs to be carefully evaluated. Note that pH values are a power function and therefore flow contributions cannot be proportioned in the same way concentration values can.

Temperature- An elevated temperature of a receiving water can indicate contamination, particularly in cold weather. Sanitary wastewater and cooling water are examples of sources in which temperature elevation may be noted.

Total Available Chlorine- Chlorine is not stable in water, especially in the presence of organic compounds. The chlorine demand of contaminated water can be very large, with chlorine concentrations decreasing to very small values after short periods of time. The presence of chlorine in dry-weather flow could indicate a significant and very close potable water flow source or industrial discharges. (Field et al. 1993a).

Appendix III: Recommended Tracer Analysis Methods

Specific Conductivity and Temperature- Field measure using a multi-parameter SCT meter from YSI. Both specific conductivity and temperature must be calibrated against standard specific conductivity solutions and a standard thermometer.

Fluoride- Lab. analysis using a field spectrophotometer and evacuated reagent and sample vessels (HACH DR/2000™ and AccuVac™ ampules using SPADNS reagent, without distillation). The samples should be filtered through a 0.45 μ membrane filter (e.g., Millipore™ filter) before analysis to minimize color interference.

Hardness- Lab. analysis using a field-titrimetric kit (HACH Digital Titrator Model 16900). Filter as for Fluoride.

Ammonia- Lab. analysis using a direct Nesslerization procedure and spectrophotometer (HACH DR/2000™ Nessler method, but without sample distillation). Filter as for Fluoride.

Potassium- Lab. analysis using either a spectrophotometer (HACH DR/2000™ Tetraphenylborate method), or a flame atomic absorption spectrophotometer (if available). Filter as for Fluoride.

Surfactants- Lab. analysis using a simple comparative colormetric (color wheel) method (from the HACH Company). Filter as for Fluoride. This procedure to be conducted under a laboratory fume hood.

Fluorescence- Lab. analysis fluorometer (Turner model 111). The fluorometer has general purpose filters and lamps and should be operated at the most sensitive setting (number one aperture).

pH- Lab. measurement using a standard laboratory pH meter after accurate calibration using at least two buffer solutions bracketing the expected sample pH value. Field measurements can be made utilizing pH meters or litmus paper depending upon degree of accuracy required and time constraints.

Chlorine- Total available chlorine was determined with the DPD method using a HACH DR/2000™ spectrometer with AccuVac™ ampules.

Water color- Lab. measurement using a simple comparative colormetric (color wheel) field test kit from the HACH Company. Apparent color (unfiltered samples), expressed in HACH color units.

Turbidity- Lab. measurement using a HACH Nephelometer.

Toxicity screening- Microtox™ (from Microbics) toxicity screening for relative toxicity values. The 100 percent screening test was most commonly used. If the light output decrease after 25 minutes (the I_{25} value) was greater than 50 percent, then the standard Microtox test was used to determine the sample dilution required for a 50 percent light decrease (the EC_{50} value). (Field et al. 1993a).

FINDING ILLICIT CONNECTIONS & DISCHARGES WITH P²IL

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Abstract

The City of Scarborough is a lower tier (area) municipality of 172 square kilometres, population of about 550,000 and borders on the north shore of Lake Ontario. About 85% of the area is fully developed with 7 distinct areas zoned as Industrial Districts (16% of total area). About 400 known ICI sites have stormwater discharges (70% are in Industrial Districts). The City is drained by three watercourses which receive stormwater from 826 outfalls. Thirty-two large outfalls discharge directly to Lake Ontario. Storm outfall and up-pipe pollution prevention efforts utilize aproximately 6,000 manhours per year. Analytic laboratory costs average $35,000 CDN per year. Equipment costs average $15,000 CDN per year. First year start up costs approximate $200,000 CDN for 70% of total area. No stormwater discharge permits are issued in Scarborough except for "once-thru cooling water" to storm. All storm water quality is specified by a Sewer Use Bylaw on a concentration basis, not load. All outfalls, drainage areas and pipes have been digitally mapped. Watercourses are monitored at select locations during dry and wet weather, and on a seasonal basis. Specific storm drainage areas receive intensive investigation. Outfall problems are identified by chemical, biological and visual criteria. Problem outfall (storm sewerage) investigative techniques include visual, biological degradation, chemical and physical assessment. Discharge characterization techniques using flow meters, non-intrusive sensors, video cameras, absorbent sticks/pads (for petroleum), dye testing, smoke testing and pressure testing assist in problem verification. Finding illicit connections and discharges requires dedicated Programs with Procedures that may be executed with Intuition and occasionally Luck (P²IL).

Introduction

Storm water issues in the Province of Ontario have received increased profile and priority since the early 1980's. The Ontario Ministry of Environment and Energy

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(MOEE) and the Ontario Ministry of Natural Resources (MNR) regulate all issues on a province-wide basis. Provincial agencies, such as Conservation Authorities, regulate some water issues on specific watershed bases.

The MOEE regulates predominantly water quality issues, and permits the taking of water from surface and groundwater sources. The MNR regulates water as a habitat and resource issue. Conservation Authorities focus on water quantity control, flood and erosion issues. Legislative authority over storm water related issues rests predominantly in the:

- Ontario Water Resources Act (enforced by MOEE)
- Environmental Protection Act (enforced by MOEE)
- Federal Fisheries Act (as enforced by Provincial MNR)

However, other legislative acts have impact on water discharge (quantity and quality) issues. The Building Code Act (1990) includes regulations pertaining to plumbing and drainage specifications for private lots and some industrial activities.

As environmental concerns and public awareness increased in the mid 1980's, the specific legislation and regulations of the late 1970's and early 1980's have been "enhanced" (with many well intentioned Interim Guidelines.... and Draft Interim Guidelines .....) without amending the legislation. The bottom line of all regulations pertaining to discharges of storm water to the environment is that the owner (or controlling party) of the discharge is deemed to be responsible.

The City of Scarborough (172 square kilometres, population 550,000) owns and operates all sewer conveyances. The City does not own or operate sewage treatment services; treatment is provided by the upper tier Metropolitan Toronto Regional government. All storm sewer conveyances discharge at outfalls or ditches (approximately 825 in Scarborough) into the local waterway (environment). Hence, the City of Scarborough is responsible for local discharge quality issues. Currently no storm water discharge permit or approval process at the municipal level (other than to allow once-thru cooling water on a site by site basis) is practiced. No specific revenues are generated on storm water; general "sewage rates" are calculated on potable water consumption .

The MOEE proposed program of Municipal Industrial Strategy for Abatement (MISA, 1986) includes detailed specifications for quantity and quality of discharge to the environment from seven industrial sectors and the municipal sector. Many of the "direct" discharge sectors (industrial) have been phased in by 1994. The final sector (municipal with "indirect" dischargers) has yet to be brought forward.

Some Regional and Area municipalities, in preparation for MISA and other proposed by-law enhancements, have undertaken waterway and outfall evaluations. The MOEE has provided varying levels of financial assistance through subsidy programs.
Municipalities within the Great Lakes Basin area of Ontario have been provided

with yet another challenge by the Canada-U.S. Great Lakes Water Quality Agreement under the International Joint Commission (IJC). Forty-three specific "Areas of Concern" were identified in the Great Lakes Basin. The Metropolitan Toronto and Region (which includes the City of Scarborough as an area municipality) was specifically identified and a Remedial Action Plan (Metro RAP, 1994) has been created. Action plans proposed in the RAP include specific Trace and Disconnect Programs for cross connections in both Residential and Industrial/Commercial/Institutional (ICI) locations.

Clearly, the intent to improve storm water discharges in Ontario has now been conveyed to public and political audiences, as well as to the municipal and private ICI corporations.
In response to this intent and scrutiny, the owner of a discharge (outfall) must carefully provide a blended response to:

- public expectation
- political promises
- regulatory requirements/due-diligence
- budgetary constraints

Such a blended response must carefully compare the benefits between short term projects and long term programs.

The City of Scarborough has developed a series of programs dedicated to pollution control and storm water issues. Finding and correcting illicit connections is a major component of these programs. These programs have specific procedures that, on occasion, may be augmented with intuition and luck.

Experience supports the premise that the most successful ventures into storm water issues should start with the creation of a long term program having specific descriptions of:

- intent (including long term environmental benefit, corporate due-diligence and regulatory compliance)
- objectives that are open to public and regulatory scrutiny, endorsement and support
- goals (measurable actions or parameters used for determining program progress)
- budgetary and staffing requirements

Program Creation

Short term ventures, seasonal projects and site specific actions all have immediate political and public appeal because dollars are quickly spent and visible action is taken. The long term success of these ventures, however, may not be readily appreciated, achieved or even verified. A program for finding and correcting illicit connections should be part of a larger, and well promoted and managed, outfall and watercourse management strategy.

At the municipal government level, the long term success and survival of the program requires a complete understanding, clear documentation and disclosure of the true intent and goals of the program. Specifically, the ideal program should;

i) be created and considered as a long term program and not as a project of a few years duration.
ii) clearly state the obvious environmental problem(s) and associated human health risks so that officials and the public have (and continue to have) a high level of comfort with budgetary and staffing issues.
iii) state realistic goals, with realistic schedules that will be reported on annually.
iv) have annual review procedures for staffing and budgetary requirements, and actively seek funding from existing or new senior government subsidies.

The City of Scarborough currently enjoys strong political and public support for its programs. This is very important to program longevity and funding as no discharge permit or approval process (and associated revenues) currently exists. All program funding is achieved through tax based annual budgets.

Program Components

A successful investigation program should be carefully and completely planned before field efforts begin; field implementation should be phased in over two years. Implementation schedules should be carefully scrutinized and reassessed throughout the second year.

Phase I

To avoid lost time, effort and incorrect assessments, the first phase should be primarily administrative with minimal fieldwork. Specifically;

i) Watershed areas should be mapped with associated overlays of street grid and sewer layout (including both sanitary and storm). A Geographic Information System (GIS) with digitized mapping facilities can provide an ideal format.
ii) Each watershed area should be mapped with locations and identification codes of all storm discharge locations (outfalls, ditches, infiltration pits/lagoons, significant overland flow routes).
iii) A drainage map for each storm drainage area, serviced by an individual discharge outfall, should be constructed with site specific identification of:
    - all manholes (maintenance holes) and catchbasins
    - combined sewer areas
    - combined sewer overflow (CSO) locations
    - sanitary pumping station overflow and forcemain locations
    - septic or holding tank sites (areas not serviced by sanitary sewer)

iv) Each drainage area map can then be enhanced with:
- industrial zones/districts
- specific industrial sites
- once-thru cooling water discharge locations
- major transportation corridors and industrial traffic routes
- individual lateral connections to the sewers may also be identified if historic connection cards and a digitized Sewer Inventory Maintenance System (SIMS) are available

Phase II

Field verification of outfall location, size and construction material should commence at the end of Phase I and continue throughout Phase II. Specifically,

i) attention should focus on access routes, access hazards/restrictions. Instructions to staff for access by gates/grates should be coded.

ii) each outfall should be photographed and coded for specific outfall identification.

iii) all outfalls (and drainage areas) should be ranked by size of pipe (hence approximate size of drainage area) and potential number of lateral connections.

iv) lateral connections can also be ranked by size and/or by code for street catchbasin, residential lot, ICI lot, etc.

Phase III

Field assessments should always be conducted by teams (minimum 2 persons per team) where each person is fully trained and certified (when appropriate) in
- confined space access
- first aid/CPR
- road closure and traffic control procedures
- sampling procedures
- chain of custody procedures
- data logging

Screening procedures should be conducted in progression as follows:
- outfall assessment
- up-pipe investigation
- focus on specific sewer branch and lateral connection
- verification and documentation for correction and/or legal action

<u>Outfall Assessment Procedure</u>

a) Visual assessment for solids, odour, colour, oil and grease "sheen", paper and rags, structural damage and acid erosion, can be enhanced with visual clues of biological degradation/enhancement (loss or proliferation of aquatic vegetation, macrophytes or invertebrates in the immediate area of the receiving water).

b) sample parameters should include field measurement of
- flow rate (L/sec)
- temperature (°C)
- dissolved oxygen (mg/L)
- pH
- conductivity (μmho's/cm)

c) Grab samples should be taken if flow is greater than a trigger limit (ie. O.1 L/sec). Analysis of samples should include parameters in Fig. 1.

Figure 1: SAMPLE PARAMETERS AND THRESHOLDS USED TO SELECT OUTFALLS FOR UP-PIPE INVESTIGATION

Parameter		Threshold	Units
Escherichia Coli	(EC)	10,000	/100 mL
Faecal Coliforms	(FC)	50,000	/100 mL
Faecal Streptococci	(FS)	50,000	/100 mL
Pseudomonas Aeruginosa	(PA)	100	/100 mL
Total Kjeldahl Nitrogen	(TKN)	5.0	mg/L
Total Phosphorus	(TP)	1.0	mg/L
Copper	(CU)	1.0	mg/L
Zinc	(ZN)	1.0	mg/L
Lead	(PB)	1.0	mg/L
Cadmium	(CD)	1.0	mg/L
Chromium	(CR)	1.0	mg/L
pH	(pH)	6.0>pH>9.5	
Total Solids	(TS)	1000	mg/L
Dissolved oxygen	(DO_2)	<5	mg/L
Temperature	(Temp)	>45	°C
Biochemical Oxygen Demand	(BOD5)	5.0	mg/L

Additional parametres may include:
- Oil/Grease reported as i) animal/vegetable
  ii) mineral/synthetic
- Chemical parameter(s) specifically related to local ICI

Characterization of outfalls is the most labour intensive and costly activity of the program. It is also a very important activity (second only to finding and removing a cross connection) and must be carefully documented for compliance and enforcement issues, long term trend analysis and watershed loading estimates.

Bacterial data should be reported as a geometric mean count per 100 ml sample volume.

Chemical concentrations should be reported as flow weighted mean concentrations (FWM); this removes some bias associated with extreme variations in flow rates,

$$FWM = \frac{qc/n}{q/n}$$

where q = flow rate
c = concentration of parameter
n = number of samples collected for parameter

Load calculations should be expressed as an arithmetic average load (L),

$$L = qc/n$$

All visual data should be summarized and ranked by presence/absence criteria. All chemical and physical data should be summarized and ranked by concentration.

Outfalls having visible problems plus chemical and physical data in exceedance of threshold values should be prioritized for immediate up-pipe testing.
Outfalls having no visible problems may have chemical or physical problems. Ranking by FWM and loadings will assist in prioritizing specific outfalls for up-pipe investigation.

<u>Up-pipe Investigation Procedures</u>

Always use the same investigation team on a prioritized outfall. Personal insight, experience and continuity of field procedures are very important in minimizing time and cost. Intuition should be considered but always verified by sampling.

The goal of up-pipe testing is to determine which leg of sewer (between sequential manholes) is receiving the offending discharge.

Regardless of the residential or ICI nature of the drainage area, visual clues and bacterial testing provide the most effective initial investigation because:

- visual clues of rags, paper, oil/grease and solids are readily seen in flow or on benching in manholes and pipes
- bacterial tests are usually reported in 24 to 36 hours (compared to 2 to 3 weeks for chemical tests)
- residential cross connections are usually whole house or basement washroom in origin; bacterial counts will be high (E.C.$>10^4$) with only some measurable chemical parameters
- industrial whole building or unit cross connections usually include locker and washroom facilities (industrial sites with multiple sewer connections will require visual and chemical testing after bacterial cross-connects are removed)

In an area which is predominantly ICI or is known to have specific chemical

users, chemical tests specific for that area will result in better investigation progress but cost significantly more in analytic costs and extended turn around times.

In areas having mixed residential and ICI, especially in large areas serviced by storm pipes >700 mm, the visual and bacterial tests should always be investigated and solved first. After bacterial sources are removed, chemical testing can proceed without interference form alternate sources.

<u>Sampling Location and Frequency</u>

a) Manhole entry locations and sampling frequencies are best determined by the knowledgeable field team.

In small drainage areas (pipes <700mm dia.), 5 to 7 manhole entries for visual and bacterial testing should provide a good definition of problem area.

In larger drainage areas (pipes >700 mm dia.) the first sampling effort may require 10 to 12 manhole entries to successfully sample major intersections and pipe branches.

b) Based upon the visual and first series of bacterial results, subsequent sample runs should include 3 to 5 sequential manholes in the suspect pipe branch.

Typically, visual clues become more evident as one gets closer to the site. Within 200 to 300 metres of the source, average EC:FC:FS:PA counts are $\geq 10^4:10^4:10^4:10^2$. Typical storm sewers and outfalls having no sanitary sewage input have average EC:FC:FS:PA counts $\leq 10^3:10^3:10^3: 10^1$.

c) When the affected leg of sewer has been identified, it must be verified by visual, bacterial and chemical testing (with flow estimates) in the upstream and downstream manholes.

d) Once verified, the difficult task of identifying the exact point of discharge to the sewer can be undertaken;
   i) Residential areas require house by house dye testing of sanitary facilities. This is laborious and typically <50% of buildings are accessible on any given day of effort. Repeated returns to the area may accomplish up to 85% of building testing but rarely is 100% access acquired without sending registered letters and pre-arranging after-hour/weekend testing.
   ii) ICI areas are significantly easier to dye test because they have

fewer lateral connections and usually have control manholes for direct access. Large individual ICI site cross connections can result from:

- site or building expansion over existing outdoor drains and catchbasins
- outside storage area and loading and receiving bays may not have spill containment facilities

iii) When access problems occur in residential sites or certain ICI sites, alternate tests may be progressively used:

- smoke tests in sanitary sewer
- smoke tests in storm sewer
- video camera (in-pipe) to find and observe offending lateral
- dye testing rain water leaders

Difficult Scenarios

Scenario #1: No definite leg of sewer (between sequential manholes) can be identified after 3 or 4 sample runs. The investigation team should suspect;

i) faulty structure or integrity of sewers which allows contaminants to escape from the sanitary sewer, cross bedding material and infiltrate the storm sewer. Pressure testing the sanitary sewer is a suitable verification test under these circumstances.

ii) more than one source of contaminant exists, however, sources are intermittent because of shiftwork or weekend schedules.

iii) the offending party has observed investigation teams efforts and has altered business schedule to avoid detection.

To deal with issue ii) and iii) the investigation team should leave the area for about a week, then return and install auto samplers that collect discrete hourly samples. These auto samplers may be augmented with flow loggers or pH sensors to help define the timing of discharges into the branch sewer.

Scenario #2: Full investigation and in-pipe video reveals no lot lateral connection (typically a chemical, not bacterial problem). The investigation team should suspect;

i) spills or illegal dumping into roadside catchbasins or utility chambers. Catchbasin sumps and chambers should be checked for evidence. Surveillance of the area using time delay video recordings or unmarked vehicles may prove successful.

ii) infiltration into storm pipe during rain events or seasonal high groundwater that is moving contaminants from adjacent lands (landfill sites, industrial site, septic beds, etc.) To verify this problem, a series of boreholes and subsequent soil/water testing should be conducted in the immediate vicinity. Positive results may lead to a large scale and costly remedial effort at source and in the utility trench.

Documentation

The initial phases of program creation (mapping, coding locations, etc.) will become the backbone of a successful program. Proper and complete documentation of all efforts, observations and findings must be carefully and securely filed.

Strict supervision of field staff and their documentation is also necessary. The "thrill of the chase" usually expedites the finding of the cross connection. Concurrent poor documentation may inhibit the correction of the alleged problem especially if the owner becomes adversarial; the good luck of quickly finding the source may turn to bad luck.

Outfall characterization data and cross connection efforts will complement other watershed or stormwater management program efforts. Proper documentation and filing of data will help explain variations in local watercourse conditions. This documentation is essential in maintaining a high level of comfort with government officials and the public.

Summary

The Program and Procedures have been created, and are currently used, in the City of Scarborough. They have evolved (and sometimes regressed) over the years, hence the current program contents have been polished with hindsight.

The creation of a similar program must have full and accurate disclosure of financial and staff requirements from its inception. Failure to properly budget and control expenditures, even if many cross connections are found and corrected, will jeopardize the survival of the program.

Start up costs, in the first year, need not be excessive. Scarborough contracted Phase I (without digitizing), Phase II and Phase III (only outfall characterization) for 70% of the City (554 outfalls) in 1986 for about $200,000 CDN (Gartner Lee, 1987). In subsequent years, staff have digitized most of original Phase I, II work and have conducted Phase I, II, III on the remaining 280 outfalls (250 outfalls in the combined sewer area having 72 CSO's).

Phase III cross connection efforts continue year round utilizing about 6,000 manhours per year. Annual equipment costs, since 1987, have averaged $15,000 CDN per year. Analytic laboratory costs average $35,000 CDN per year.

Phase III outfall characterization is being repeated on a five year schedule with certain outfalls visited more frequently based upon complaints (or spill occurrences) and as verification after a cross connection correction.

Typically, the first and second year of the Phase III effort reveal the greatest number of cross connections per unit effort as gross visual problems (ie. bean sprouts, oil/grease, fish scales/eyes, acid erosion, etc.) are assessed and quickly traced. Subsequent efforts, dealing with clear water chemical problems require significantly more effort and cost. Success per unit effort is maximized by having a dedicated program and specific procedures with allowance for intuition and luck.

Positive reporting to City officials and the public on initial successes and subsequent follow up efforts is very important. It should be stressed that cross connections can appear at any time and place and that only with a long term program can storm water and waterways be maintained to the public and regulatory standards.

Acknowledgements

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Gartner Lee Ltd., *Highland Creek and Rouge River Pollution Study*, for the City of Scarborough, 1987.

Metro RAP, *Clean Waters, Clear Choices*, Metro Toronto and Region Remedial Action Plan, 1994.

MISA, *White Paper on Municipal-Industrial Strategy for Abatement*, Ontario Ministry of Environment, 1986.

FINDING ILLICIT CONNECTIONS & DISCHARGES WITH P²IL

Key Words:

- cross-connections
- storm water
- characterization
- investigation
- illegal

Tuesday, August 9, 1994

SESSION III: SYSTEM RUNOFF CHARACTERIZATION

1. **NPDES Monitoring - Atlanta, Georgia Region**
   Michael Thomas
   Atlanta Regional Commission;
   Scott McCelland
   Camp, Dresser & McKee, Inc.

2. **NPDES Monitoring - Dallas Ft. Worth, Texas Area**
   Samuel Brush
   N. Central Texas COG;
   Marshall Jennings
   U.S. Geological Survey;
   P. Jonathan Young
   Alan Plummer and Associates, Inc.

3. **Stormwater NPDES Monitoring in Santa Clara County**
   Keith Whitman and David Drury
   Santa Clara Valley Water District;
   Peter Mangarella, Terry Cooke, Chow Lee and Revital Katznelson
   Woodward-Clyde Consultants

NPDES MONITORING - ATLANTA, GEORGIA REGION

P. Michael Thomas,[1] Scott I. McClelland,[2]

INTRODUCTION

The impact of stormwater runoff on urban streams is becoming more significant as urban areas continue to expand and as treated wastewater discharge quality is improving. Urban stormwater runoff can contain significant amounts of various pollutants including bacteria, sediments, nutrients and heavy metals (U.S. EPA, 1983). The urbanization or development of a watershed can have a variety of impacts on the stream, including increased flooding, streambank erosion and pollutant export (Schueler, 1987). As a result, the U.S. Congress affirmed in the 1987 Clean Water Act Amendments, that stormwater pipes are point sources of pollution and must be permitted through the NPDES permit program. This paper describes a regional stormwater monitoring plan developed and implemented in the Atlanta Region to comply with NPDES rules and to characterize local stormwater discharges.

Coordinated Regional Response - After the U.S. Environmental Protection Agency (EPA) issued the final stormwater permit rules in 1990, the Georgia Environmental Protection Division (EPD) announced that they would issue a uniform region-wide permit for a five county Metro-Atlanta area of Clayton, Cobb, DeKalb, Fulton and Gwinnett Counties. EPD defined this area as a large municipality, despite the fact that it contains over 40 governments ranging in population from 2,642 (Palmetto) to 468,000 (unincorporated DeKalb County). The population for the entire five county area was 2,218,600 in 1990. The result of EPD's action meant that small cities who had never heard of the NPDES stormwater program, had six months to prepare their Part I application. EPD's rationale for this action was that all these jurisdictions were contributing to violations of water quality standards in Atlanta area rivers and streams.

The local governments joined together with the regional planning agency, the Atlanta Regional Commission, to form the Atlanta Region Storm Water

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Management Task Force to develop efficient and consistent stormwater permit applications. EPD's strategy was to issue a single permit for the five county area allowing each government to apply independently or as a coapplicant with a larger government. This resulted in 21 independent or lead applicants and 16 coapplicants (Table 1). By coordinating activities and sharing resources, the local governments were able to reduce the resources required in all aspects of the application process including the stormwater characterization work. The Task Force members also worked together to develop a regional approach for a long-term stormwater monitoring plan.

TABLE 1. Independent or lead applicants and coapplicants to the region-wide NPDES stormwater permit for the Metropolitan Atlanta area and their 1990 population.

Independent Applicants		Lead Applicant & Coapplicants	
Government	Population	Government	Population
Cobb County	453,400*	Clayton County	142,000*
Fulton County	156,005*	Forest Park	17,083
Acworth	4,547	Jonesboro	3,661
Alpharetta	13,104	Morrow	5,206
Atlanta	415,200	Riverdale	9,488
Austell	4,201	DeKalb County	467,871*
College Park	20,823	Chamblee	7,860
East Point	34,858	Clarkston	5,483
Fairburn	4,053	Decatur	17,498
Hapeville	5,510	Doraville	7,723
Kennesaw	9,039	Lithonia	2,482
Marietta	46,213	Stone Mountain	6,560
Palmetto	2,642	Gwinnett County	282,752*
Powder Springs	6,970	Buford	8,862
Roswell	48,257	Duluth	9,125
Smyrna	31,328	Lawrenceville	17,054
Snellville	12,137	Lilburn	9,389
Union City	8,483	Norcross	6,034
		Sugar Hill	4,598

*Population listed is for the unincorporated portion of the County

DESIGN OF THE REGIONAL MONITORING PLAN

To comply with the permit application requirements, a regional characterization plan was developed and each major government was assigned appropriate sampling responsibilities. A number of different governments and agencies were involved in instrumenting these sites and collecting information from appropriate storm events. The data collected from each site were compiled and used to develop local stormwater event mean concentrations and pollutant loading estimates for the Region.

NPDES Monitoring - The rules promulgated by the U.S. EPA, required that each permit applicant collect "quantitative data from representative outfalls" of stormwater runoff. The objectives of this sampling work can be summarized as follows:

a) determine the type and magnitude of pollutants in stormwater runoff; and
b) relate the water quality characteristics to land use type.

An important consideration was to collect enough samples to develop statistically valid event mean concentrations for each pollutant by land use (the rules require that three storm events be sampled at each site). Also, it may be important to collect samples during different seasons to determine if there are seasonal fluctuations in stormwater quality.

Sampling Site Selection - One of the first issues addressed by the Task Force was to determine how many sites should be monitored and who would be responsible for instrumenting the sites and collecting and analyzing the samples. The EPA rules required that each applicant select five to 10 representative outfalls for collection of samples for three storm events. It was obvious that five sites for the entire Region was not adequate and that five sites for each of the 21 independent applicants was excessive. The compromise developed by the Task Force was to locate an average of five sites in each county for a minimum of 25 sites. ARC staff developed a method of allocating the responsibility for these sites among the permit applicants based on population and employment as an estimate of the relative amount of stormwater runoff that would be generated by each jurisdiction. The allocation of sites resulted in the five counties and four largest cities being assigned from one to six sampling sites each. The smaller cities, which lack the resources to conduct this type of work, were not assigned a sampling site but were asked to share in the cost of the monitoring work based on the percentage of their population in their respective county.

After the number of sites per government was selected, general site locations were determined based on existing monitoring networks, land use and watershed characteristics. Specific monitoring sites were then located based on size of the drainage area, type and continuity of land use and use of stormwater pipe or stream sites. Existing local government stream monitoring sites were utilized where possible. Sites were then visited and evaluated based on accessibility, safety, security and suitability for flow measurement and sample collection. Hydraulic factors considered for stream sites included open-channel sites with existing stage-discharge relations or sites where adequate stage-discharge relations could be established, stable channel conditions, and adequate distance from major tributaries to allow for complete mixing. Other general site considerations included avoiding sites having steep slopes, poor visibility, and heavy traffic.

Most of the sites were located in the Chattahoochee River basin because more of the five county area lies within this basin than any other and because this river is of great significance to the region, providing over 70% of our water supplies. Figure 1 shows the general location of the 27 sites. Because land use is the main factor that impacts the quality of stormwater runoff and is often used in models to predict stormwater quality (ARC, 1992c), sampling sites were selected to represent the major land uses in the area (Table 2). Where possible, small drainage areas which represented a single land use were chosen.

FIGURE 1. Stormwater Sampling Locations in the Atlanta Region

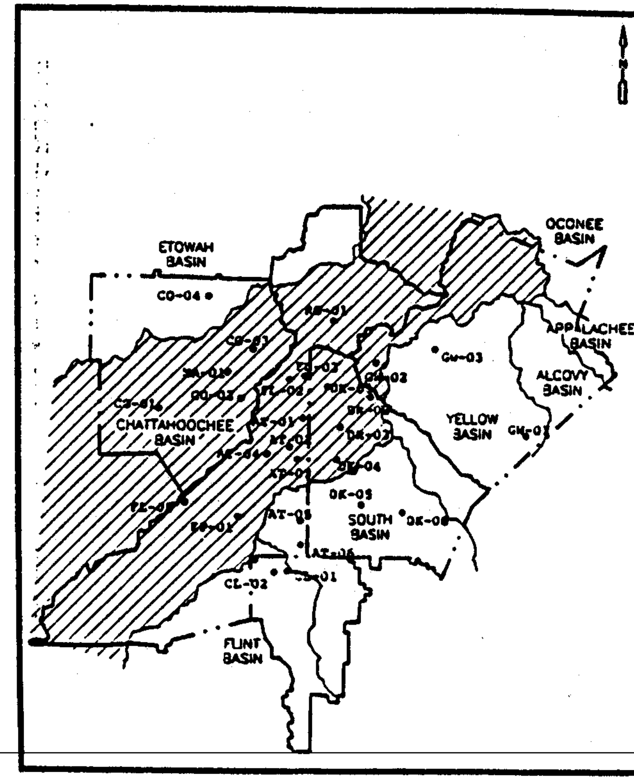

TABLE 2. Sampling Site Description and Land Use Category

Station Number	Site Description	Land Use Category
AT-01	Outfall - Tributary to Nancy Creek - parking lot of large shopping mall, draining commercial land use area.	Commercial
AT-02	Outfall - Tributary to Peachtree Creek - parking lot and roadway, area of commercial and light industrial land use.	Commercial
AT-03	Outfall - Tributary to Clear Creek - draining single family residential area.	Residential
AT-04	Outfall - Tributary to South River - draining a light industrial park.	Industrial
AT-05	Outfall - Tributary to South River - draining an area of industrial land use.	Industrial
AT-06	Outfall - Tributary to Chattahoochee River - draining an area of industrial and transportation land use.	Industrial
CL-01	Junction Box - Tributary to Flint River - draining an area of heavy industry.	Industrial
CL-02	Outfall - Flint River, Clark Howell Highway - draining commercial, business and transportation land use.	Commercial
CO-01	Stream - Olley Creek Tributary to Sweetwater Creek - draining an area of industrial and commercial activity including a closed sanitary landfill.	Commercial
CO-02	Outfall - Unnamed Tributary to Rottenwood Creek - draining a commercial/business park area.	Commercial
CO-03	Outfall - Tributary to Sope Creek - draining moderate density residential area.	Residential
CO-04	Stream - Noonday Creek Tributary to Lake Allatoona - draining an area of residential and commercial land uses.	Residential
DK-01	Stream - Bubbling Creek Tributary to Nancy Creek - draining an area of public parks and residential land uses.	Residential

TABLE 2. Sampling Site Description and Land Use Category (continued)

DK-02	Stream - Unnamed Tributary to North Fork Peachtree Creek - draining a heavy industrial area.	Industrial
DK-03	Stream - Unnamed Tributary to North Fork Peachtree Creek - draining a residential area.	Residential
DK-04	Stream - Tributary to South Fork Peachtree Creek - drains an area of residential and public land uses.	Residential
DK-05	Stream - Tributary to Shoal Creek - drains an area of residential land use.	Residential
DK-06	Outfall - Tributary to Snapfinger Creek - an area of light industrial land uses.	Industrial
EP-01	Outfall - Tributary to South River - draining an industrial area inside the city.	Industrial
FL-01	Outfall - Tributary to Chattahoochee River - draining area of light/moderate industrial land use.	Industrial
FL-02	Outfall - Tributary to Chattahoochee River - draining area of commercial and transportation land use.	Commercial
FL-03	Outfall - Tributary to Chattahoochee River - area of commercial land use.	Commercial
GW-01	Stream - Tributary to Big Haynes Creek - draining an area of moderate density residential land use.	Residential
GW-02	Junction Box - Tributary to Chattahoochee River - draining an area of industrial land use.	Industrial
GW-03	Junction Box - Tributary to Sweetwater Creek/Yellow River - commercial area around a large shopping mall.	Commercial
MA-01	Outfall - Tributary to Rottenwood Creek - commercial/business park area.	Commercial
RO-01	Outfall - Tributary to Chattahoochee River - draining moderate density residential area.	Residential

DATA COLLECTION

A regional consultant was selected (Camp, Dresser & McKee, Inc.) by the Task Force to develop standard operating procedures for the monitoring program and to conduct most of the sampling work. The use of the regional consultant allowed the work to be done quickly and consistently. Some of the large local governments were able to use their own staffs to conduct part of the monitoring work. As the local governments move from the permit application phase to the long-term monitoring program, most will conduct the work with their own staff. Table 3 lists who was responsible for conducting the sampling and lab analysis in each jurisdiction. The involvement of many different parties in the sampling program raises a concern over the consistency of the data collected. The use of the standard operating procedures and the use of the same analytical laboratory for 63% of the sample analyses reduced inconsistencies.

TABLE 3. Sampling Program Responsibilities

Participant	No. of Sites	Equipment Procurement	Sample Collection	Sample Analysis
Atlanta	6	City	Reg. Cons.[1]	Reg. Cons.[1]
East Point	1	City	Reg. Cons.	Reg. Cons.
Marietta	1	Reg. Cons.	Reg. Cons.	Reg. Cons.
Roswell	1	City	Reg. Cons.	Reg. Cons.
Clayton County	2	Reg. Cons.	Reg. Cons.	Reg. Cons.
Cobb County	4	County	County	County
DeKalb County	6	County	County/USGS	County/USGS
Fulton County	3	County	Reg. Cons.	Reg. Cons.
Gwinnett County	3	County	County	Reg. Cons.

[1]The Regional Consultant (Reg. Cons.) was Camp Dresser & McKee, Inc. The City of Atlanta utilized a different lead consultant but used the same subconsultants as Camp Dresser & McKee did for sample collection and analysis.

Representative Storm Event Criteria - The EPA rules required that each applicant collect samples of stormwater runoff. The rules recommended that "representative storm events" be sampled which met the following criteria:

- the storm event must be greater than 0.1 inches in magnitude;
- the event must be at least 72 hours from the previously measurable event (>0.1 inches);
- where feasible, the variance of event duration and total rainfall should not exceed 50 percent of the average or median rainfall event; and
- the three storm events must be one month apart.

These criteria were proposed to insure that "representative" storm events are sampled and that a preceding dry period is provided to allow a normal period of pollutant deposition on land surfaces.

A statistical evaluation of long-term rainfall records for the Atlanta Region conducted by ARC determined that only an average of 6.2 storms per year would meet these criteria (ARC, 1992a). An additional analysis was conducted to determine if expanding the criteria to ±75% of depth and duration would significantly improve the number of acceptable events. The result was an increase to an average of 14 events per year which still was not a practical operating criteria once the actual sampling work began. Seasonal differences in rainfall patterns and the required 30 day period between events made collection of samples from an acceptable storm event very difficult. The Task Force requested a modification of storm event criteria from EPD and received approval to sample any storm event of a depth of 0.1 inches or more with a 72-hour dry period preceding it. No restrictions were placed on duration of the storm event or the time period between sampling events.

Site Instrumentation - All 27 sites were instrumented in a similar manner, although several organizations were responsible for this activity. A typical site instrumented by the U.S. Geological Survey for DeKalb County consisted of a tipping-bucket rain gage, a staff-type gage, and a stream-stage-shaft-encoder, automatic sampler, and datalogger housed in a monitoring shelter. The equipment was purchased by DeKalb County and maintained for operational readiness during the study by the USGS. Repair and replacement costs to structures and equipment were the responsibility of DeKalb County.

A typical site instrumented by the regional consultant included either a tipping bucket or totalizing rain gage, an automatic sampler with integral data logger and a temporary equipment shelter. Both ISCO and American-SIGMA samplers were used, depending on the preference of the local participating agency. Equipment was either purchased by the local agency and operated by the consultant, or leased and operated by the consultant. All maintenance during the program was provided by the consultant.

Sample Collection and Analysis Procedures - At the DeKalb County/USGS sites the datalogger was programmed at each site to record data at 1-min. intervals once a rainfall threshold of 0.1 in. was met or exceeded. A theoretical culvert rating was programmed into the datalogger which converted the recorded stages into discharges. The datalogger then triggered the automatic samplers each time about 10 percent of the estimated storm volume passed the site. Runoff samples were withdrawn from the stream over the storm hydrograph by the automatic samplers and composited into one sample that represented the water quality conditions for the storm event. For a typical rainfall event, procedures were to activate the rainfall and stream-stage recorders at the sites to be sampled prior to the impending storm. The automatic samplers were checked and outfitted with 2.5 gal. containers. When the rainfall amount at each site reached 0.1 in., the datalogger would begin to collect rainfall and stage data at 1-min. intervals. When the stream stage reached a preset level (activation level), the volume of water flowing by the site was computed from the recorded stage and accumulated by the datalogger. The datalogger would then trigger the sampler at increments of about 10 percent of storm volume, and the sampler would pump 2 liters of water into the composite bottle. During sampling of the runoff period, ten 2 liter sub-samples were collected in two 2.5 gal. containers. The samples were chilled with ice during the sample collection period and prior to processing. In addition to storm-composite samples, grab samples for measurement of water temperature and pH, and the analysis of cyanide, oil and grease, volatile organic compounds (VOCs), and phenols were collected by hand on the rising side of the storm hydrograph. Water temperature and pH were determined at the site. Grab samples were delivered to DeKalb County Water Quality Lab immediately after collection for the analysis of selected constituents.

Composite samples collected by the automated sampler were processed by the USGS at the District Office. Processing included splitting the composite sample into appropriate bottles using a 16 liter teflon-lined churn splitter, filtering and preserving samples. Processed samples were delivered to DeKalb County Water Quality Lab for inorganic analysis and shipped to the USGS lab in Denver for organic analysis.

Sample collection procedures for the sites administered by the regional consultant were similar to the USGS procedures. Samplers were programmed to collect a sample at equal intervals of flow based on the estimated flow that would be generated from a 0.1 inch rainfall event and the minimum amount of sample required for laboratory analysis. Each sampler was programmed with a theoretical stage-discharge curve and set to initiate sampling when a threshold level was reached.

When a rainfall event alert was issued, each site was visited to check the equipment and activate the battery powered sample. Composite sampling was then initiated automatically when the threshold flow was reached. Grab samples were taken on the rising side of the storm hydrograph. During the grab sample visit, field analysis were made and recorded, the automatic sampler was checked for proper operation, and ice was added to chill the samples of the storm duration. Grab samples were also chilled or fixed in the field. Eventually, composite samples were delivered to the laboratory at the end of the sotrm event. All sample processing including splitting of alloquats, filtering, preserving and analysis was done by the contract laboratory. Typically, all analyses were completed and reported within three weeks.

Several different laboratories were involved in the analysis of the stormwater samples but the majority of the analysis was conducted by a private lab used by the regional consultant. Other labs included the USGS National Water Quality Laboratory, the DeKalb County Water Quality Control Laboratory and the Cobb Water System Laboratory. All laboratories used EPA approved methods for sample analysis. Each sample was analyzed for the full list of over 100 parameters required in the NPDES permit application rules.

Experience with stormwater runoff sampling in previous studies indicates that about 10 attempts at storm sampling are needed to successfully collect one storm event sample. The USGS found that once equipment problems were solved, such as problems with the datalogger and rainfall recorder, and the criteria for suitable storms were eased, that the success rate for sampling was about 90 percent of the events sampled.

Quality Control of Sampling and Analysis - A quality assurance plan was developed and implemented for this study to ensure that data collected were in accordance with accepted industry standards. The USGS developed a plan to ensure that data were collected in accordance with the U.S. Environmental Protection Agency's program requirements for stormwater sampling and that met the technical standards of the Water Resources Division of the USGS. The USGS plan addressed, in part, quality assurance measures for sample handling procedures, chain-of-custody procedures, and analytical methods that included quality control (QC) samples, and evaluation and reporting of QC data. The quality-control procedures provide a mechanism for control and evaluation of the data quality during the project, and define the data quality for the constituents in terms of precision and accuracy.

The regional consultant and local governments involved in sample collection and analysis used similar QC procedures which are documented in the regional Standard Operating Procedures Manual (ARC, 1992b) prepared by the regional consultant.

SAMPLING RESULTS

For the 81 site events (27 sites sampled three times each), the storm durations ranged from 0.5 hours to 26.4 hours and storm magnitudes ranged from 0.12 inches to 4.22 inches. Table 4 shows information on the storm events sampled during this program.

Impact of Land Use on Stormwater Quality - A review of the sampling results by land use category illustrates some apparent differences among land uses (Table 5). However, the differences may not be statistically significant because of the highly variable nature of stormwater quality. Surprisingly, residential land use appears to have more of an impact on some constituents than commercial and industrial land uses. Residential areas were characterized by much higher concentrations of total suspended solids, copper, fecal coliform and fecal streptococcus bacteria. Industrial areas were characterized by much higher concentrations of dissolved phosphorus and zinc. Commercial areas had much

TABLE 4. Storm Event Characteristics

Site	Land Use	Duration (hours)	Rainfall (in)	Average Rate (in/hr)	Flow (gal)	Average Rate (gal/hr)
Averages						
	Residential	8.6	1.13	0.14	17,006	4,700
	Commercial	5.4	0.71	0.10	556,087	206,322
	Industrial	5.9	0.70	0.15	293,885	47,881
	TOTAL	6.6	0.85	0.13	335,129	79,868

TABLE 5. Summary of Results for All Land Uses

Constituent[1]	Residential Avg.	Residential S.D.	Commercial Avg.	Commercial S.D.	Industrial Avg.	Industrial S.D.
BOD	15	17	12	16	16	19
COD	68	55	71	91	79	70
TSS	574	1,159	103	114	97	114
TDS	68	54	47	28	57	48
Total P	0.44	0.51	0.18	0.18	0.36	1.04
Dissolved P	0.09	0.06	0.10	0.11	0.24	0.87
TKN	1.35	0.74	2.57	6.93	1.63	1.49
NO2 + NO3	0.69	0.39	0.67	0.57	0.66	0.50
Ammonia	0.22	0.16	0.51	0.43	0.41	0.31
Oil & Grease	4.9	6.2	16.4	40.9	6.3	5.4
Lead	0.036	0.043	0.024	0.005	0.024	0.018
Copper	0.053	0.067	0.020	0.002	0.023	0.020
Zinc	0.116	0.103	0.132	0.063	0.195	0.145
Cadmium	0.010	0.002	0.009	0.003	0.008	0.003
pH	6.6	0.5	6.8	1.0	6.7	0.7
Fecal Coliform	7,653	--	2,460		3,436	
Fecal Streptococcus	28,864	--	6,800		7,805	

S.D. = Standard Deviation

[1] All units are in mg/l except for the fecal coliform and streptococcus which are in MPN/100 ml

higher concentrations of total kjeldahl nitrogen. Of the 16 parameters detected at each site, average concentrations were higher in residential areas for nine parameters. However, as described below, some of the higher values in residential areas may be explained by the number of sampling locations located in streams rather than direct outfall pipes. Seven of the ten stream sampling sites were in residential areas.

For comparison purposes, the Atlanta Region stormwater quality data are compared to the results of EPA's Nationwide Urban Runoff Program (NURP) studies (1983) and some of the recent sample results from the Florida Part 2 NPDES Stormwater Permit Application wet weather sampling. The Florida data were compiled by Camp, Dresser and McKee, Inc. (CDM) from Jacksonville, Orlando, St. Petersburg, Sarasota County and Palm Beach County.

Residential - Table 6 shows a summary of analytical data collected during three storm events at nine residential sites for classic pollutants and metals (27 data points). Also shown are results from the NURP study for residential land uses. In

TABLE 6. Summary of Analytical Results for Residential Land Uses

Constituent	Units	Atlanta Region Average	NURP Min	NURP Max	Florida* NPDES Average
BOD	mg/l	15	5	28	11
COD	mg/l	68	33	234	64
TSS	mg/l	574	25	2216	43
TDS	mg/l	68			168
Total P	mg/l	0.44	0.22	4.09	0.38
Dissolved P	mg/l	0.09	0.07	0.45	0.23
TKN	mg/l	1.35	0.05	10.80	1.35
NO2 + NO3	mg/l	0.69	0.31	9.54	0.39
Ammonia	mg/l	0.22			
Oil & Grease	mg/l	4.9			
Lead	mg/l	0.036	0.034	2.745	0.0085
Copper	mg/l	0.053	0.006	0.312	0.0014
Zinc	mg/l	0.116	0.054	1.388	0.0550
Cadmium	mg/l	0.010			0.0015
pH		6.6			
Fecal Coliform	MPN/100 ml	7,653			
Fecal Streptococcus	MPN/100 ml	28,864			

Note: Based on data from Jacksonville, Orlando, St. Petersburg, Sarasota County and Palm Beach County NPDES Stormwater Permit Applications (1992-93).

summary, the data are highly variable with the standard deviations (Table 5) frequently approaching or exceeding the means. The minimum observed values for most constituents were at or below the detection limits so that most of the averages shown on the table are slightly high.

Concentrations of constituents measured in samples from residential land uses are very comparable to NURP data: average concentrations for all of the Atlanta Region data fall within the NURP concentration ranges and almost all of the averages are at the low end of the NURP ranges. The only exception is BOD which is about in the middle of the NURP range.

Analytical results for the Atlanta Region and Florida Part 2 studies are similar for the classic pollutants except for TSS. The Atlanta Region data show an average TSS (574 mg/l) which is 10 times higher than the TSS in Florida Part 2 data (54 mg/l). This difference and others, in stormwater quality between the Atlanta Region and Florida data may be due largely to differences in soil characteristics. The Atlanta Region is in the Piedmont physiographic province, which is characterized by highly erodible, clay soils. These soils provide a good substrate for adsorption of pollutants and can be easily transported into nearby streams. The Florida sites, located in the coastal plain, are generally characterized by sandy soils and minimal slopes which minimizes soil erosion and transport into nearby streams. The metal concentrations in the Florida data (Table 6) are considerably less than the concentrations in the Atlanta Region data including concentrations for lead and copper, which are less than the minimum values observed in the Atlanta Region data.

Of the other pollutants detected in samples from the Atlanta Region residential sites, the most frequently occurring was phenol. Phenol was detected in 15 of 27 samples. Chromium was the second most frequently detected (13 of 27), followed by tetrachloroethylene (11 of 27), and toluene, methylchoride, chlordane and diazinon (each 6 of 27). However, of these pollutants, concentrations were generally low with only phenol and chlordane being detected in concentrations in excess of State water quality standards.

Commercial - Table 7 shows the analytical results for the classic pollutants and metals for the commercial land uses. As for the residential land uses, there were 27 events (3 storms at 9 sites). The data were highly variable with large standard deviations and the minimums were generally below the detection limits.

Oxygen demand, solids and nutrient concentrations for, the Atlanta Region data were generally lower that the NURP data although the differences in concentrations are not significant at one standard deviation. Concentrations of lead, copper and zinc for the Atlanta Region data are less than for the NURP data, with lead being 10 times less and copper and zinc about three times less. The lower lead may be attributable to the elimination of lead from gasoline. Since commercial land uses are heavily influenced by parking lots, the lower values for copper and zinc may also be attributed to changes in automotive technology; however, no clear conclusion can be drawn.

In comparison to the Florida Part 2 data, concentrations of parameters in the commercial data, unlike the residential data, are similar for most parameters. The major differences in concentrations are for total nitrogen (TKN plus NO_2+NO_3) and cadmium. Total nitrogen concentrations for the Atlanta Region data is 3.24 mg/l compared to 2.29 mg/l in the Florida data. Average Cadmium concentrations in the Florida data are 10 times less than the Atlanta Region data.

Several other trace metals and organic compounds were detected in individual samples but none of the data sets contained a sufficient number of detections to develop a reliable event mean concentration (EMC).

TABLE 7. Summary of Analytical Results for Commercial Land Uses

Constituent	Units	Atlanta Region Average	NURP Average	Florida* NPDES Average
BOD	mg/l	12	14	7
COD	mg/l	71	92	50
TSS	mg/l	103	186	41
TDS	mg/l	47		114
Total P	mg/l	0.18	0.29	0.15
Dissolved P	mg/l	0.10	0.17	0.08
TKN	mg/l	2.57	1.61	1.24
NO2 + NO3	mg/l	0.67	0.89	1.05
Ammonia	mg/l	0.51		
Oil & Grease	mg/l	16.4		
Lead	mg/l	0.024	0.2350	0.0117
Copper	mg/l	0.020	0.0618	0.0179
Zinc	mg/l	0.132	0.3990	0.0785
Cadmium	mg/l	0.0087		0.0008
pH		6.8		
Fecal Coliform	MPN/100 ml	2,460		
Fecal Streptococcus	MPN/100 ml	6,800		

Note: Based on data from Jacksonville, Orlando, St. Petersburg, Sarasota County and Palm Beach County NPDES Stormwater Permit Applications (1992-93).

Industrial - As with the other land use categories, 27 samples were collected from industrial land use sites. Also, as with the others, the data were highly variable with the standard deviations often approaching or exceeding the means. Table 8 shows mean values for the industrial sites in the Atlanta Region. The Atlanta Region, NURP and Florida Part 2 data are similar except for zinc which was about five times higher in the NURP and Florida NPDES values.

Contrary to the commercial land uses, nutrients are similar in all datasets, and the cadmium concentrations for the Florida data is about seven times smaller than for the Atlanta Region data. In every case, the concentrations of metals in the NURP data are higher than for either the Atlanta Region or Florida Part 2 data.

As with the commercial land use, other constituents were detected in individual samples but too infrequently to compute a reliable EMC. The most frequently detected compounds were phenol and bis(2-ethyl-hexyl)phthalate (seven detects each).

TABLE 8. Summary of Analytical Results for Industrial Land Uses

Constituent	Units	Atlanta Region Average	NURP Average	Florida* NPDES Average
BOD	mg/l	16	10	12
COD	mg/l	79	61	91
TSS	mg/l	97	120	99
TDS	mg/l	57		160
Total P	mg/l	0.36	0.50	0.34
Dissolved P	mg/l	0.24	0.14	0.17
TKN	mg/l	1.63	1.52	1.49
NO2 + NO3	mg/l	0.66	0.80	0.37
Ammonia	mg/l	0.41		
Oil & Grease	mg/l	6.3		
Lead	mg/l	0.024	0.1150	0.0313
Copper	mg/l	0.023	0.0317	0.0228
Zinc	mg/l	0.195	0.9800	0.1602
Cadmium	mg/l	0.008		0.0013
pH		6.7		
Fecal Coliform	MPN/100 ml	3,436		
Fecal Streptococcus	MPN/100 ml	7,805		

Note: Based on data from Jacksonville, Orlando, St. Petersburg, Sarasota County and Palm Beach County NPDES Stormwater Permit Applications (1992-93).

Comparison of Results to State Water Quality Standards - The Georgia EPD has developed instream water quality standards for over 100 different pollutants. These standards apply to all levels of flow, including wet weather flows. The Georgia EPD has also defined State Waters in such a way as to include water in an enclosed stormwater pipe as "waters of the State" for which the instream water quality standards would theoretically apply.

Table 9 shows the number of times that pollutant concentrations in a storm event sample for this study exceeded water quality standards. The parameter that was most often detected above water quality standards was fecal coliform bacteria. Lead, copper and zinc were also often found in concentrations in excess of water quality standards. Concentrations of pollutants in excess of water quality standards were found across all land use types and in stream and outfall sampling sites. It will be extremely difficult for stormwater runoff to ever achieve compliance with water quality standards developed for low flow periods.

Stream Versus Outfall Sampling Sites - As discussed above, 10 of the 27 sampling sites were in small urban streams rather than on a direct pipe discharge. These sites were utilized because local governments had already established monitoring sites and stage-discharge relationships at these locations for existing trend monitoring programs and because of the existing historical data available at these sites. It can be noted in Table 9 that for lead, copper and fecal coliform, a much greater percentage of the samples from the stream sites exceeded the instream water quality standards. Also a number of organic pollutants were detected in the samples from stream sites that exceeded water quality standards, such as chlordane and phenol (Table 10). Concentrations of chlordane and phenol were not found at these levels in the direct pipe discharges.

The specific reason for the generally higher concentrations in samples from streams compared to samples from direct-pipe discharges is unknown. It could be the result of several factors, including the resuspension of contaminated sediments in the stream bed or in runoff, or saturated soil water flow into the stream channel from residential lawns, industrial or commercial sites.

TABLE 9. Pollutant Concentrations which Exceeded State Water Quality Standards - Inorganic Pollutants and Fecal Coliform

Site Type	# of Samples	Pb	Cu	Zn	Cd	F. Coli	Cya-nide
Water Quality Standard***		7.7	21*	190*	2*	4000**	5.2
By Land Use:							
Industrial	27	8	2	9	2	11	
Resid.	27	10	12	4	2	17	1
Comm.	27	4	1	5	1	8	
Site Type:							
Outfall	51	9	4	11	3	20	
Stream	30	13	11	7	2	16	1
Total	81	22	15	18	5	36	1

*For metals, sample results were compared to the highest limit associated with an instream hardness level.
**Single sample maximum for fishing classification.
***all unit in ug/l except Fecal Coliform (MPN/100 ml) and pH (std. units)

TABLE 10. Pollutant Concentrations which Exceeded State Water Quality Standards - Organic Pollutants

Site Type	# of Samp.	BIS 2-E-H phthalate	Phenanthene	Pyrene	Chlordane	Phenol	2-4-Dinitrotoluene	Heptachlor Epoxide	pH
Water Quality Standard***		5.92	0.0311	0.0311	0.0043	300	9.1		6.0-9.0
By Land Use:									
Industrial	27	7	1	2					2
Resid.	27	2			5				1
Comm.	27	6				2	1	1	4
Site Type:									
Outfall	51	11							6
Stream	30	4	1	2	5	2	1	1	1
Total	81	15	1	2	5	2	1	1	7

*For metals, sample results were compared to the highest limit associated with the instream hardness level.
**Single sample maximum for fishing classification.
***all unit in ug/l except Fecal Coliform (MPN/100 ml) and pH (std. units)

Implications for Long-Term Monitoring Programs - The stormwater quality data reported in this paper was collected over a short period of time, primarily to provide information for development of the NPDES permit application. To learn more about the nature of stormwater quality and the impacts of land use and best management practices and to comply with the NPDES permit, long-term monitoring programs should be developed and implemented. This long-term program should be structured to identify water quality trends and evaluate the effectiveness of BMPs, including structural controls.

Additional sampling would provide a large database and hopefully, reduce the statistical variability of the data in order to detect statistical trends or differences between land uses. Although instream sampling sites are useful for detecting general water quality trends and watershed-wide program impacts, continued sampling of direct outfall pipes is needed to better quantify pollutant concentrations and loads coming directly from the municipal storm sewer system.

Development of Pollutant Loadings - The Watershed Management Model developed by Camp, Dresser & McKee (CDM-WMM) was chosen by the Task Force to develop estimates of pollutant loadings. The CDM-WMM model was specifically developed for planning-level estimates of system-wide pollutant loads. The most recent version contains estimates of the 12 pollutants required by the NPDES regulation. Using Lotus 1-2-3 as a model platform, CDM-WMM calculates annual loads and flows based upon land uses, imperviousness, and land

use specific event mean concentrations. The model uses 12 land use categories with associated literature-based EMCs and imperviousness. For the purposes of the Atlanta Region, 10 of these land uses were used for the load estimates with Cropland being combined with Agriculture and Wetlands being combined with Water.

The model estimates annual runoff volume from the pervious and impervious areas of each land use category, annual rainfall, and runoff coefficients, as follows:

$$R_L = [C_P + (C_I - C_P)\ IMP_L]I$$

where R_L = annual runoff for land use L (in/yr);
C_P = pervious area runoff coefficient (0.20);
C_I = impervious area runoff coefficient (0.95);
IMP_L = fractional imperviousness of land use L; and,
I = annual rainfall (in/yr).

The total annual runoff for the municipality is the sum of the R_L for all of the 10 land uses. Based upon available information (ARC, 1992a), the annual average runoff-producing rainfall for this area is 46.8 inches using the Atlanta Airport gage.

The load estimates are then calculated using the land use specific EMCs, runoff and area of the land use within the watershed:

$$M_L = 0.2266\ EMC_L\ R_L\ A_L$$

where M_L = the annual load from land use L (lb/yr);
0.2266 = a conversion factor;
EMC_L = the EMC for land use L (mg/l); and,
A_L = the area of land use L (acres).

As above, the total annual load for the watershed is the sum of the M_L for all of the 10 land uses. It can be seen that this model can easily be used for seasonal estimates as long as seasonal rainfall and justifiable seasonal EMCs are available.

As an added feature in the CDM-WMM model, for future assessments, the model can estimate the change in load resulting from the use of regional best management practices (BMP), such as wet or dry detention ponds, retention ponds, etc. The model can adjust the pollutant load for a BMP as follows:

$$M_L' = M_L \left(1 - \frac{A_{BMP}}{A_L} REM\right) A_L$$

where M_L' = the BMP-reduced load from land use L (lb/yr);
A_{BMP} = the area of land use L draining to the BMP (acres); and,

REM = the removal efficiency of the BMP for the pollutant.

This feature can be used to estimate the effectiveness of watershed pollution control plans as well as test various strategic pollution reduction alternatives.

Comparison of the EMCs measured as part of the Atlanta Region study and the EMCs from the CDM-WMM model shows that for the oxygen demanding substances, sediment, and nutrients, the EMCs are comparable. The CDM-WMM EMC for TDS is high and the model EMCs for lead and zinc are considerably higher than the measured ones. On the other hand, the model EMCs for cadmium are low compared to the measured results. This is a result of the availability of EMC data for the development of the CDM-WMM model. Only limited EMC studies were available and the literature basis of the data focused primarily on the NURP studies. It should be noted that due to the lack of timely storms, the estimate of pollutant loads had to be completed before the Atlanta Region sampling work was complete. For this reason, and because the CDM-WMM EMCs are generally high, the predicted loads from the municipal storm sewer system probably represent an upper limit of pollutant discharges. The estimated pollutant loads also represent loads from the entire political jurisdiction rather than just the area draining to the municipal system because these drainage areas have not been adequately identified.

SUMMARY

The Atlanta Region governments were successful in implementing a regional stormwater sampling program. These same governments are now involved in implementing a regionally-coordinated long-term monitoring program. During the NPDES permit application sampling program, we were successful in determining the type and magnitude of pollutants in stormwater and how to measure them, however, there is still more to learn about their relationship to land use. With regard to stormwater quality, the following is apparent:

- stormwater runoff often contains pollutants in concentrations in excess of Georgia's instream water quality standards;
- stormwater runoff quality in the Metro-Atlanta area is comparable to national stormwater quality statistics;
- stormwater characteristics vary by land use but the variability of stormwater quality is so great that it will require much more data from drainage areas composed of a single land use type to statistically validate those differences.

With regard to stormwater sampling procedures, we learned the following:

- the EPA recommended "representative storm event" criteria were not practical for this region;
- once new equipment problems are resolved and reasonable storm event criteria are established, sampling success can reach 90% of all attempts.

This information will be valuable in implementing the long-term stormwater sampling program but because of the inherent difficulties involved in wet weather sampling and the variability of stormwater quality, it will require a longer sampling history to confidently make conclusions about stormwater quality that can be used with confidence in developing potentially expensive stormwater management programs. Also, sites with a single land use type should be selected; Some of the drainage areas for the sites sampled in this study did not contain a single predominant land use type.

It is recommended that EPA continue to be flexible in the implementation of stormwater monitoring and management programs as we continue to learn more about this problem. It also evident that even though local stormwater quality data may be comparable to national averages, strong regional differences may occur based on natural factors such as rainfall patterns and soil characteristics. Therefore, programs that work well in one region may be impractical or ineffective in others due to these differences.

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Storm Water NPDES Monitoring in Santa Clara Valley

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Abstract

Results from stormwater monitoring conducted in Santa Clara Valley from 1987 through 1994 are presented. During this period, hydrologic, water quality, and toxicity data have been obtained from a variety of small and large catchments and within storm drains and in streams and rivers. Approximately 200 station-events have been monitored for water quality, primarily focused on heavy metals. Both flow composite and manual grab samples have been obtained. Data presented address water quality characterization, effects of land use on water quality, compliance with water quality objectives, urban versus natural erosional sources of metals, water quality correlations with flow, equilibrium partitioning between dissolved and particulate forms of metals, spatial and temporal differences based on analysis of variance (ANOVA) and analysis of covariance (ANACOVA), power analysis for designing monitoring programs to measure long term trends, and toxicity testing.

Introduction

The Santa Clara Valley is located at the southern end of San Francisco Bay, encompasses about 1800 square kilometers (700 square miles) of which about 50% is urbanized, and has a population of 1.4 million people (Figure 1). The valley contains major cities such as San Jose, as well as "Silicon Valley". The valley is semi-arid with mean annual precipitation on the valley floor of 355 mm (14 in) per year.

In 1986 the San Francisco Regional Water Quality Control Board revised their Basin Plan to require that storm water discharges into the southern portion of San Francisco Bay be characterized and controlled. In response to this requirement,

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thirteen cities, Santa Clara County, and the Santa Clara Valley Water District (SCVWD) formed the Santa Clara Valley Nonpoint Source Pollution Control Program (Program). In 1989 the State Water Resources Control Board listed the south Bay as an "impaired water body" as required under Clean Water Act Section 304(L) because water quality standards for heavy metals were frequently exceeded. The Program applied for and received an early NPDES stormwater permit in June 1990.

This paper summarizes findings from the extensive monitoring conducted by this program. The first two fiscal years (FY 87-88 and FY 88-89) of monitoring prior to the first permit period included wet weather monitoring at 7 stations that drained different land use areas and wet and dry weather monitoring at 4 waterway stations. These data were used to characterize storm water runoff water quality and to estimate the distribution of annual metals loads to the Bay.

In FY 89-90, monitoring was continued at the four waterway stations to evaluate long term compliance with water quality objectives and at one industrial land use station which was being used as a pilot demonstration project for evaluating the effectiveness of an intense industrial inspection program.

The monitoring activities during the first 5 year permit period (starting in FY 1990) included automatic flow-composite sampling at the four waterway stations. Because the permit required that sampling be conducted at locations which were representative of the discharge, two of these locations were in the largest watersheds in Santa Clara Valley, Guadalupe River and Coyote Creek. For comparison, one sampling station was in a relatively small watershed with a predominantly natural channel, Calabazas Creek, and a fourth was in a constructed channel, Sunnyvale East. The data from these stations are being used to meet the objectives of evaluating water quality trends, and to determine if storm water discharges are in compliance with applicable water quality and toxicity objectives.

To meet other objectives of the monitoring program, monitoring was conducted during the first permit period at two industrial land use stations to characterize storm water quality and to evaluate storm water quality improvements due to the implementation of pollution prevention actions resulting from a pilot inspection program conducted in one of the areas. To characterize storm water quality from transportation corridors, two stations were installed and operated for three years on an eight lane freeway and on a local 4 lane expressway. The Program also evaluated the use of automated flow-composite sampling equipment compared to grab sampling, to ensure that representative samples were being obtained. As part of the grab sampling effort, the Program conducted studies to evaluate how pollutant concentrations vary over the course of a storm event, the duration of water quality exceedences for pollutants during storm events, and whether or not pollutants persist after the event concludes and flows return to pre-storm levels. Toxicity testing was conducted at the land use and transportation stations for two years, and at the waterway stations all five years of the first permit period.

Monitoring Stations

Monitoring stations consisted of two types: stations located in relatively small catchments (typically 10-1,000 hectares) containing predominantly one land use; and stations that drained relatively large watersheds (1,000-30,000 hectares) which contained a mixed land use. The former stations are referred to as "land use" stations and are commonly located in small streams or municipal storm drain pipes. Data from these stations are indicative of urban runoff water quality from urban and non-urban sources and were used to characterize water quality and as input to loading estimates. The latter type of stations, referred to as "waterway or stream stations" were located in larger streams and rivers near the Bay and represented local receiving waters. Data from these stations were used for compliance and reflect the effects of upstream non-urban areas and stream sediment processes. Table 1 describes the various stations.

Monitoring Methods

Storm water sampling was generally conducted with automatic flow composite samplers. Station designs varied but generally consisted of ISCO Model 2700 or 3700 automatic samplers, a Campbell Scientific CR-10 data logger and controller, a Druck diaphragm-type pressure transducer, and 10 or 20 liter borosilicate glass bottles to contain the composite samples. Each station was flow rated using established or new flow rating curves or where weirs were installed, appropriate weir equations. Based on the anticipated runoff, the controller was programmed to collect twenty 500 ml sub-samples over the course of the runoff event. Initially stations could only be controlled on site, then telemetry was added to allow remote control and monitoring. This change significantly improved the storm coverage and quality of data obtained.

Manual grab samples were collected for volatile organics, bacteria, and total oil and grease. Manual samples sometimes were obtained for other pollutants to define pollutographs.

Analytical Suite

In the early part of the Program, a full suite of analyses was conducted which included 10 metals for total and dissolved fractions (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc), organics (organochlorine pesticides, organophosphate pesticides, volatile organics, semi-volatile organics, total oil and grease, and total organic carbon), and other parameters (pH, hardness, turbidity, and total suspended solids). Parameters that were consistently not detected were dropped from the full suite to a reduced suite of analyses that has become the routine analytical suite for the past 4 years of monitoring. The reduced suite is shown in Table 2.

Note that in Table 2 the method detection limit for mercury was reduced by modifying the analysis techniques in order to quantify mercury levels. Analysis methods were also modified to lower the method detection limits for selenium and PAHs.

Quality Assurance and Quality Control

Since the start of the Program, stringent field and laboratory QA/QC procedures were developed and implemented to ensure high quality data. Field QA/QC includes following strict sampling protocols as specified in standard operating

procedures and evaluation of potential contamination through the analysis of field equipment blanks. Laboratory QA/QC addressed:

- Accuracy (analysis of matrix spike recoveries on each batch of samples and quarterly analysis of certified samples)
- Precision (analysis of matrix spike duplicates)
- Contamination (analysis of method blank, and filter blank)
- Holding Time (specified holding times associated with each chemical method)
- Certified Methods of Analysis (EPA or State certified methods of analysis)

Metals Detected

Figure 2 shows the percent of waterway samples in which metals were detected during storm events from 1988 to 1992. Of the metals detected by the total recoverable methods (total metals), cadmium, chromium, copper, lead, nickel and zinc were consistently detected. Total arsenic was detected in 74% of the samples while total mercury, selenium and silver were detected in approximately half the samples. Of the dissolved metals only chromium, copper and zinc were consistently detected. Dissolved nickel was detected in 71% of the samples and dissolved lead was detected in 54% of the samples. Less than half the samples had detectable concentrations of dissolved cadmium, selenium and silver. Dissolved mercury was undetectable using standard EPA methods.

Effects of Land Use on Water Quality

During the first two years of the Program (1987-88, 1988-89), monitoring data were collected at seven land use stations (Table 1, stations L1-L7) to characterize water quality from open, residential/commercial, and industrial land uses. To characterize water quality from transportation corridors, two stations were installed and operated for three years on an eight lane freeway and on a local 4 lane expressway (Table 1, stations T1, T2). Figure 3 shows the median concentrations of total cadmium, copper, lead, nickel and zinc at the land use stations and at the waterway stations (Table 1, stations S1-S4). Total zinc and cadmium at the heavy industrial station were 4 to 6 times higher than concentrations at the other land use areas. (Note: pilot inspection programs implemented in this catchment indicated a source of cadmium and zinc from metal plating operations.) Total cadmium in the other land use areas was only slightly elevated relative to the waterway concentrations. Total lead concentrations were highest at the transportation and heavy industrial stations. Total nickel concentrations were highest at the transportation, heavy industrial, and waterway stations. Total copper concentrations were highest in the heavy industrial station. Total median copper concentrations at the other urbanized land uses are consistently around 30 µg/L/L. Copper concentrations in samples obtained from open space stations were approximately one third of this value suggesting a substantial amount of copper may originate from open space land use areas.

Statistical tests of these data indicate that metals concentrations in samples obtained from open space versus residential/commercial samples versus heavy industrial samples are significantly different. The tests do not show statistically significant differences in concentrations of samples collected in different types of residential areas (eg, single versus multi-family) or between residential and commercial areas (SCVNPS, 1989).

Enrichment of Metals Associated With Suspended Particulates

Metals in storm water runoff are often associated with suspended solids. Metals in these solids may arise from either 'natural' sources (erosion of soils containing minerals) or manmade sources. One measure of the amount of manmade metal in a given sample is the "enrichment factor" defined as the ratio of the suspended metal concentration in a storm water sample collected in an urbanized portion of a watershed to the surficial soils concentrations in upland open areas of that watershed. (The enrichment concept is that if there were no additional input, or "enrichment", of metals from sources other than erosion, the suspended metals concentration would equal upland surficial sediment concentrations and the enrichment factor would be of the order of unity.)

The suspended metal concentration (µg/g) is defined as the ratio of the particulate metal concentration (g/L) to total suspended solids (TSS) concentration (g/L); where the particulate metal concentration (g/L) is the total metal concentration minus the dissolved metal concentration. The suspended metals concentrations are expressed on a dry weight basis (as are TSS values).

Data from Shacklette and Boerngen (1984) for the San Francisco Bay Area were used to characterize upland surficial sediment concentrations. The hills in the South Bay contains serpentine outcrops as well as other mineral formations which are a source of nickel, copper, chromium, and mercury and metals concentrations in Bay Area soils were in the upper quartile of national data compiled by Shacklette and Boerngen.

Figure 4 shows enrichment factors for a variety of metals and sampling station types. The highest enrichment factors for land use stations are for zinc, lead, and cadmium which have enrichment factors between 10 and 40 for the three urban land use area types. In the waterway stations suspended solids had higher enrichment factors for most metals than bed sediments. Several factors may contribute to the observed higher enrichment factors in suspended versus bed sediments including differences in particle size.

Enrichment analysis is a tool for identifying the relative importance of urban versus upland erosional sources. These results indicate that urban sources for cadmium, lead, and zinc are much larger than upland erosional sources, whereas for copper and nickel both sources are important. Chromium appears to be primarily an erosional source.

Water Quality Flowrate Correlations

There has always been an interest in potential correlations between water quality and flow and efforts at correlation using flow composite data have not been successful. However, grab sampling results for five storm events (28 data points) from the Guadalupe River Station (S3) were successfully correlated with flowrate.

Figure 5 shows discrete TSS concentrations versus instantaneous stream flowrate. Linear regression analysis indicated a correlation coefficient of 0.781. The best-fit linear regression equation describing this relationship is:

$$TSS\ (mg/L) = 0.277\ FLOWRATE\ (cfs) + 58.49$$

Because of the high affinity of metals to solids, and since TSS is correlated with flowrate, we tested the relationship between total copper and flowrate. Figure 6 shows a positive correlation ($R^2 = 0.820$) between total copper concentration (TCu) and flowrate with a best-fit linear regression equation given by:

$$TCu\ (\mu g/L) = 0.0403\ FLOWRATE\ (cfs) + 12.02$$

Equilibrium Partitioning

The form (as well as presence) of pollutants is important as the dissolved form of the constituent is more biologically available than the particulate form. In order to be able to characterize dissolved versus particulate partitioning we examined the applicability of equilibrium partitioning theory to storm water. A sorption isotherm describes the partitioning of chemicals between the dissolved phase and the sorbed phase. Assuming a linear isotherm for dilute solutions yields the following equilibrium partitioning equation (Maidment, 1992):

$$F_{dis} = 1/[1 + (K_d\ TSS)]$$

where

F_{dis} = ratio of dissolved to total concentration
K_d = Distribution coefficient (L/Kg)
TSS = Total Suspended Solids Concentration (µg/L)

When the grab sample data for copper were fitted to this theoretical relationship (Figure 7), there was a significant correlation ($R^2 = 0.937$). The distribution coefficient which yielded the best-fit regression curve shown in Figure 7 is 29,079 L/kg.

The distribution coefficient is the ratio of the sorbed concentration (g/Kg) to the dissolved concentration (g/L); therefore the higher the value of K_d, the lower the dissolved fraction. The distribution coefficient for lead is greater than that for zinc which is greater than that for copper. This means that in the sorbed phase, there is a higher fraction of lead than zinc than copper.

In conclusion, these storm water data support the linear isotherm equilibrium partitioning theory and this theory may be applied to estimate the dissolved fraction given the TSS and total concentration. Although not shown, this theory also applied reasonably well to data taken in storm drains (SCVNPS, 1993).

Exceedances of Water Quality Objectives

The metals data from four years of monitoring waterway stations have been compared to water quality objectives contained in the April 1991 California Inland Surface Waters Plan. Since the average storm runoff duration at waterway stations is about 36 hours in Santa Clara Valley, comparison of urban runoff water quality to the freshwater aquatic lifel-hour and 4-day objectives are used to "bracket" the actual exposure . The 4-day average objective is referred to as the "chronic" objective, and the 1-hour average objective is referred to as the "acute" objective. Given the duration of storm events, exceedance of an acute objective is considered a better indicator of a potential toxicity problem. In addition, exceedances of objectives by dissolved metal concentrations are considered better indicators of potential toxicity problems than exceedances by total metals concentrations because dissolved metals are more bioavailable.

Table 3 summarizes the water quality objective exceedances for various metals at the four waterway stations using dissolved and total metals data collected during the 90-91, 91-92, 92-93, and 93-94 wet weather seasons. Acute and chronic water quality objectives for total copper and total zinc were consistently exceeded in samples collected from Calabazas Creek (station S1) and Sunnyvale East Channel (S2). The objectives for total zinc were only occasionally exceeded in storm water samples from Guadalupe River (S3) and Coyote Creek (S4). The objectives for total copper were less frequently exceeded, and the concentrations were nearer the objectives, in storm water samples from Guadalupe River and Coyote Creek than in samples from Sunnyvale East Channel and Calabazas Creek. The chronic objectives for total nickel and total lead were always exceeded in samples from Sunnyvale East Channel and Calabazas Creek, and frequently exceeded in samples from Guadalupe River and Coyote Creek. Acute objectives for total lead were rarely exceeded, and acute objectives for total nickel have never been exceeded. Total cadmium has not exceeded acute objectives, and exceeded chronic objectives in 8 of 61 storm samples; the most recent observed exceedance was in October 1991.

Dissolved constituents seldom exceed objectives. Dissolved copper exceeded the chronic objectives in 2 of 42 samples, and has not exceeded acute objectives. Dissolved lead was detected in 10 of 43 samples and one of these ten samples exceeded the chronic objectives; no lead samples exceeded the acute objectives.

Those 304(l) metals of concern that have never exceeded water quality objectives include total mercury (acute objectives only, chronic objectives were lower than the MDL), total selenium, dissolved cadmium, and dissolved zinc. Total silver is generally not detected, and dissolved silver and chromium (VI) have never been detected in storm water samples from the four waterway stations.

Figure 8 compares the total copper data with acute and chronic objectives for the four waterway stations. This figure shows the effect of urbanization on water quality exceedances. Most exceedances occur at the stations (S1 and S2) whose watersheds are smaller and more highly urbanized.

Duration Of Water Quality Objective Exceedances

If flow-weighted concentrations exceed the WQOs, it is often assumed that the duration of exceedance equals the duration of the runoff event. In order to test this assumption, the actual duration of exceedance was determined by collecting and analyzing discrete samples during six storm events at the Guadalupe River Station (S3). For each storm event, about six samples were collected over the rising, peak, and receding limb of the hydrograph.

Table 4 shows that the duration of exceedance of acute WQOs for total copper, lead and zinc is always less than the duration of the storm runoff event. The frequency of exceedance varies depending on the metal, and was greatest for copper (5 of 6 events), then zinc (4 of 6), and then lead (2 of 6). For copper, exceedance duration ranged between 8-38 hours or about 20 to 95% of the duration of the storm runoff. For zinc, the exceedance durations ranged between 3-28 hours (8 to 74% of storm runoff duration) and for lead the two exceedances were each 6 hours or 20-25% of the storm runoff duration. For those cases where an exceedance was measured, the average duration of exceedance (expressed as a percent of the storm duration) was approximately 60% for copper, 40% for zinc, and about 20% for lead.

Statistical Analyses

Statistical analysis were used to determine if there were differences in water quality between monitoring stations and between monitoring years. The results were also used to help select future stations for long term monitoring and to determine the number of samples that need be collected to detect a given trend in water quality (power analysis).

Two way analysis of variance (ANOVA) and analysis of covariance (ANACOVA) were used to perform comparisons between stations and years. Parametric procedures (using the actual values of the data) rather than non-parametric procedures (using the ranks of the values) were chosen because they allow the statistical results to be used to determine the number of samples necessary to determine a given difference between years and/or stations (power analysis). Previous data analysis indicated total metals are lognormally distributed and therefore, statistical analyses used log-transformed data.

ANOVA Results - Station Differences

Figure 9 presents total copper box plots for the four waterway stations for samples collected during the permit period. The figure indicates total copper concentrations are highest and more variable in Calabazas Creek (S1) and Sunnyvale East Channel (S2), with lower concentrations and less variability seen in Guadalupe River (S3) and Coyote Creek (S4). The stations with the higher concentrations drain smaller more urbanized watersheds.

The results of the ANOVA statistical analysis (top of Figure 13) indicate Calabazas Creek (S1) had significantly higher total copper concentrations than Guadalupe River (S3) and Coyote Creek (S4) and Sunnyvale East Channel (S2) was significantly higher than Coyote Creek (S4). If the data for the two stations (S1,S2) having the higher concentrations are pooled, these data are significantly higher than the pooled data for stations S3 and S4 ($p=0.002$).

ANACOVA Results - With TSS as Covariant

Much of the total copper in waterways during storms is associated with suspended solids, with the dissolved fraction typically ranging from 15% to 30% of the total concentration (Figure 7). Variations in TSS from event to event may mask apparent station and or year differences. To examine this effect, analysis of covariance (ANACOVA) was used to account for differences in total copper concentrations caused by variations in suspended solid concentrations by including TSS as a covariant. Differences not due to variations in TSS are seen as better indicators of station and year differences.

Station Differences

Figure 10 presents the suspended sediment total copper percentile box plots. The figure indicates the total copper concentrations in suspended sediments are highest in Sunnyvale East Channel, with lower concentrations in Calabazas Creek, Guadalupe River and Coyote Creek. Sunnyvale East Channel is not a natural channel while the other waterways are natural channels with little or no improvements. This suggests that total suspended sediment concentrations are lower in constructed waterways (because of minimal or no bottom or bank erosion) which, for a given total metals concentration, results in lower copper concentrations in suspended sediments.

Results of the ANACOVA statistical comparison are presented at the top of Figure 10. The results indicate Sunnyvale East Channel (S2) had significantly higher total copper concentrations than Calabazas Creek, Guadalupe River and Coyote Creek. Total copper concentrations in Calabazas Creek, Guadalupe River, and Coyote Creek are not significantly different after accounting for differences due to TSS.

Annual Differences

Data from the three similar stations (Calabazas, Guadalupe, and Coyote) were used to conduct a two-way ANACOVA using year and stations as the effects to be tested. The results shown in Figure 11 indicate total copper was significantly lower in 1992 as compared to 1991 ($p=0.044$). No other significant differences between years were observed. These observed differences may be due to increased rainfall in 1992 (19.5 inches total) as compared to 1990 (11 inches) and 1991 (14 inches) or other factors.

In conclusion, these analyses indicate the advantage of conducting ANACOVA statistical testing taking into account the effects of TSS as a covariate. The results indicate that, by taking into account TSS, differences between stations were illuminated which would otherwise have been masked using an ANOVA analysis. The ANACOVA results also showed a statistically valid annual difference which was not evident in the ANOVA analysis.

Power Analysis for Detection of Long-term Trends

There is considerable interest in storm water monitoring to detect long term trends in water quality that may be associated with BMP implementation. The following describes the application of the statistical tool called power analysis to help address this issue.

The ability to distinguish long-term trends in a dataset is influenced by several factors including the magnitude of the difference to be observed, the amount of variability in the data, the number of samples, and the desired confidence intervals for the statistical tests. The probability of observing a given trend increases when sample size is increased and decreases when variability and/or desired statistical confidence intervals are increased. Additionally, the larger the trend to be observed the higher the probability it will be observed, other factors being equal. The main variables which can be controlled are the number of samples and which stations will be monitored.

Results of the ANOVA statistical testing indicated the four monitoring stations could be grouped into subsets based on total copper concentrations. Each of the subsets contained differing degrees of variability with the Calabazas Creek Sunnyvale East Channel subset (S1&S2) having higher variability than the Guadalupe River Coyote Creek subset (S3&S4). As variability is a factor influencing statistical power, separate power analysis was conducted for each station subset.

Figures 12 presents the results of the power analysis for total copper data collected at the Coyote Creek and Guadalupe River monitoring stations. Presented are the number of samples per year (total for both stations) and the power (probability of detecting the trend) for three projected trends. For example, this figure indicates that, at the 80 percent confidence level, it would take about 22 samples per year to confirm a 40% change over a 10 year period. If the trend analysis were to be conducted at the other two waterway stations where the data are more variable, the analysis shows that about 30 samples would be required.

An alternative power analysis was conducted using the ANACOVA statistical results which examines differences in total copper caused by factors other than changes in total suspended solids (Figure 13). When compared to the previous power analysis presented in Figure 12 it is apparent that changes in TSS-corrected total copper are easier to detect using the ANACOVA model, reflecting the lower unexplained error after changes due to TSS are taken into account. (For example, 15 samples per year are sufficient to detect a 40% cnange).

The disadvantage to using the ANACOVA model is that it is more difficult to relate the observed differences to actual changes in pollutant concentrations and loads. The advantage of the model is that, by correcting for changes in TSS in individual storms, some of the influence due to changes in stream hydrology during individual storms is taken into account and annual differences due to other factors may become more apparent.

Toxicity Testing

The purpose of toxicity monitoring was to characterize toxicity at different land use stations and to provide a long term assessment of toxicity (frequency and intensity) in waterway stations. Storm water samples were collected in Santa Clara County during several winters. Some of these were used in chronic, 7-day toxicity tests with *Ceriodaphnia dubia* (USEPA,1989), and some were used for further characterization employing toxicity identification evaluations (TIE) phase I protocols (USEPA, 1988).

The results of chronic toxicity tests are presented in Figure 14, arranged by categories of toxicity intensities. The legend lists the categories in ascending order of intensity (F being more intensive than A) and defines each toxicity category. The mortality endpoint is based on how long it took for a sample to cause mortality of 50% of the test organisms, and samples were assigned to one of three groups: extremely toxic (F, less than 24 hours), highly toxic (E, 1-4 days), or moderately toxic (C and D, 4-7 days). Impaired reproduction (or lack of reproductive effect) was assessed for all samples that did not cause mortality within 5-7 days, using the average number of offspring per female per reproductive day (OFRD) as compared to control OFRD. Moderately toxic samples were assigned to category D if they did not impair reproduction and to category C if they did. Samples which did not kill the organisms but caused impaired reproduction were defined as non-lethal (category B), and samples that did not have any deleterious effect were categorized as non-toxic (category A). Generally, the term "acute toxicity" for *C. dubia* refers to toxic effects delineated in categories E and F (mortality within four days), while the term "chronic toxicity" refers to situations encountered in categories B, C, and D.

Samples from various stations revealed distinctly different distribution among toxicity categories (Figure 14). In the heavy industry station (L-2), all of the samples collected during 1991-1993 were extremely toxic (category F). All samples collected at residential and commercial areas in 1989 caused mortality, and half were extremely toxic. The majority (80%) of the waterway stations samples collected during 1989-1994 were lethal to *C. dubia* (categories D, E and F), but only 20% were extremely toxic. It is important to emphasize that moderately toxic and non-lethal samples from residential, commercial, and mixed land use catchments did not inhibit reproduction of *C. dubia*, except for one unusual event (SE-27) in which all samples collected in Santa Clara Valley impaired reproduction. On the other hand, most of the transportation stations samples inhibited reproduction, and were categorized either as moderately toxic (category C) or non-lethal (category B).

Figure 15 shows the relative intensities of toxicity as measured in Coyote Creek (Station S4, Table 1) during three years of monitoring. The white upper portion of each bar represents the median time to lethality (LT_{50}), which is the duration of exposure that killed 50% of the test animals. The shorter the LT_{50} the higher the toxicity. The duration of the entire test is 7 days (168 hours). To more easily visualize variations in toxicity, we have defined a relative toxicity intensity unit that equals 168 hours minus LT_{50}, shown by the lower darker part of each bar. Taller dark portions mean higher intensity of toxicity, and absence of a dark portion means that toxicity was not detected at all. As can be seen in Figure 15, the variability in toxicity between storm events is very high, and due to this variability it is difficult to see a trend. However, toxicity was detected in autumn and spring storms more often than in mid-winter storms. The environmental significance of laboratory toxicity tests using sensitive non-native organisms is unclear. But the fact that the actual runoff duration in waterway stations is consistently less that the observed LT_{50}s suggests that storm water may not be creating toxic conditions in the tributary streams.

TIE testing has been conducted in a limited way, in part because such tests require highly toxic samples that have not been observed in waterway samples since 1991. TIE tests (3 samples) from industrial stations showed that dissolved metals accounted for a substantial portion of the toxicity observed. This is consistent with the fact that, at industrial stations, dissolved metals also exceeded WQOs and the toxicity intensity correlated with the magnitude of the exceedance.

At waterway stations (5 samples) and transportation stations (1 sample) the major causes of toxicity were non-polar organics (e.g., pesticides or hydrocarbons), or metal-organic complexes. This is consistent with the lack of exceedances of WQOs by dissolved metals and lends support to the appropriateness of dissolved (rather than total) concentrations as the preferred indicator of acute toxicity (Cooke and Lee, 1993). Instead of metals, pesticides, particularly diazinon, have been implicated as a major cause of toxicity in urban runoff samples from residential areas in Alameda County (S.R. Hansen, personal communication) and in the Central Valley (Connor et al, 1994).

<u>Conclusions</u>

(1) The effects of land use on water quality is statistically significant only when data are pooled into the following broad land use categories: open, residential/commercial, and heavy industrial. No statistically significant differences in water quality have been determined for data sets within these broad land use categories.

(2) Enrichment analysis indicates that urban sources of cadmium, lead, and zinc are much larger than upland erosional sources, whereas for copper and nickel both sources are important. Chromium appears to be primarily an erosional source.

(3) Discrete grab sample water quality data correlate with flow whereas past attempts with correlations using flow composite data have been largely unsuccessful.

(4) Linear Isotherm equilibrium partitioning theory applies to storm water samples in alluvial streams and to a lesser extent in storm drains. This theory is very useful in predicting the dissolved versus particulate fraction of metals which is important in evaluating the potential toxicity and treatability of the sample.

(5) Exceedances of acute water quality objectives have not been observed with dissolved metals data and only 2 copper samples (out of 42) exceeded the chronic objectives. Toxicity data indicate that toxicity does not correlate with total concentrations of the metals and that toxicity is not reduced by filtering the sample. These results support the current EPA recommendations (EPA, 1993) that dissolved forms of metals are preferred for evaluating compliance with water quality objectives.

(6) If total metals data is used to evaluate compliance, grab sample data indicate that the duration of exceedance is 20-60 % of the storm event duration depending on the metal.

(7) Evaluating differences between stations and between years appears to be facilitated if one uses ANACOVA analysis using TSS as a covariate. This effectively eliminates hydrologic effects associated with increased TSS (and implicitly increased flows). This analysis indicated that water quality in a watershed where the channels have been

significantly improved (e.g., lined with concrete) was statistically different from water quality collected in natural watersheds.

(8) The results of a power analysis to design a monitoring program to detect potential long term trends in water quality shows that accounting for TSS as a covariate could reduce the sampling burden. Nonetheless the number of samples per year required to measure trends are large (eg. 20-40 samples) and it is questionable whether such resources should be applied, especially every year. The authors suggest that monitoring resources should be balanced between compliance and trends analysis versus focused special studies of limited duration.

(9) Toxicity effects have been characterized in six categories depending on the type of effect (mortality and/or reproduction) and time scale of effect. Based on this classification, toxicity testing data indicate that runoff from different land uses exhibit different levels of toxicity to *Ceriodaphnia dubia*. The most toxic samples were found in industrial land use areas, and the least toxic were collected at transportation corridors. However, samples from transportation corridors specifically inhibited reproduction of *C. dubia*.

The cause of toxicity also varied. Data suggest that dissolved metals are the principal cause of observed toxicity at the heavy industrial station whereas at waterway stations the cause appears to be related to non-polar organics or metal-organic complexes. Pesticides, particularly, diazinon, have been implicated in storm water monitoring conducted in other areas of the state.

Future Direction Of Monitoring Program

The two major watersheds, Guadalupe River and Coyote Creek, will continue to be monitored annually for five storm events per year to evaluate long term trends in water quality and to determine if storm water discharges are in compliance with water quality and toxicity objectives. Sunnyvale East Channel and Calabazas Creek will be monitored every other year to meet these objectives, and to provide comparative data. The program will continue to conduct studies to evaluate control measure effectiveness, such as the development of BMPs for the control of pollutants from urban parking lots, scheduled for completion in December 1995. Toxicity testing will continue, but new approaches to evaluating the causes of observed toxicity will be implemented to better understand this complex environmental issue.

In addition to taking a more targeted approach specifically to stormwater quality monitoring, the Program will initiate efforts in the next permit period to expand the scope and purpose of monitoring. New monitoring objectives include greater emphasis on source identification, integrating monitoring into the goals of public education and participation, and expanding the scope of monitoring as a component of watershed management.

The Program recently completed a pilot Citizen Monitoring Project and will be supporting an expansion of this throughout the Santa Clara Valley in an effort to encourage public education and participation and to help prevent illegal dumping through increased community awareness. A pilot watershed-based sediment sampling and analysis project will be conducted in late 1994 to test such an approach to source identification, with particular emphasis on potential erosion and sediment management measures to reducing total copper loads to South San Francisco Bay. Finally, the Program, in cooperation with the Bay Area Stormwater Management Agencies Association and the San Francisco Estuary Institute, will be developing comprehensive watershed monitoring goals, objectives, protocols, and data management and analysis guidelines. A watershed monitoring approach will then be implemented in the Santa Clara Valley during the next permit term as component of watershed management.

Acknowledgements

The authors would like to express their appreciation to the member agencies of the Santa Clara Valley Nonpoint Source Pollution Control Program for supporting this work. We particularly wish to thank Mr. Roger James who, as Chair of the Program Management Committee during the 1st Permit Period, established a proactive program. Kinnetic Laboratories Incorporated (KLI) designed, installed, and maintained the equipment and collected the samples. Special appreciation is given to the field crews who collected these data under often difficult conditions. Marty Stevenson and Richard Mattison of KLI were key players in executing the field program. Toxscan, Inc. Laboratories conducted the chemical analyses and toxicity testing. Josephine Shum of SCVWD assisted in toxicity testing data interpretation. Marco Lobascio of Woodward Clyde assisted in designing and implementing the data management system. Michael Paquet of Woodward Clyde assisted in coordinating the field work and tracking weather.

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TABLE 1
STATION DESCRIPTIONS

Station ID	Type of Station	Location	Principal Land Use	Drainage Area hectares (acres)	Conveyance	Remarks
L1	Land Use	Junction Avenue	industrial park	8.9 (22)	0.76m (30") R.C.P.	Manhole station, with weir installed
L2	Land Use	Walsh Avenue	heavy industry	11.3 (28)	0.68m (27") R.C.P.	Manhole station, with weir installed
L3	Land Use	Fremont and Bernardo avenues	commercial	107 (265)	1.06m (42") R.C.P.	Manhole station, with weir installed
L4	Land Use	Hale Creek	low-density single-family residential	661 (1,633)	open channel	SCVWD gaging station No. 33
L5	Land Use	Sunnyvale East Channel	single-family residential (valley)	842 (2,080)	channelized	Highly-erodable channel, rating developed
L6	Land Use	Pomona and Williams	multi-family residential	34 (85)	0.84m (33") R.C.P.	Manhole station, with weir installed
L7	Land Use	Stevens Creek	open (forest)	3400 (8,410)	natural	Rating developed but not considered reliable because of backwater effects
L8	Land Use	Packwood Creek	open (ranchland)	2617 (6,464)	natural	SCVWD gaging station No. 57
L9	Land Use	West San Carlos Ave.	industrial	16 (40)	storm drain	Storm drain outfall into Los Gatos Creek
T1	Land Use	Montague Expressway	transportation	4.9 (12)	storm drain	Four lane expressway Average Daily traffic (ADT) about 45,000
T2	Land Use	Interstate 280	transportation	14 (35)	pump station	Eight lane freeway - ADT about 213,000
S1	Waterway	Calabazas Creek	mixed	3731 (9,216)	natural	SCVWD gaging station No. 26A
S2	Waterway	Sunnyvale East Channel	mixed	1391 (3,437)	channelized	SCVWD gaging station No. 74
S3	Waterway	Guadalupe River	mixed	6438 (15,904)	natural	USGS gaging station No. 169000
S4	Waterway	Coyote Creek	mixed	32,207 (79,552)	natural	SCVWD high-flow gaging station No. 2060

Table 2. CHEMICAL ANALYTICAL SUITE AND METHOD DETECTION LIMITS

Parameter	Units	Methodology	EPA Method (a)	Method Detection Limit
Inorganics				
pH	pH	pH electrode	150.1	-
Hardness	mg/L	Titrimetric EDTA	130.2	1
Turbidity	NTU	Nephelometric	180.1	1
TSS	mg/L	Gravimetric	160.2	10
Metals - Total Recoverable				
Arsenic	µg/L	Furnace-AA	206.2	1
Cadmium	µg/L	Furnace-AA	213.2	0.2
Chromium (Total)	µg/L	Furnace-AA	218.2	1
Copper	µg/L	Furnace-AA	220.2	1
Lead	µg/L	Furnace-AA	239.2	1
Mercury	µg/L	Cold Vapor - AA/AF	245.1	0.2/0.001
Nickel	µg/L	Furnace-AA	249.2	2
Selenium	µg/L	Hydride - AA	270.3	0.025
Silver	µg/L	Furnace-AA	272.2	0.2
Zinc	µg/L	Furnace-AA	289.2	1
Metals - Dissolved (< 0.45 µm)				
Cadmium	µg/L	Furnace-AA	213.2	0.2
Copper	µg/L	Furnace-AA	220.2	1
Lead	µg/L	Furnace-AA	239.2	1
Mercury	µg/L	Cold Vapor - AA/AF	245.1	0.2/0.001
Silver	µg/L	Furnace-AA	272.2	0.2
Zinc	µg/L	Furnace-AA	289.2	1
Organics				
PAH	µg/L	GC-MS	8270 (modified)	0.0005
TOC	mg/L	Combustion	9060	1
Total Oil and Grease	mg/L	IR	413.2	0.2

(a) Methods for Chemical Analysis of Water and Wastes (1983) EPA-600/4-79-020

Table 3
SUMMARY OF WATER QUALITY OBJECTIVES EXCEEDANCES FOR WATERWAY STATIONS

Station ID	Cadmium		Chromium	Copper		Lead		Mercury	Nickel	Selenium	Silver		Zinc	
Exceedance of Acute Water Quality Objectives at Waterway Stations (#samples exceeding/total samples) FY 90-91 Through FY 93-94														
	Total	Diss.	Total	Total	Diss.	Total	Diss.	Total	Total	Total	Total	Diss.	Total	Diss.
S1	0/12	0/7	N/A	11/11	0/7	1/12	0/7	0/12	0/12	0/12	0/12	0/7	11/12	0/7
S2	0/12	0/8	N/A	12/12	0/8	2/12	0/7	0/12	0/12	0/12	0/12	0/8	12/12	0/7
S3	0/17	0/12	N/A	9/17	0/12	2/17	0/12	0/17	0/17	0/17	0/17	0/8	7/17	0/12
S4	0/20	0/16	N/A	10/20	0/15	0/20	0/16	0/20	0/20	0/20	0/20	0/9	7/20	0/16
Exceedance of Chronic Water Quality Objectives at Waterway Stations (#samples exceeding/total samples) FY 90-91 Through FY 93-94														
	Total	Diss.	Total	Total	Diss.	Total	Diss.	Total	Total	Total	Total	Diss.	Total	Diss.
S1	2/12	0/7	N/A	11/11	0/7	12/12	0/7	NC	12/12	0/12	N/A	N/A	12/12	0/7
S2	3/12	0/8	N/A	12/12	2/8	12/12	0/7	NC	12/12	0/12	N/A	N/A	12/12	0/7
S3	1/17	0/12	N/A	13/17	0/12	16/17	0/12	NC	13/17	0/17	N/A	N/A	7/17	0/12
S4	2/20	0/16	N/A	14/20	0/15	17/20	1/16	NC	14/20	0/20	N/A	N/A	8/20	0/16

N/A - No Objective For This Metal
NC - Not Comparable (Method Detection Limit > Objective)

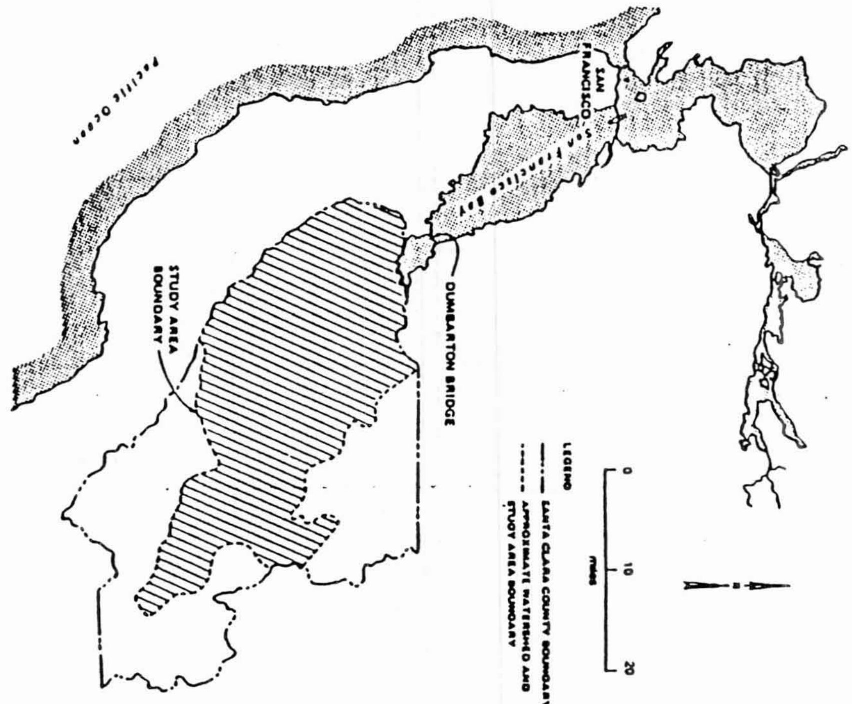
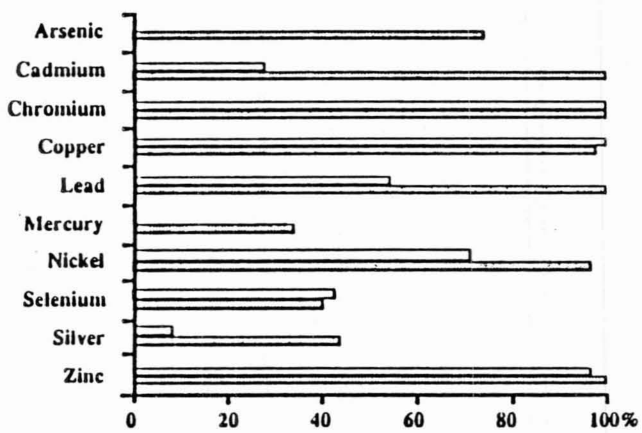


Figure 1 STUDY AREA LOCATION



(Total Number of Samples)

	Total	Dissolved
Arsenic	62	7
Cadmium	62	39
Chromium	53	7
Copper	62	39
Lead	62	39
Mercury	62	7
Nickel	62	7
Selenium	62	7
Silver	62	39
Zinc	62	39

Monitoring Period: 1988 to 1992

Figure 2 PERCENT OF WATERWAY SAMPLES IN WHICH METALS WERE DETECTED DURING STORM EVENTS

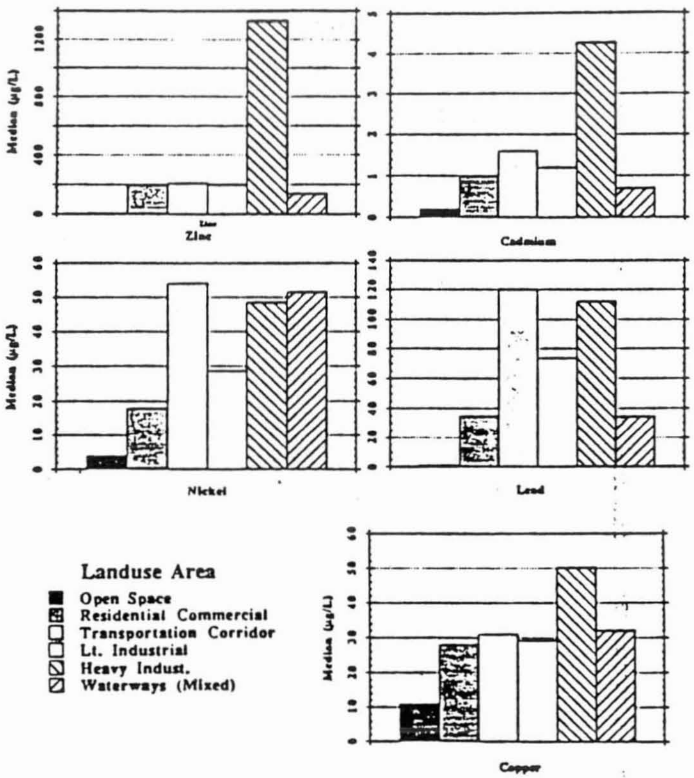


Figure 3 MEDIAN METAL CONCENTRATIONS IN STORM RUNOFF

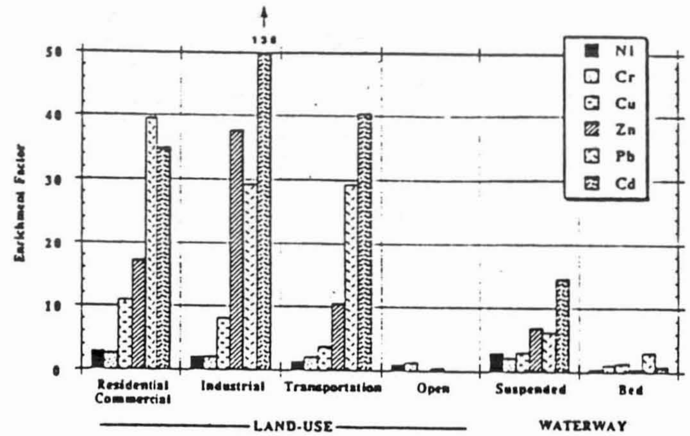


Figure 4 ENRICHMENT FACTORS FOR SUSPENDED SOLIDS

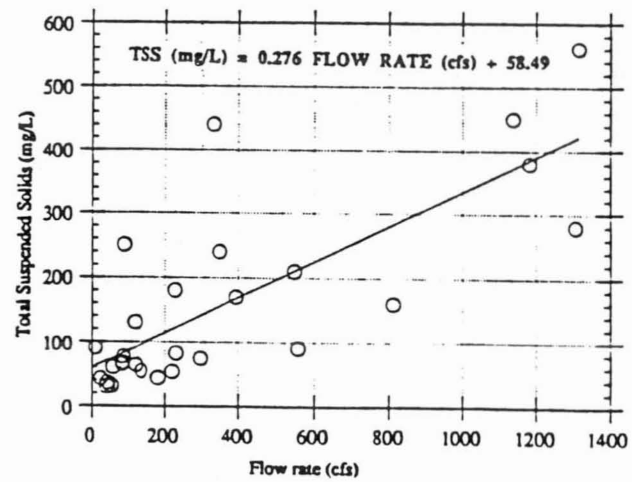


Figure 5 TOTAL SUSPENDED SOLIDS VERSES FLOW RATE IN GUADALUPE RIVER

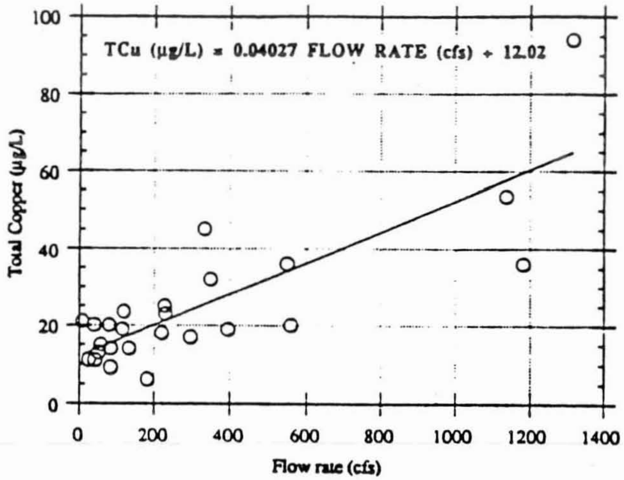


Figure 6 TOTAL COPPER CONCENTRATIONS VERSES FLOW RATE IN GUADALUPE RIVER

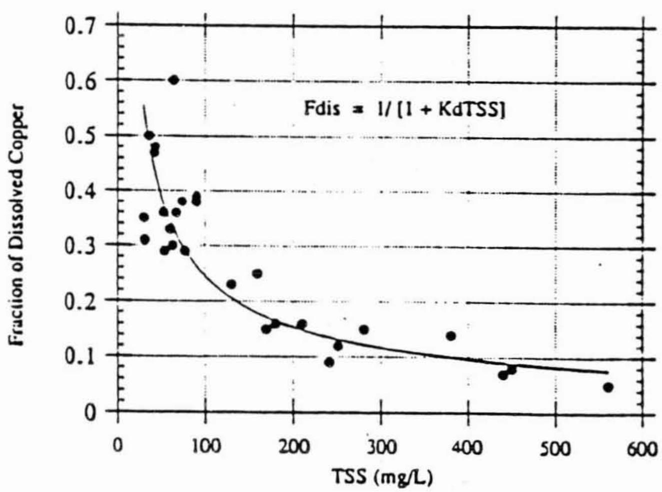


Figure 7 RELATIONSHIP BETWEEN FRACTION DISSOLVED COPPER AND TOTAL SUSPENDED SOLIDS

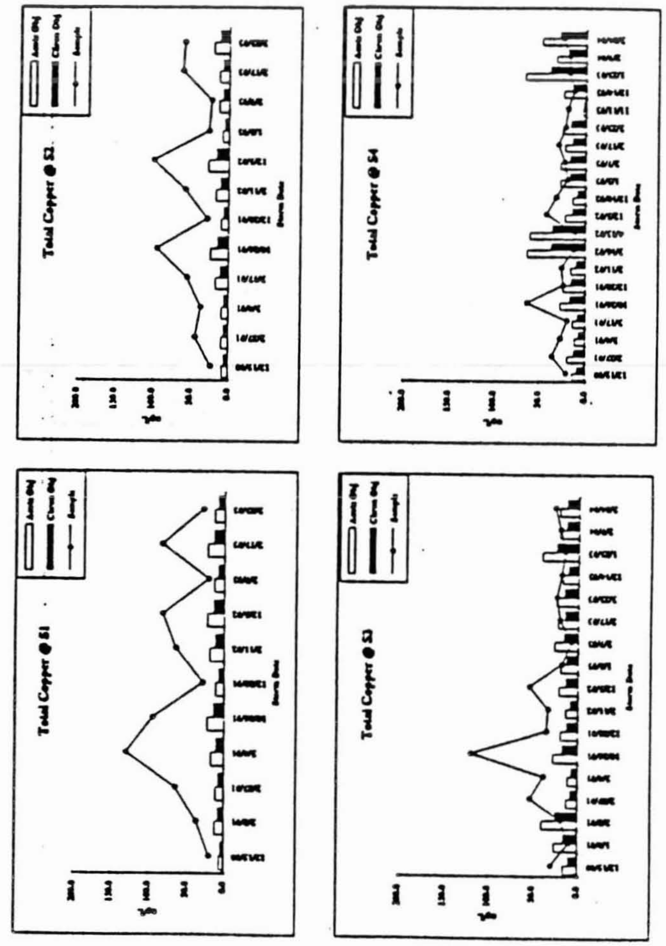


Figure 8 COMPARISON OF TOTAL COPPER CONCENTRATIONS IN STORM WATER SAMPLES TO WATER QUALITY OBJECTIVES AT FOUR WATERWAY STATIONS

Results of ANOVA Comparison Between Waterway Stations

Parameter: Total Copper

STID i:j	S1	S2	S3	S4
S1		=	>	>
S2			=	>
S3				=
S4				

Confidence level: 0.05 (95%)

> means row is greater than column station
= means row not different than column

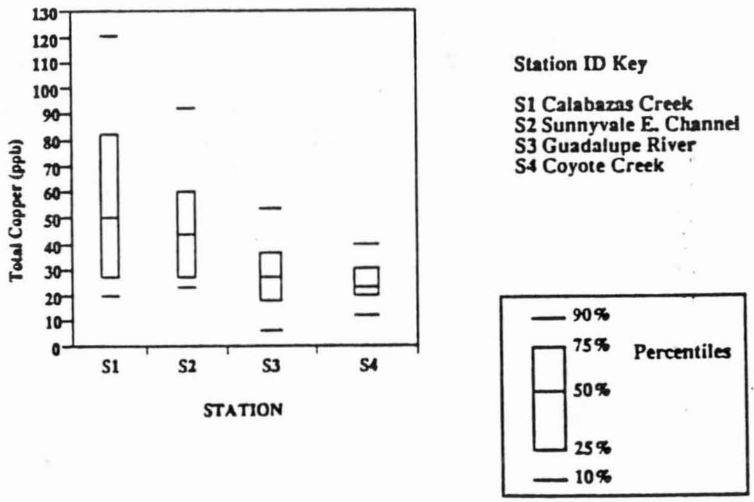


Figure 9 TOTAL COPPER PERCENTILE DISTRIBUTION AT WATERWAY STATIONS

Results of ANACOVA Comparison Between Waterway Stations
TSS used as covarient

Parameter: Total Copper

STID i:j	S1	S2	S3	S4
S1		<	=	=
S2			>	>
S3				=
S4				

Confidence level: 0.05 (95%)

= means row not different than column station
> means row is greater than column station
< means row is less than column station

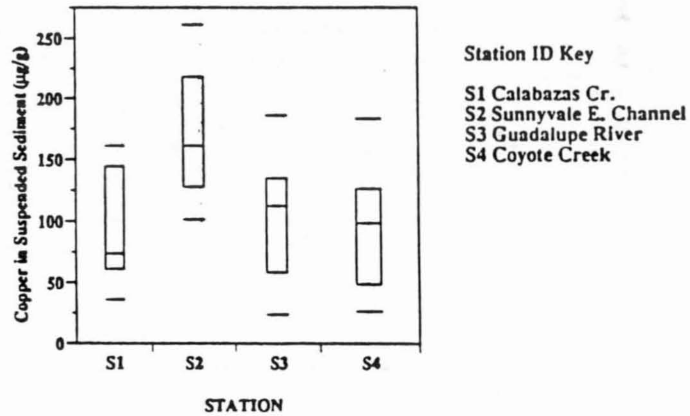


Figure 10 TOTAL COPPER IN SUSPENDED SEDIMENTS IN SANTA CLARA VALLEY WATERWAY STATIONS

Results of ANACOVA Comparison Between Monitoring Years
(Calabazas, Guadalupe & Coyote Stations)
TSS used as covarient

Parameter: Total Copper

Year i;j	1990	1991	1992
1990		=	>
1991			=
1992			

Confidence level: 0.05 (95%)

= means row not different than column station
> means row is greater than column station
< means row is less than column station

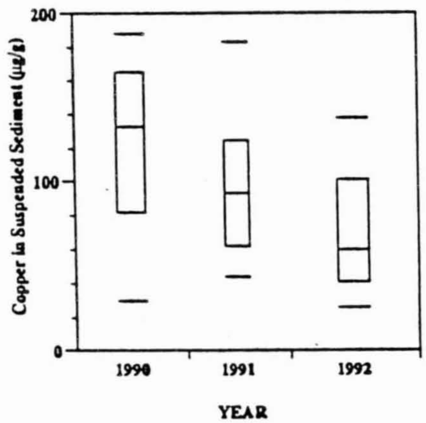


Figure 11 TOTAL COPPER IN SUSPENDED SEDIMENTS AT CALABAZAS, GUADALUPE RIVER, AND COYOTE CREEK

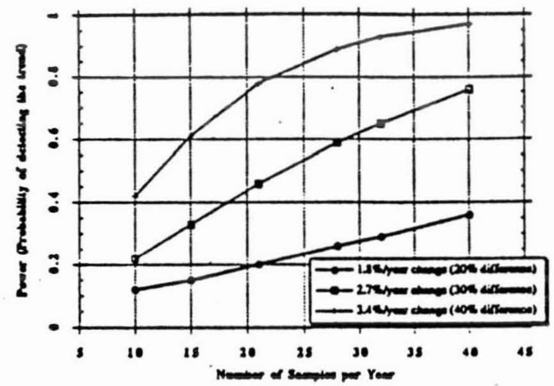


Figure 12 NUMBER OF WATERWAY SAMPLES NEEDED TO DETECT A 10-YEAR TREND IN TOTAL COPPER CONCENTRATIONS IN STORM WATER SAMPLES (Guadalupe and Coyote Stations)

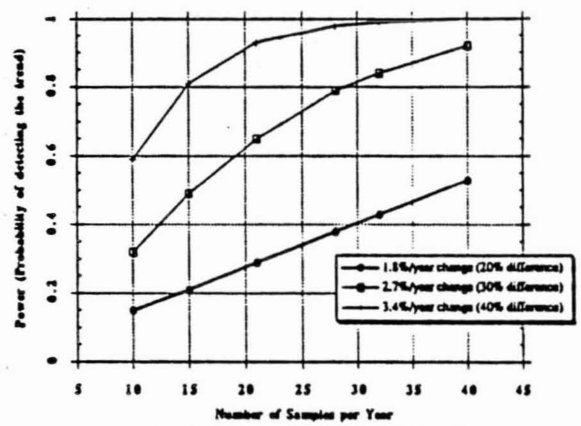


Figure 13 NUMBER OF WATERWAY SAMPLES NEEDED TO DETECT A 10-YEAR TREND IN TOTAL COPPER BASED ON ANACOVA USING TSS (Calabazas, Guadalupe, and Coyote Stations)

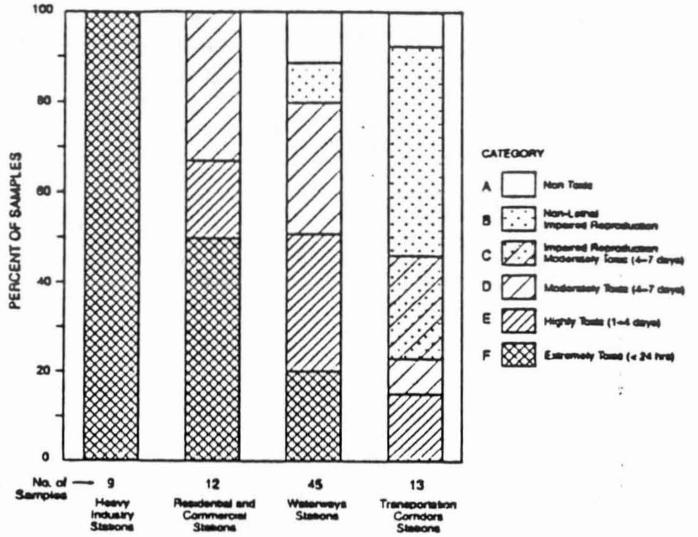


Figure 14. CATEGORIES OF TOXICITY OBSERVED IN DIFFERENT LAND-USE STATIONS IN SANTA CLARA VALLEY

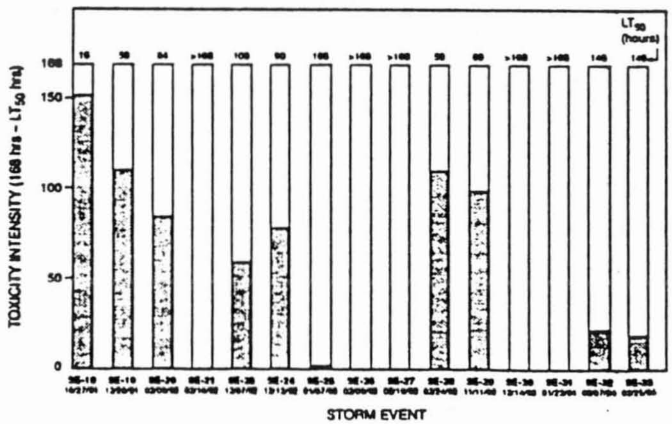


Figure 15. INTENSITY OF TOXICITY AT COYOTE CREEK STATION (S4) DURING THREE YEARS OF MONITORING

Tuesday, August 9, 1994

POSTER SESSION ON STORMWATER AND ITS MONITORING

1. **"CDOT Highway Stormwater Runoff Monitoring Results"**
   Philipp Sieber
   Colorado DOT

2. **"Methods for Assessing Urban Stormwater Pollution"**
   Chauny Soeur, William Burd, George C. Chang, and Steve Stecher
   City of Austin

3. **"Practical Experience with the Filippi Flow Limiters"**
   Anders A. Rorholt
   Tarts-EX SA, Switzerland

4. **"Low Cost Automatic Stormwater Sampler"**
   Lynn A. Dudley
   Vortox Co., Claremont, California

5. **"High-Accuracy CSO and Stormwater Flow Monitoring"**
   Terrance Burch and Joanna Phillips
   ORE International, Inc.

6. **"RCRA-Related Implications of Sediments in BMPs"**
   Jonathan Jones
   Wright Water Engineers, Inc.;
   Scott Anderson
   ARCO Coal Company

7. **"Pesticide Concentrations & Fluxes in an Urban Watershed"**
   Paul Wotzka
   Minnesota Department of Agriculture;
   J. Lee
   Minnesota Parks & Recreation Board;
   P. Capel
   U.S. Geologic Survey
   M. Lin
   University of Minnesota

8. **"The Use of Special Inlet Devices, Filter Media and Filter Fabrics for the Treatment of Stormwater"**
   Robert Pitt and Shirley Clark
   University of Alabama at Birmingham

Tuesday, August 9, 1994 (continued)

9. **"Treatment of Stormwater from Critical Source Areas Using a Multi-Chambered Treatment Train (MCTT)"**
   Robert Pitt, Brian Robertson and Ali Ayyoubi
   University of Alabama at Birmingham

10. **"Potential Groundwater Contamination From Stormwater Infiltration"**
   Keith Parmer, Robert Pitt and Shirley Clark
   University of Alabama at Birmingham;
   Richard Field
   U.S. Environmental Protection Agency

CDOT HIGHWAY STORMWATER RUNOFF MONITORING RESULTS

Philipp Sieber*

Abstract

Extensive stormwater monitoring efforts have been undertaken by municipalities and transportation agencies. The Federal Highway Administration (FHWA) and the Colorado Department of Transportation (CDOT) have been involved in such monitoring.

Findings and conclusions from the FHWA and CDOT monitoring efforts, and comparisons between the two are presented in this document.

Introduction

The National Pollutant Discharge Elimination System (NPDES) stormwater regulations have required municipalities and transportation departments across the country to recently engage in extensive stormwater monitoring efforts.

The intent of the NPDES regulation is to characterize pollutants present in stormwater runoff. For transportation departments, the above translates to pollutants present in highway runoff.

CDOT compiled highway stormwater runoff characterization data collected in the past by FHWA. In addition, CDOT performed highway runoff monitoring during 1993 in Denver, Colorado.

Background data

Most of the existing background data characterizing highway stormwater runoff is from studies performed by FHWA in the mid-seventies and eighties. These studies included monitoring data from 993 separate storm events including 16 events in Denver, Colorado. A summary of the FHWA data (shown as median values for highway site median concentrations) is included in Table 1.

*Sieber, Water Quality Engineer, Staff Design - Hydraulics, Colorado Department of Transportation, 4201 E. Arkansas, Denver, CO 80222.

Table 1
Highway Site Median Concentration (FHWA[4], 1990)

POLLUTANT (mg/L)	ADT* < 30,000	ADT* > 30,000
Total suspended solids	41	142
Chemical oxygen demand	49	114
Nitrate + Nitrite	0.46	0.76
Total Kjeldahl Nitrogen	0.87	1.83
Total phosphorus	0.16	0.40
Copper	0.022	0.054
Lead	0.080	0.4
Zinc	0.080	0.329

*ADT = Average Daily Traffic

Highway Stormwater Runoff

FHWA defined common sources, and types of pollutants found in highway stormwater runoff, and these are listed in Table 2.

Table 2
Sources of Common Highway Pollutants (FHWA[2], 1984)

POLLUTANT	SOURCE
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, Phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline, tire wear, lubricating oil and grease, bearing wear
Zinc	Tire wear, motor oil, grease
Iron	Autobody rust, steel highway structures, moving engine parts
Copper	Plating, bearing/bushing/brake wear, engine parts, insecticides
Cadmium	Tire wear, insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	fuels, oils, metal plating, bushing wear, brake lining wear, asphalt
Manganese	Moving engine parts
Bromide	Exhaust
Cyanide	Anticake compound used to keep deicing salt granular
Sodium, Calcium	Deicing salts, grease
Chloride	Deicing salts
Petroleum	Spills, lubricants, antifreeze and hydraulic fluids, asphalt
P-chlorinated biphenyl	Pesticides, atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria	Soil, litter, bird droppings, livestock and stockyard waste
Rubber	Tire wear
Asbestos	Clutch and brake lining wear

The concentration of pollutants in highway stormwater runoff is affected by factors such as: precipitation intensity, duration, and volume; temperature; surface wind speed and direction; highway configuration, design, geometrics, and drainage features; pavement composition, condition, and quantity; traffic characteristics (Average Daily Traffic - ADT); vehicular transported, generated, and deposited inputs; maintenance practices; and surrounding land use (urban vs rural). ADT was identified as one variable having a significant impact on pollutant concentrations.

Some overall conclusions reached by FHWA on highway stormwater runoff and its effects on receiving waters were:

- Highway stormwater runoff for highways with ADT < 30,000, with no curb and gutter design, exerts minimal to no impact on the aquatic components of most receiving waters.

- Annual pollutant loads from highways are low relative to loads from entire watersheds.

- Of five species (mayfly, isopod, water flea, gammarid, fathead minnow) used in acute laboratory bioassays, only the gammarid exhibited a toxic response to undiluted highway runoff.

CDOT Monitoring

Location

Initially, CDOT considered using the same site that had been used by FHWA, which was located on interstate I-25, extending from just south of fully directional interchange with interstate I-70 to Fox street. This site had an ADT of 149,000 with a drainage area of 14.29 Ha. The monitoring period was between August 1976 and July 1977 during which data from 16 events was collected. Using this site was, however, not possible due to the I-25 re-construction work currently in progress where the site used to be.

CDOT therefore evaluated several other alternatives, and selected a new site for the monitoring. The site was located on Interstate 225 (I-225) at milepost 2.25. ADT for I-225 is 95,000. Drainage area for this outfall was 7.59 Ha of CDOT's right-of-way (ROW), starting at milepost 2.35 just east of Cherry Creek and ending at milepost 3.07 further east. The drainage area includes paved surfaces (six highway lanes plus shoulder) as well as vegetated surfaces (median and areas between the edge-of-oil and the ROW fence). Stormwater runoff from this area discharges into Cherry Creek through a 60.96 cm outfall.

The following criteria were used to select the monitoring site:

- Location: The site should be located within the cities of Denver, Lakewood, or Aurora.

- Type of runoff: The drainage area had to be exclusively CDOT's ROW with a minimum or no outside contributions. Also, the conveyance for the highway runoff should not have any connections with conveyances draining water from areas outside CDOT's ROW.

- Safety: The site had to have an area to install the monitoring equipment in such a way that no safety hazards were created for the traveling public, nor for personnel operating and servicing the monitoring equipment.

- Accessibility: The area should have easy access to facilitate sample collection.

- Drainage area: The drainage area for the site had to be 4.05 Ha or more.

Equipment

The following equipment was used for the monitoring:

- Automatic sampler with power supply
- Relay to drive autosampler
- Data logger with power supply
- Data storage module
- Pressure transducer
- Con-a-flow bubbler system
- Rain gauge

Description

Surface drainage for the monitored area is collected by inlets located in the median and the roadway ditch, and is conveyed through a storm drain. The storm drain runs in the median on a 3% slope.

Sampling occurred at the last inlet located in the median, just prior to the outfall to Cherry Creek. The inlet is located at milepost 2.25, 30.48 m upstream from the outfall. Because the outfall is actually located outside CDOT's ROW, it was not possible to perform the sampling at the outfall.

A shelter was constructed to house the monitoring equipment which was installed about 4.57 m from the sampling point.

To provide flow measuring ability, a 60.96 cm Palmer-Bowlus flume was constructed just upstream of the outlet of the storm drain into the inlet. Samples were collected just downstream of the flume.

A base flow existed in the storm drain, however its magnitude was so minimal (0.0001 m^3/s) that it was considered negligible. It was assumed that the source of this baseflow is groundwater seepage into the storm drain.

CDOT contracted with the U.S. Geological Survey (USGS), Water Resources Division, Colorado District Office to perform the monitoring. Most samples were analyzed by the USGS National Water Quality Laboratory in Denver; analysis of fecal coliform, fecal streptococcus, and specific conductance was performed by USGS field personnel; analysis for Biochemical Oxygen Demand (BOD) was contracted with the Metro Wastewater Reclamation District laboratory.

Procedure

According to the regulation, samples were to be collected from three storm events occurring at least one month apart and with a preceding 72 hour dry-period. However, due to Colorado's climatic conditions, CDOT used (with previous approval from the Colorado Department of Health) a variance in the sampling requirements according to the following criteria:

- A 7 day separation between storm events.
- A change in the 72 hour dry-period as follows:

Preceding Storm Depth	Dry Period
≤ 5.08 mm	24 hours
≤ 12.70 mm	48 hours
> 12.70 mm	72 hours

Collected samples were analyzed for the constituents listed in the NPDES stormwater regulation [40 CFR 122.26 (d)(2)(iii)(A)].

From the data collected at the I-225 monitoring site, estimates of annual pollutant loads and Event Mean Concentrations (EMCs) were calculated for the following constituents: total suspended solids, total dissolved solids, biochemical oxygen demand, chemical oxygen demand, total nitrogen, total Kjeldahl nitrogen, nitrate plus nitrite, total phosphorus, dissolved phosphorus, cadmium, copper, lead, and zinc.

Individual EMCs were combined and a runoff-volume-weighted average EMC was calculated for each constituent. The calculated EMCs represent Site-average EMCs for the I-225 monitoring site. These EMCs do, however, not account for runoff volumes lost due to storage, infiltration, or evaporation.

Since CDOT has only one land use (highway), in addition to the Site-average EMCs, the calculated EMCs represent the Land-Use average EMC.

Estimated pollutant loads from the state highway system were estimated for the cities of Denver, Lakewood, Aurora, and Colorado Springs. The pollutant loads were calculated as:

Drainage area × Rainfall × Runoff coefficient × EMC

Drainage areas for the state highway system within Denver, Lakewood, Aurora, and Colorado Springs were calculated based on CDOT's highway database. This database contains information on pavement widths and lengths.

Drainage areas were calculated as:

Pavement width × Pavement length

Information regarding median widths, or edge-of-oil-to-ROW-fence widths, is not available, and therefore was not included as part of the drainage area computations. Only pavement area was used for the calculations. However, the pavement is where most of the pollutants are expected from.

Using criteria established by Urban Drainage and Flood Control District for the Denver Metro area, and rainfall data submitted by the city of Colorado Springs, an annual runoff producing precipitation of 327.66 mm was selected for the four cities.

A runoff coefficient of 0.90, which is standard for paved highway surfaces, was selected.

Results

Table 3 includes CDOT's monitoring results for the I-225 site (only for those constituents that were detected). Table 4 includes calculated EMCs for both the FHWA I-25/I-70 site and the CDOT I-225 site. For comparison purposes, the EMCs for the I-25/I-70 site were also calculated as runoff-volume-weighted average EMCs using the same procedure as the one used to calculate the I-225 EMCs.

Table 3
I-225 Monitoring Data

CONSTITUENT	UNITS	STORM 1	STORM 2	STORM 3
Date		07/20/93	08/05/93	08/30/93
Rainfall	mm	10.41	10.16	3.81
Storm runoff	m^3	47.86	48.14	25.49
Storm duration	hours	2.58	0.92	0.58
Dry period	hours	144.00	120.00	48.00
Drainage area	Ha	7.59	7.59	7.59
Storm runoff	mm	0.63	0.64	0.34
Total Suspended Solids	mg/L	2910.00	628.00	114.00
Total Dissolved Solids	mg/L	158.00	170.00	119.00
Biochemical Oxygen Demand	mg/L	31.00	34.00	40.00
Chemical Oxygen Demand	mg/L	380.00	180.00	220.00
Total Nitrogen	mg/L	4.70	5.80	5.90
Total Kjeldahl Nitrogen	mg/L as N	3.10	4.10	4.30
Nitrate plus nitrite	mg/L as N	1.60	1.70	1.60
Phosphorus, total	mg/L as P	0.43	0.88	0.27
Cadmium, total recoverable	ug/L as Cd	3.00	1.00	N/A
Copper, total recoverable	ug/L as Cu	75.00	32.00	34.00
Lead, total recoverable	ug/L as Pb	260.00	53.00	24.00
Zinc, total recoverable	ug/L as Zn	690.00	290.00	400.00
Oil and grease	mg/L	9.00	2.00	11.00
Fecal coliforms	cols/100 ml	1680.00	1650.00	38000.00
Fecal streptococci	cols/100 ml	9200.00	10500.00	15000.00
pH	S.U.	8.10	7.90	7.70
Bis(2-ethylhexyl)phthalate	ug/L	N/A	9.00	25.00
Arsenic, total	ug/L as As	4.00	2.00	1.00
Chromium, total recoverable	ug/L as Cr	27.00	8.00	4.00
Mercury, total recoverable	ug/L as Hg	N/A	0.20	N/A
Nickel, total recoverable	ug/L as Ni	22.00	10.00	7.00
Phenols, total	ug/L	7.00	9.00	21.00
Sodium, dissolved	mg/L as Na	20.00	20.00	13.00
Potassium, dissolved	mg/L as K	3.60	7.20	2.20
Alkalinity	mg/L (CaCO3)	46.00	59.00	14.00
Sulfate, dissolved	mg/L as SO4	16.00	16.00	16.00
Chloride, dissolved	mg/L as Cl	14.00	21.00	14.00
Nitrite	mg/L as N	0.08	0.07	0.06
Ammonia	mg/L as N	1.90	1.40	3.40
Total organic carbon	mg/L as C	80.00	55.00	61.00
Specific conductance	us/cm	177.00	228.00	172.00
Magnesium, dissolved	mg/L as Mg	0.97	2.00	1.50
Calcium, dissolved	mg/L as Ca	9.50	16.00	11.00

Table 4
EMCs I-225 and I-25/I-70

CONSTITUENT	EMCs I-225	EMCs I-25/I-70
Total suspended solids (mg/L), TSS	1419.138	344.737
Total dissolved solids (mg/L), TDS	154.573	N/A
Biochemical oxygen demand (mg/L), BOD	34.077	33.293
Chemical oxygen demand (mg/L), COD	267.179	207.632
Total nitrogen (mg/L), TN	5.388	N/A
Total Kjeldahl nitrogen (mg/L), TKN	3.748	2.835
Nitrate plus nitrite (mg/L), NO2+NO3	1.640	N/A
Total phosphorus (mg/L), TP	0.575	0.649
Dissolved phosphorus (mg/L), DP	0.458	N/A
Cadmium, total recoverable (ug/L), Cd	1.578	17.137
Copper, total recoverable (ug/L), Cu	49.359	108.664
Lead, total recoverable (ug/L), Pb	128.462	579.323
Zinc, total recoverable (ug/L), Zn	470.653	477.256

Comparison

The I-225 data obtained by CDOT, and the I-25/I-70 data obtained by FHWA are graphically compared in Figure 1.

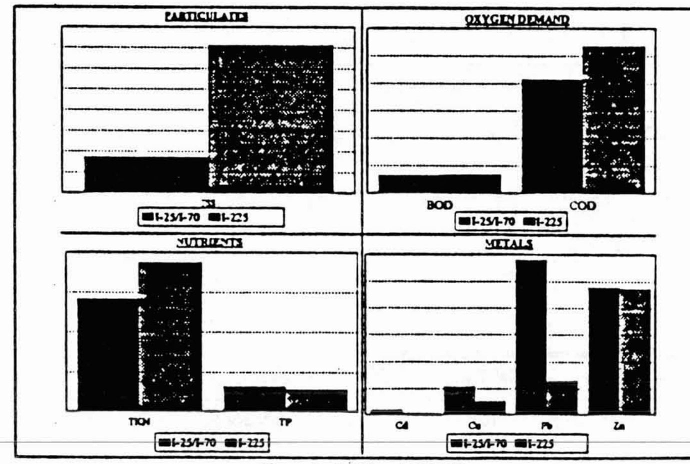


Figure 1: I-225 vs I-25/I-70

By comparing CDOT's data vs FHWA's data it can be concluded that:

- No major differences are observed in oxygen demand or nutrients.
- The most noticeable differences are in Total suspended solids (TSS) and in Lead (Pb).

  The difference in TSS is mostly due to a very high EMC recorded for storm #1 at the I-225 site (2910 mg/L). Values for storm #2 and #3 are much lower (628 mg/L and 114 mg/L) which are more in line with the values recorded at the I-25/I-70 site. The high TSS value recorded at storm #1 could be due to a special condition that day which caused an increase in sediment loads, or it could be also due to a human or mechanical error during the sampling. However, no sufficient data exists which could justify the discarding of this value.

  The difference in Pb is most probably due to the change in gasoline from leaded to unleaded.

- In general, a reduction in metals is observed which could be due to: improvements in refining processes producing cleaner motor oils and greases; reduction in insecticide applications due to environmental concerns: elimination of leaded gasoline; and improvements in tire manufacturing processes.

Future CDOT Monitoring

From a regulatory perspective, CDOT does not expect at this time to engage in additional stormwater monitoring efforts for several reasons:

1. Existing data. Much data already exists that characterizes highway stormwater runoff. Additional data will not show different results than those already obtained.

2. Cost/benefit ratio. Benefits of new data will be very low when compared with the high cost of monitoring.

3. Current monitoring efforts by other DOTs. Other transportation departments (i.e. Texas, Washington, Oregon) across the country are still involved in highway runoff monitoring efforts . In the future, CDOT expects to compile this data and compare it versus CDOT's and FHWA's data. After evaluating this data, CDOT will be in a better position to assess any further monitoring needs.

From a research perspective, CDOT expects to engage in monitoring efforts

with specific goals:

1. Goal 1: Monitor three (out of 13) permanent sediment ponds that were constructed as part of CDOT's Straight Creek Water Quality and Erosion Control project. The intent is to assess the efficiency of those ponds in removing sediments in highway and snow-melt runoff, which are caused by sanding from CDOT's winter operations, and by erosion in cut slopes.

2. Goal 2: Monitor highway snow-melt runoff during winter in several locations where various de-icers will have been applied. The intent is to assess impacts to receiving waters from these various de-icers.

Conclusion

CDOT performed monitoring as required by the NPDES stormwater regulation. EMCs and pollutant loads of highway stormwater runoff discharges were estimated.

Data collected during monitoring at I-225 adds more data to that available from FHWA. However, this new data may not be very representative due to the small number of events sampled. According to FHWA: "because of the inherent variability in EMCs, a limited sampling effort consisting of only a few storm events may produce a poor estimate of site characteristics[4]."

Monitoring requirements such as the ones included in the NPDES regulation result in high costs with little benefits due to: the lack of defined and specific goals and guidelines; the existing data; and the high cost of monitoring equipment and sample analyses. It is expected and hoped that in the future, regulatory agencies will assess the above prior to require the regulated community to engage in costly monitoring efforts which will produce little benefits towards the improvement of stormwater quality.

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Methods for Assessing Urban Storm Water Pollution

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Abstract

This paper presents methods for quantifying urban development conditions and characterizing the impact of urbanization on storm water pollution. Based on data collected by the City of Austin (COA), it was found that storm water pollutant mean concentrations can be correlated with development indices and watershed sizes. Use of the arithmetic mean of event mean concentrations (EMCs) to characterize storm water pollution may lead to biased results if the EMC data set are not large enough or not carefully reviewed.

Introduction

The City of Austin (COA) has had several storm water monitoring programs since 1975. The objectives of the programs are to evaluate the impacts of urban development on storm water pollution and to identify Best Management Practices (BMPs) for mitigating these impacts. Based partially on the findings (COA, 1984) of the monitoring programs, the City has implemented a series of watershed ordinances (COA, 1986-92) and protection programs.

Funded by the City's Drainage Utility (COA, 1992), the COA currently has two storm water monitoring programs (COA, 1993). One program is establishing a network of forty-five (45) runoff monitoring stations to test land use and structural BMPs. The other program monitors in-stream storm water quality at eleven (11) creek locations through a COA/USGS (U.S. Geological Survey) cooperative project. Table 1 shows a compilation of the monitoring stations and the corresponding monitoring and watershed information used in this study. This study proposes methods to characterize urban storm water pollution using concentration data and information generated from previous COA studies.

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TABLE 1

DESCRIPTION OF MONITORING STATIONS

Watershed Description	NO. of Stations Monitored	Drainage Area (acres)	Impervious Cover (%)	NO. of Storms Adequately Sampled
Size :				
Large Watershed	12	1.416 - 79.360	3 - 47	7 - 25
Small Watershed	17	1 - 371	3 - 97	7 - 29
Land Use :				
Undeveloped	6	3 - 79.360	3 - 5	7 - 20
SF Residential	6	26 - 371	21 - 39	7 - 29
MF Residential / Office	4	1 - 3	50 - 88	9 - 25
Commercial / Industrial	5	3 - 197	65 - 97	8 - 23
Transportation	1	10	81	22
Mixed	7	1.416 - 32.832	12 - 47	12 - 25
Watershed Type :				
Urban	8	3 - 7.872	43 - 97	9 - 25
Suburban	15	1 - 32.832	12 - 39	7 - 29
Rural	6	301 - 79.360	3 - 5	7 - 20

TABLE 2

STATISTICS FOR THE REGRESSION* OF INSTANTANEOUS CONCENTRATIONS ON STORMWATER RUNOFF FLOW RATES

Watershed	Drainage Area (acres)	Imp. Cover (%)	Pollutant Parameters TSS R-square**	TOC R-square	TKN R-square	TP R-square
Walnut Ck @ Webberville Rd.	14.272	25	0.43	0.42	0.08	0.20
Shoal Creek @ 12 St.	7.808	47	0.67	0.33	0.23	0.35
Waller Creek @ 38 St.	1.416	43	0.63	0.18	0.34	0.53
Hart Lane @ NW Austin	371	39	0.30	0.01	0.02	0.09
Lost Creek @ SW Austin	160	27	0.30	0.02	0.04	0.29
Barton Ck. Square Mall	47	86	0.21	0.007	0.001	0.02
Lavaca St.	14	97	0.35	0.0007	0.06	0.23

* A normal error regression represents $C = a_1 Q^{a_2}$, where C is instantaneous concentration, Q is the corresponding flow rate, and a_1 and a_2 are regression coefficients.

** R-square is the coefficient of determination. Bold R-square values indicate a significant regression.

Previous Studies

Previous COA studies (COA, 1990) on storm water pollution indicated that for most of the runoff pollutant parameters, there is no significant difference in the average event mean concentrations between all residential and adequately-maintained commercial sites. However, some differences exist between undeveloped, residential, and less-maintained commercial sites. The average EMCs for large, mixed land-use, creek basins are generally greater than those of small, single land-use watersheds. Most of the City's creeks are affected primarily by storm water pollution because there are few significant point sources. In order to compute runoff pollutant loads, a relationship between basin runoff coefficient (Rv, the ratio of the average annual runoff to average annual rainfall depth) and percent impervious cover was developed. This relationship can be described by a quadratic polynomial equation (COA, 1992). The equation was substantiated by additional data from this study. In general, a linear approximation to the runoff coefficient versus imperviousness relationship tends to overestimate Rv values, especially for low impervious cover sites. For any low to medium impervious cover site, the single event runoff coefficient generally increases with increasing amount of rainfall. The average Rv for this site should not be calculated as the arithmetic mean of all Rv values unless there is a sufficient number (to be described later) of these values. Gilbert (Gilbert, 1987) suggested that the arithmetic mean may be a biased estimation of the population mean if the coefficient of variation of the data is greater than 1.2.

Definitions of Variables

Mean concentration (MC): MC is either the arithmetic mean of event mean concentrations or the flow weighted mean of instantaneous concentrations for a pollutant parameter for any specific watershed. Flow weighted mean is the flow-volume weighted average of concentrations corresponding to various classes of runoff flow rates.

Percent impervious cover (IC): IC is the ratio of gross impervious area in a watershed to the drainage area of the watershed, expressed in percentage of the drainage area.

Undeveloped site (UNDS): UNDS is a basin or watershed in which little area has been disturbed by human's activity. The ground of the basin is mostly covered by natural vegetation.

Development index (DI): DI is a quantity that represents one or any combination of three variables, including percent impervious cover, land use index, and watershed type index. Land use is classified into five types: undeveloped; single family residential (SF); office or multi-family residential (MF); commercial and

industrial (Com/Ind); and roadway. Watershed-type means the degree of cleanliness which is determined mainly by the age of roads and structures, and the practice of housekeeping work in the area. In addition, it may also be identified by the watershed's relative location in the metropolitan area. For the Austin area, the watershed-types are urban, suburban, or rural watershed which correspond to the definitions used in the Austin's Comprehensive Watershed Ordinance (COA, 1986).

Mean Concentrations for a Specific Site

The use of the average of event mean concentrations (EMCs) for characterizing storm water pollution for a specific site may lead to biased results if the EMC data are not carefully reviewed and treated. Primarily, it is important to determine whether or not the EMC values represent the average concentrations of the corresponding storm runoff. The majority of the runoff volume (e.g., 80% or more) from a rainfall event should be sampled in order to provide sufficient data for the estimation of an EMC. For any monitored rainfall event, the number of samples should range from three (3) to as many as sixteen (16) depending on the complexity of the hydrograph. An EMC value should not be used if the sampling does not cover the full range of the hydrograph. Secondly, the flow measurement system should be designed carefully and the quality of the data thoroughly reviewed. The measurement of flow in a storm drain system is fairly difficult in considering the changing flow conditions during a storm. Inaccurate discharge values can result in erroneous flow volume calculations, which will impact the EMC estimation for the storm. Finally, the flow-weighted mean concentration (FWMC) can be computed as a verification. The FWMC should be approximately the average of EMCs if there is sufficient flow and instantaneous concentration data. In order to calculate the FWMC, the flow rate of runoff should be divided into several classes. Corresponding to each flow rate class, there is a concentration value and a measurement of percent volume of the average annual flow. The FWMC is the sum of the products of concentration values and the percent volumes of annual flow.

If the average of the EMCs is used to represent watershed mean concentrations, the number of the sampled events should be sufficient to cover the entire range of rainfall classifications. As shown in Figure 1, EMC values decrease with an increase in storm runoff volume. This relationship is not clearly shown unless the number of sampled events are sufficient and the corresponding EMC values are grouped. Also, the EMC values may be dependent on build-up conditions at the onset of rainfall events. Based on the SWMM Manual (U. of Florida, 1988), a COA study (COA, 1994) derived the relationship between load and the number of dry days for specific land uses. As shown in Figure 2, the total suspended solids (TSS) load accumulated at a roadway site is significantly related to the number of dry days before a storm, although there is considerable scatter in the data.

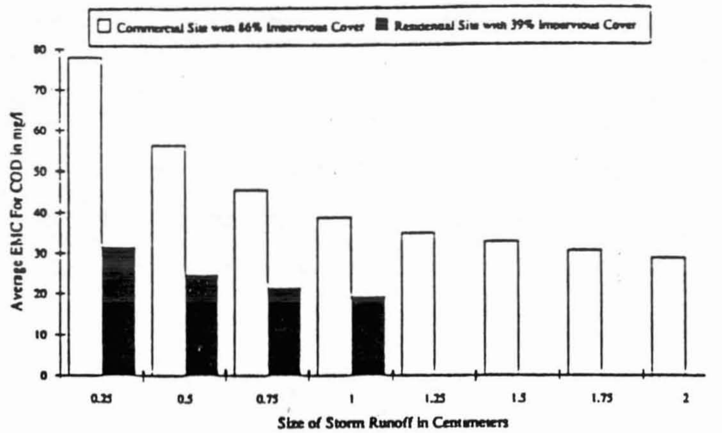

FIGURE 1. RELATIONSHIP BETWEEN AVERAGE EMC AND SIZE OF STORM RUNOFF

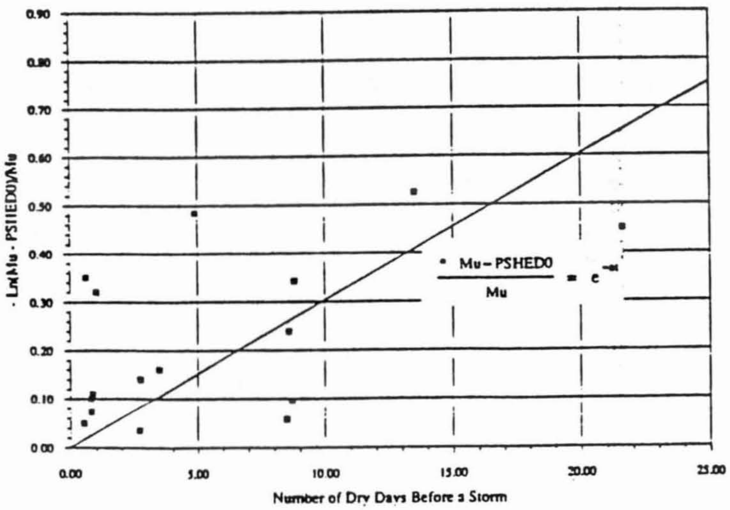

FIGURE 2. AN EXPONENTIAL TYPE BUILD - UP EQUATION DERIVED FOR A ROADWAY LAND USE SITE - FOR TSS

* An exponential type build-up equation (as shown in SWMM manual) was assumed, where Mu is the upper limit of load which can be accumulated on the ground, t is the number of dry days before a storm, PSHED0 is the load on the ground before a storm corresponding to t, and a is regression coefficient.

The EMC values can also vary with the runoff flow rates during rainfall events since the instantaneous concentration for some parameters is related to the flow rate (Table 2). The relationship tends to increase with the increasing of drainage area, and is probably the result of increases in peak flow in relation to both drainage area and growing urbanization. The increases in peak flow typically results in increased channel and bank erosions (COA/ECSD, 1992; Schueler, 1987). If the relationship between instantaneous concentration and flow rate is significant, the mean concentrations of a site should be represented by the flow-weighted mean concentrations. The average EMCs can represent the site mean concentrations only if the EMCs were computed from a sufficient number of storms which cover the full range of the flow rates.

For the Austin area, a storm water monitoring period should generally run between two (2) to four (4) years in order to adequately represent the entire range of classifications of rainfall events. Typically this would provide about twenty to thirty (20-30) EMCs. To ensure accurate representation of the different classifications of storm event, the number of dry days before a storm should be divided into a minimum of two (2) groups and the size of storm divided into a minimum of three groups; therefore the number of combinations of these two factors is six (2 x 3). Considering a minimum of three replicates is needed for each class of events, the number of adequately-sampled events should be at least eighteen (18). For the rainfall conditions of the Austin area, this will require a minimum of two (2) years of monitoring to satisfy. Because of the difficulty of maintaining and operating a large number of monitoring stations and the potential for drought conditions to occur during the sampling period, this minimum time requirement of two years is typically not sufficient. Therefore it is prudent to plan for storm water monitoring over at least a three (3) year period.

<u>Derivation of Development Index</u>

The development index (DI) represents watershed development conditions which can be quantified using one or any combination of three variables: percent impervious cover, land-use index (LI), and watershed-type index (WTI). In this study, DI is assumed to be a linear combination of LI and WTI. The following is an example of computation for obtaining DI:

Step one: Develop a matrix of mean concentration (MI) values for the relationship of land-use types versus pollutant parameters. Given five (5) pollutant parameters, the matrix is as follows:

Land-use	TSS	TOC	NO3	TKN	TP
Undeveloped	77	7	0.13	0.32	0.04
SF Residential	151	12	0.70	1.60	0.28
MF Res./Office	97	14	0.63	1.76	0.38
Com./Ind.	216	14	0.61	2.24	0.46
Roadway	320	25	0.40	1.20	0.22

Step two: Standardize all mean concentration values to a dimensionless variable which has a randomly-assigned arithmetic mean and standard deviation (in this example, M = 3, and S = 1.581 for a series of numbers 1, 2, 3, 4, and 5). Using SAS STANDARD procedure (SAS Institute, 1987), the standardized mean concentration is

$$\text{Stan MC} = [(MC - \overline{MC}) / \sigma_{MC}][S] + M \qquad [1]$$

where $\overline{MC}$ is the arithmetic mean of MC values for the five land use types for each of the five pollutant parameters, and σ_{MC} is the standard deviation of these five MC values. Corresponding to the MC matrix above, the standardized MC matrix is:

Land-use	TSS	TOC	NO3	TKN	TP	Avg.
Undeveloped	1.47	1.23	0.52	0.58	0.68	0.90
SF Residential	2.67	2.42	4.38	3.39	3.06	3.18
MF Res./Office	1.80	2.85	3.95	3.74	3.99	3.27
Com./Ind.	3.70	2.94	3.79	4.79	4.82	4.00
Roadway	5.37	5.55	2.36	2.51	2.44	3.65

The values in the matrix above are the land-use indices for each pollutant parameter. The values in the column labeled "Avg." are the overall land-use indices for each of the land-use types.

Step three: The watershed-type index (WTI) can be derived in the same manner as steps 1-2. In this case the matrix of MC values consists of watershed types (rural, suburban, and Urban) and pollutant parameters.

Step four: Assuming the development index is a linear combination of LI and WTI in the following form:

$$DI = (LI + WTI)/2, \qquad [2]$$

then the development index of a watershed can be computed for each of the pollutant parameters in the matrix.

Assessing Storm Water Pollution

The values of mean concentrations and development indices for several pollutant parameters and for all twenty-nine monitoring sites were computed. The pollutant parameters evaluated using local data are total suspended solids (TSS), chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD5), total organic carbon (TOC), total phosphorus (TP), total nitrogen (TN), nitrite plus nitrate (NO2+NO3), total kjeldahl nitrogen (TKN), ammonia (NH3), total lead (TPb), fecal coliform (Fe. Col.), and fecal streptococci (Fe. Stp.). These are standard parameters considered in assessing non-point source pollution from storm water (EPA, 1983; Shueler, 1987).

Mean concentrations for some parameters such as TP, TKN, TN, COD, and TPb can correlate well with the development indices. As shown in Figure 3, the TP mean concentration for any specific watershed in the area can be reasonably estimated from the development condition of the watershed, i.e., the land-use index and the watershed-type index of TP. Additionally, the percent watershed imperviousness is also an adequate index for estimating mean concentrations for the above mentioned pollutant parameters. On the other hand, regressions of mean concentrations on development indices for other parameters are less significant. As shown in Figure 4, the mean concentration values of nitrite plus nitrate corresponding to the higher values of the development indices vary independently from the development index. There are no significant differences in concentrations among watersheds of all the development conditions except for the undeveloped sites. To further review the data, the NO2+NO3 concentrations are generally higher for the SF residential land-use sites, probably because of fertilizer applications.

For the TSS-related parameters such as TSS, TP, TKN, and TOC, the mean concentrations are significantly related to the drainage area of the watershed, as described earlier in this paper. As shown in Figure 3, the relationships between TP concentrations and development indices are represented by two separate regression lines (for watershed size $\leq$ 1000 acres and > 1000 acres).

Conclusions

Based on the findings, the following conclusions can be drawn:

1. This study used data collected from the City of Austin's storm water monitoring programs. Although the data is preliminary, its quantity and quality are

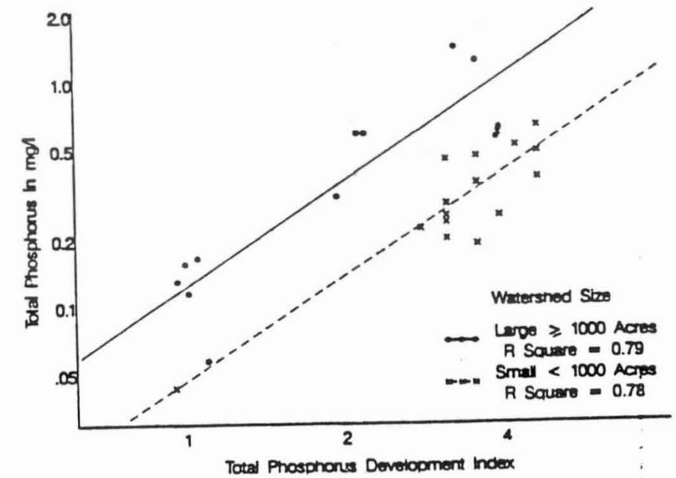

FIGURE 3. MEAN CONCENTRATION OF TOTAL PHOSPHORUS VERSUS DEVELOPMENT INDEX FOR AUSTIN WATERSHEDS

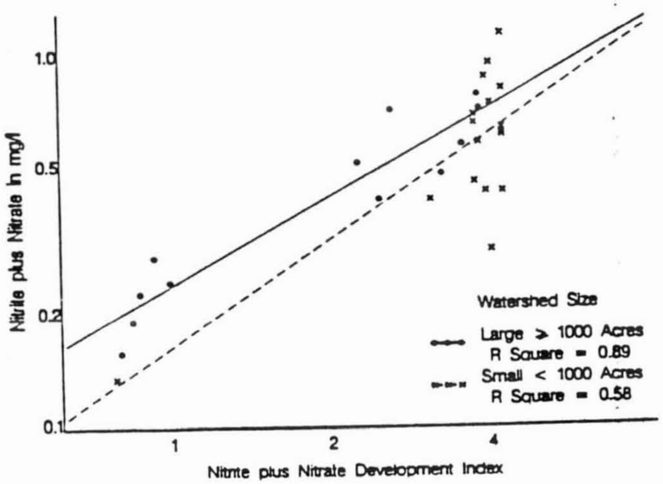

FIGURE 4. MEAN CONCENTRATION OF NITRITE PLUS NITRATE VERSUS DEVELOPMENT INDEX FOR AUSTIN WATERSHEDS

sufficient for the development of a simplified method to characterize urban storm water pollution.

2. The impacts of urban development on storm water quality can be identified by the relationships of watershed mean concentrations versus development indices. A development index may be a linear combination of land-use and watershed-type indices which characterize basin development conditions. This index correlates well with the percent impervious cover. For some parameters such as TSS, TP, TKN, and TOC, the described relationships also depend on the sizes of watersheds or drainage areas.

3. The use of average EMCs to represent watershed mean concentrations is adequate only if the sizes and antecedent conditions of the sampled events can adequately represent the entire ranges of the rainfall event classifications. It is recommended that the EMC data presented by different organizations should not be combined for analysis unless the methods and procedures for obtaining such data are carefully reviewed.

4. The use of arithmetic means to characterize average conditions of EMCs and runoff coefficients may be biased if the size of data sets is insufficient or the coefficients of variations are large (greater than 1.2). This is particularly true in computing the average runoff coefficient for a watershed since the runoff coefficient generally increases with increasing depth of storm rainfall. It is recommended that using medians, adjusted geometric means (Gilbert, 1987), or the rainfall or flow-weighted means will best represent the average conditions of these two variables.

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"Low Cost Automatic Stormwater Sampler"

Lynn A. Dudley[1]

Abstract

The Vortox Co. of Claremont, CA., has developed and applied for patents on a method of sampling stormwater sheetflow, outfalls (from end of the pipe) and "in-the-pipe" during partial or full flow. This unique method is automatic, 100% mechanical and inexpensive when compared to other automatic samplers. The Vortox sampler is finding widespread acceptance among state regulators, environmental consultants, industrial sites, municipalities, as well as military bases.

Introduction

Who is Vortox? How did we become involved in the design and manufacture of a stormwater sampler?

The Vortox Company has been in the business of manufacturing air cleaners for internal combustion engines for 76 years. We held one of the first patents for the oil bath air cleaner. Vortox supplies to OEM's such as Chrysler, Peterbilt, Kenworth as well as some aftermarket applications in alternate fuel conversions. We also lend our expertise in design and sheet metal fabrication to the jobshop market.

Our involvement in stormwater sampling was the result of studying the CWA regulations as it pertained to our industrial site. This led us into an investigation into the accepted methods of sampling stormwater and a

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determination that no one method of sampling was convenient, simple, safe, obtained a quality sample and was cost effective. At the Vortox plant site we have three (3) points which must be sampled. After determining that we could not sample manually we obtained quotes on electronic samplers which would cost several thousand dollars for three (3) machines. At this point, Vortox was determined to develop a simple sampling concept and gain acceptance from the Los Angeles Regional Board for its use at Vortox. We built a prototype and submitted it to the board with a request to use the method for collecting stormwater samples at the Vortox plant. The regulators at the Los Angeles region not only gave us approval but thought enough of the method to ask us to show the prototype to the other Regional Boards throughout the state. All the Regional Boards in California stated they would accept this method of sampling, including the man credited with writing most of California's stormwater regulations, Tom Mumley from the San Francisco Bay Region. Vortox made the decision to patent the concept and enter into manufacturing and marketing the sampler. We traveled to adjoining states asking regulators, chemists and consultants to critique the approach we had taken.The feedback was always positive and in addition to California's acceptance, we obtained acceptance from Utah, Colorado, Oregon, Wisconsin, Washington and South Carolina. After 2½ years of production, we have over 350 samplers operating in the field which includes military bases (Navy and Air Force), airports (Santa Barbara & Los Angeles County, CA), municipalities (City of San Diego, CA, City of San Francisco, CA, Counties of Orange and San Bernardino CA). The U.S.G.S. has officially recommended the Vortox sampler be used in some of their stormwater responsibilities for the military. Industrial site applications range from the very largest corporations (CocaCola) to the small businessman.

We demonstrated the sampler for Bill Swietlik, Rod Fredrick, Kim Hankins and Nancy Cunningham of U.S.E.P.A. in Washington, DC, with very positive feedback and a request to have an independent laboratory run a test comparing the results of an electronic automatic sampler setting next to a Vortox automatic sampler in a spiked stream of water collecting samples at different flow rates. The results from the two samplers were virtually the same. Copies of the laboratory report is available upon request.

Figure 1, will identify the key components of the samplers as all the samplers work on one basic principle.

How does the Vortox sampler work? The primary design of this product is to capture grab samples and/or composite (continuous collection) samples. The type 316 & type 304 stainless steel sampler is manufactured in three (3) configurations: Figure 1, The 3 liter (.8 gallon) sampler for surface flow. Figure 2, The 21 liter (5.5 gallon) sampler for surface flow. Figure 3, The 3 liter (.8 gallon) "In-The-Pipe" sampler for end of pipe or underground stormwater systems. The 3 liter (.8 gallon) is sufficient for the standard tests for Ph, TSS, TOC, metals and specific conductivity. The 5.5 gallon sampler is used for applications requiring larger sample volumes (i.e. bio-assay tests) such as stream beds.We have had requests for a more inert surface than stainless steel. To meet this request, we developed an FDA approved Teflon coating which is applied, as an option, to most of the internal parts of the sampler.

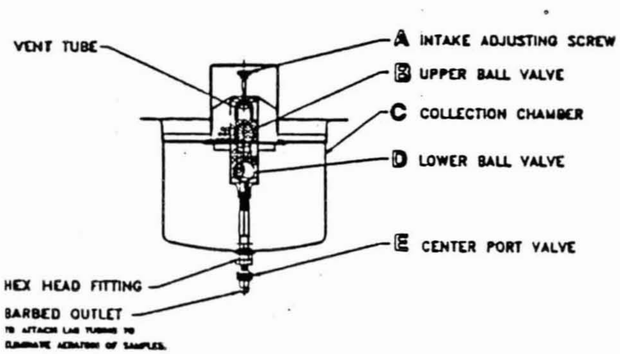

FIGURE 1
3 LITER (.8 GALLON) STORM WATER SAMPLER

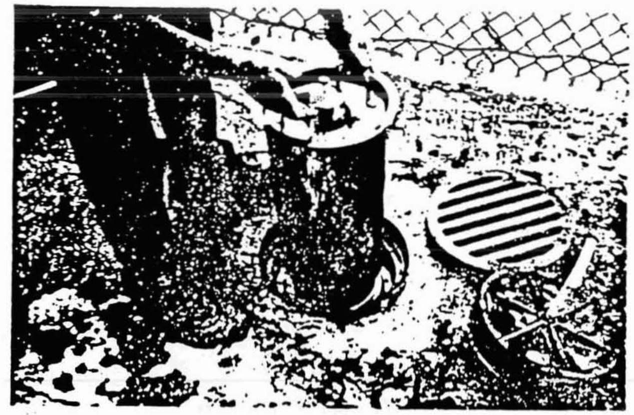

FIGURE 2
21 LITER (5.5 GALLON) SAMPLER PLACED INTO SUMP HOUSING

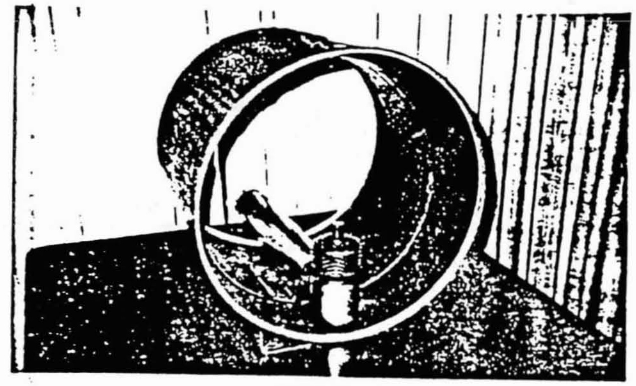

FIGURE 3
"IN-THE-PIPE" 3 LITER (.8 GALLON) SAMPLER
IN 610MM (29 INCH) PIPE

The three (3) configurations are available with a dam around the orifice (Fig. 4) to allow heavy particles in the effluent to settle out in the sediment pan before entering the sampler or without the dam (Fig. 5) so the fluid flows immediately into the sampler.

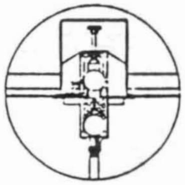

FIGURE 4

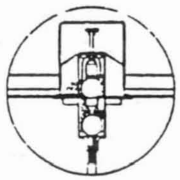

FIGURE 5

Each design has an intake adjusting screw at the top of the ball valve for controlling the rate at which the liquid enters the sampler. As the adjusting screw is turned downward, the ball is restricted in its vertical lift and throttles the orifice opening. When the adjusting screw is adjusted down against the ball, the valve is closed and this is the reference point for all adjustments. When the intake adjusting screw is opened one-half (1/2) turn from the fully closed position it will take <u>clean water</u> approximately 20 minutes to fill the 3 liter (.8 gallon) sampler and shut off the internal ball valve. When the intake adjusting screw is fully open, the 3 liter (.8 gallon) sampler will fill in approximately two (2) minutes. The 21 liter (5.5 gallon) sampler will fill in approximately 10 minutes when the adjusting screw is fully open and well over three and one-half hours (3½ hrs) when throttled down. The adjusting screw is a precision machined screw with slight resistance so as not to slip from its selected position. Because the effluent is site specific, some experimenting might be required to obtain the desired setting.

With the centerport valve closed, top orifice closed by the ball and vent tube open, the sampler is ready to collect samples. The upper ball valve will stay closed (B, Fig.1) keeping contaminants out of the sampler until liquid causes the ball to lift and expose the orifice. This allows liquid to enter the collection chamber (D, Fig.1). As the chamber fills the lower ball valve (C, Fig.1) rises, air is forced from the head space above the liquid and the orifice is closed by the lower ball, preserving the sample. If flow stops and only a partial sample is collected, the upper ball returns to the closed position, preserving the sample.

<u>Transferring the sample</u>

To transfer the sample to laboratory bottles (Fig. 6,7,8) simply attach a flexible tube to the barbed outlet at the end of the center port valve, (E Fig.1) place the opposite end of the tube in the bottom of your laboratory

sample bottle and open the valve. The sample will be transferred with very little exposure to the air. Occasionally shake the sampler to keep the heavy particles in suspension and insure equitable transfer of all particulate material.

FIGURE 6

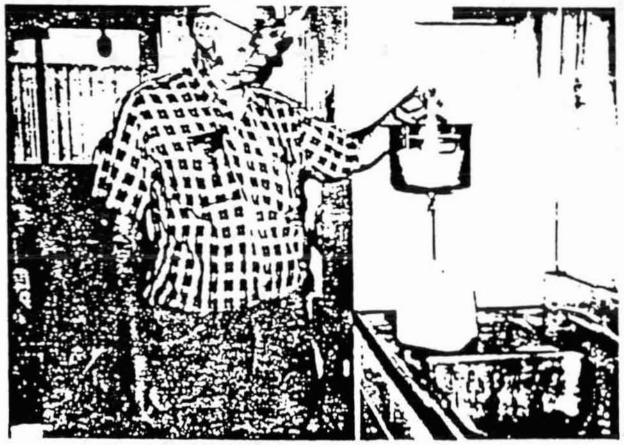

FIGURE 7

FIGURE 8

Cleaning the sampler

After transferring the sample, the sampler can be disassembled for clean up by turning the hex head of the centerport valve (Fig. 1) clockwise. This disengages the centerport valve from the double ball valve head and separates the sampler into three (3) components; valve, collection chamber and the double ball valve head. These parts can be placed in a container of hot water and non phosphate detergent and scrubbed with a brush to remove any heavy soils. Rinse with deionized water, dry and reassemble. Before placing the sampler into service, blow air through the vent tube to ensure free passage of air, check that the centerport valve is closed and the intake adjusting screw is positioned in the desired position.

Applications

The 3 liter (.8 gallon) sampler can be suspended by stainless steel cable beneath existing grates with a drop box depth of approximately 406 mm (16 in). The cable is laced through the openings in the grate and attached to the eyebolts on the sampler. (The cable and eyebolts are available as an option). As the grate is lowered into place (Fig. 9) the sampler is located at the low point on the grate, when in place. The sample is collected as sheet flow moves across and through the grate into the top of the sampler. Note: The 21 liter (5.5 gal) sampler cannot be suspended due to the weight when full.

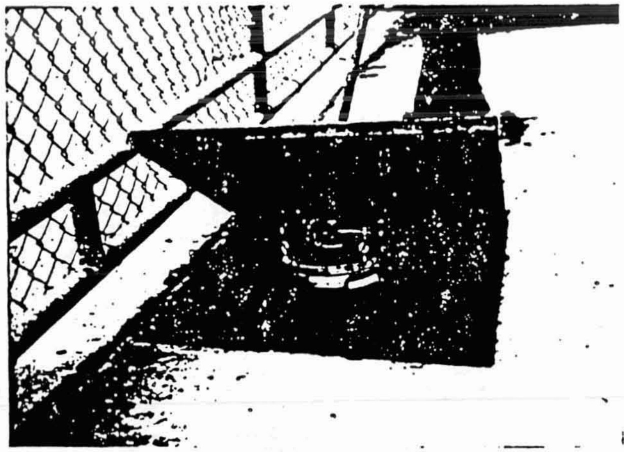

FIGURE 9
SUSPENDED 3 LITER (.8 GALLON) SAMPLER
IN EXISTING DROP BOX WITH GRATE

In situations where there are no existing drop boxes (Fig. 10), we have a kit approach in both the 3 liter (.8 gallon) and 21 liter (5.5 gallon) sampler (Fig. 11) which includes the sampler, sump housing and a traffic rated grate for below grade installation. You simply dig or bore a hole in the ground (508 mm)(20 inches) in diameter and 610 mm (24 inch) deep for the 3 liter (.8 gallon) sampler or 559 mm (22 inch) in diameter and 838 mm (33 inch) deep for the 21 liter (5.5 gallon) sampler to accommodate the sump. The sump is placed in the hole and the grate rests on the top flange of the sump. The top surface of the grate should be at grade level or slightly below. The sump and grate can be a permanent installation by pouring concrete around them or they can be portable, as in stream beds (Fig. 12) by using soil or gravel around the sump. Field experience has shown these installations take a little over one hour.

Once the sump housing and grate rim are in place, the sampler drops inside the sump (Fig. 10) and locks in place by aligning two (2) keyhole slots in the flange of the sampler with welded studs located on the horizonal surface of the sump collar. A slight turn of the sampler will engage the stud and lock the sampler in place. Replace the grate plate in the rim, secure with two (2) Allen screws and you are ready to collect your sample.

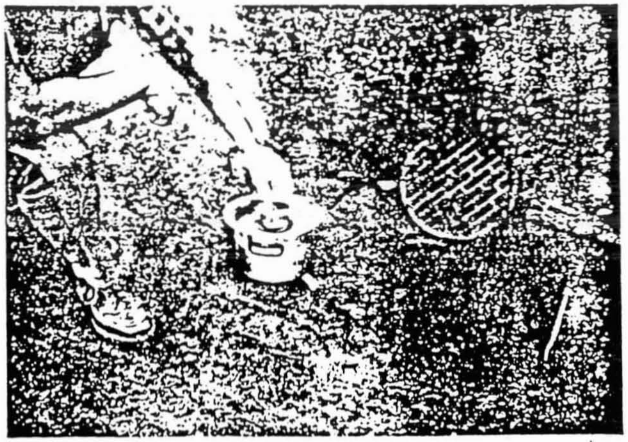

FIGURE 10
3 LITER (.8 GALLON) SAMPLER WITH SUMP AND GRATE

FIGURE 11
21 LITER (5.5 GALLON) SAMPLER
WITH SUMP (IN THE GROUND) AND GRATE

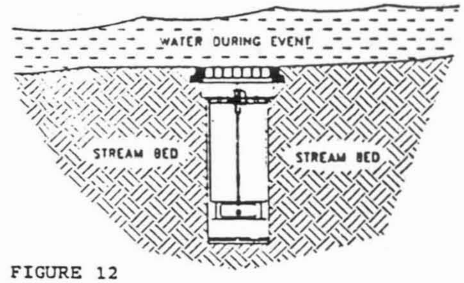

FIGURE 12

The "in-the-pipe" sampler was developed out of requests from California municipalities to be able to bypass a small base flow and catch samples at high or full flow. We were asked to accommodate pipe sizes from 305 mm (12 inches) diameter to 914 mm (36 inches) diameter. The concept we developed uses the same double ball valve, intake adjusting screw and outlet valve (Fig. 8) packaged in a 76 mm (3 inch) diameter stainless steel pipe. The device for anchoring the sampler (in-the-pipe) is an expanding stainless steel band which is locked into place by an inflatable bladder or a mechanical turnbuckle. The expanding band can remain in-the-pipe and the sampler simply disengages by sliding out the open end of the pipe.

FIGURE 13
3 LITER (.8 GALLON) "IN-THE-PIPE SAMPLER

What we have presented is a brief description of a family of liquid samplers which offers a variety of methodology for sampling. The equipment is simple, durable, 100% mechanical and user friendly at an affordable cost.

HIGH-ACCURACY CSO AND STORMWATER FLOW MONITORING

Terrance L. Burch[1] and Joanna M. Phillips[1]

Abstract

Growing concern over Combined Sewer Overflow (CSO) discharges has led to the U.S. Environmental Protection Agency's new CSO Overflow Control Policy for incorporation into the National Pollutant Discharge Elimination System (NPDES) permit process. The policy creates a new emphasis on comprehensive CSO system discharge monitoring and documentation programs. Acoustic transit-time flowmeters can be used to meet these monitoring and documentation requirements by providing high-accuracy and continuous flow data during dry- and wet-weather conditions in conduits that flow partially full and/or surcharged. Transit-time flowmeters provide bi-directional flow measurement capability and can be configured for multiple acoustic paths, making them highly accurate over a wide range of changing water level and flow conditions, as well as in locations where other flow measurement methods cannot be used reliably. This paper provides an introduction to the acoustic transit-time technique and its applicability to a wide range of difficult measurement sites and includes descriptions of existing CSO flow monitoring installations.

Introduction

The U.S. Environmental Protection Agency (EPA) is adopting a new Combined Sewer Overflow (CSO) Control Policy for incorporation into the National Pollutant Discharge Elimination System (NPDES) and Municipal Discharge permitting processes. This action is being taken in response to growing public concerns and Clean Water Act requirements for attaining minimum water quality standards in the receiving waters affected by CSO discharges. In many cases, the new CSO Policy and permitting process will require municipalities to develop and implement CSO system monitoring programs for planning, compliance, and reporting purposes.

The new regulatory focus on long-term CSO control programs increases the need for accurate flowrate measurement and monitoring systems that may be deployed at multiple locations within municipal networks. Flow monitoring data collected from key locations over a range of CSO system loadings frequently reveal significant

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differences in comparison to flow predictions resulting from computer models such as the Stormwater Management Model (SWMM). Such data is valuable for verification of the overall modeling approach and specific system features to be analyzed, and for calibration of the CSO flow network response to inflow events. However, achieving high accuracy with flow measurements is critical to meaningful system modeling and analysis since the propagation of uncertainties (errors) through flow networks can rapidly grow to unmanageable proportions.

Ultrasonic transit-time flowmeters can be used to meet these CSO monitoring and documentation requirements by providing highly accurate and continuous flowrate measurement during dry- and wet-weather conditions. Transit-time flowmeters include bi-directional (reverse flow) measurement capability and can be configured for multiple acoustic paths, making them highly accurate over a wide range of changing water level and flow conditions, as well as in locations where other measurement methods cannot reliably function.

In addition to providing the data needed for system modeling and evaluation, accurate flow information is valuable for:

- Regulatory reporting and compliance documentation
- Planning and evaluation of CSO control alternatives
- Alerting operators to CSO system malfunctions
- Optimizing operation of treatment facilities
- Allocating user costs and billings
- Pacing chemical treatments for CSO discharges

Requirements for CSO and Stormwater Flowmeter Systems

Flowmeters for CSO monitoring typically are required to operate under both free-flowing (i.e., in partially-filled conduits or open channels) and surcharged (pressurized) conditions. Additional measurement requirements can arise at locations subject to backflow, reverse flow, or tidally governed hydraulics. The need to accurately determine flowrates over such a wide range of conditions places stringent requirements on the methods and technology that can be successfully utilized in CSO applications. Methods that derive flowrate from measurements of water level only (using stage vs. flowrate relationships) are simply not capable of meeting these requirements.

A more suitable approach is developed from consideration of the hydrodynamic continuity equation, with a derived principle that applies to flow through any conduit section; i.e., flowrate is equivalent to multiplication of a true average current profile velocity times the cross-sectional area of the conduit flow. Since flows in conduits range from partially full through surcharged conditions, measurement of water level is used to determine the cross-sectional flow area (based upon the geometry of the conduit), and water velocities are measured to estimate the corresponding true average flow velocity.

Since flow velocity profiles in surcharged conduits are significantly different than under free-flow conditions, a "compound" approach that automatically selects an appropriate integration method for computing representative velocity profiles and resultant averages will provide better flowrate accuracy. Conduit sections that are well-removed from upstream bends, obstructions, or other flow disturbances will exhibit "fully developed" flow velocity profiles; as will be discussed below, the multi-path transit-time method can provide accurate flowrate information even at sites where flow profiles are not well developed.

Ultrasonic Transit-Time Flow Measurement Principles

The Accusonic multi-path transit-time flowmeters discussed in this paper have been installed worldwide for high-accuracy flow measurement in over 1000 large pipes, open channels, and conduits that flow partially full to surcharged. The flowmeters, which operate in clean or "dirty" water environments, have been used in hydroelectric and water system applications since the 1960s. The flowmeters have been installed in numerous large CSOs and wastewater treatment plant influent and effluent channels for high accuracy and reliable flow measurement. Because the flowmeters use relatively low-frequency, high-power ultrasonic pulses for flow measurement, they are capable of operating in water with relatively high concentrations of suspended sediments, as is common in CSO environments.

The transit-time acoustic technique is based on the principle that an acoustic pulse traveling at an angle across a pipe will be accelerated in the downstream direction by the water flowing through the pipe and will arrive at a receiving transducer in less time than an acoustic pulse traveling in the upstream direction, which is decelerated. By mounting transducers to define a path crossing the pipe or channel at an angle to the flow axis (Figure 1) and measuring the difference in acoustic transit times in the upstream and downstream directions, an average flow velocity at the level of the acoustic path is calculated according to the following formula.

$$V = \frac{(T_1 - T_2)}{T_1 T_2} * \frac{L}{2\cos\theta},$$

where:

- V = average fluid velocity at the level of the path,
- T_1 = acoustic transit time in the upstream direction,
- T_2 = acoustic transit time in the downstream direction,
- L = acoustic path length between transducers, and
- θ = acoustic path angle relative to flow axis.

In the multiple-parallel-path method, average velocity is measured nearly simultaneously at more than one elevation in the flow. These simultaneous velocities define a velocity profile throughout the flow cross-section for use in calculating an integrated flowrate. This should be contrasted with the use of a single-point or single-path velocity to estimate the average velocity throughout the cross-section. The use of multiple simultaneous velocities also makes the method responsive to changing flow profiles associated with quickly changing CSO flow regimes, which can go from completely dry to surcharged within minutes during a rain event.

In addition to the multiple flow velocities, water level within the conduit is measured. With the Accusonic multi-path acoustic technique, as the water level rises above each acoustic path, additional velocity information becomes available. The flowmeter computer changes integration method as appropriate to the number of submerged paths. The highest accuracy is available when the conduit becomes surcharged, and a full-pipe integration technique is applicable. Numerous independent field and laboratory tests have shown that accuracies of ± 0.5 to 1% of actual flowrate can be achieved in surcharged conduits with a 4-path configuration. These accuracies can be maintained even at sites with poor hydraulic conditions by adding a second plane of transducers in a cross-path configuration. The crossed-plane approach compensates for any errors due to cross-flow through the measurement section caused by upstream disturbances.

Under free-flowing (non-surcharged) conditions, flowrate accuracies of ± 2.0 to 3.0% of true flow are typically achieved with a 3-path system. The increased uncertainties are generally associated with determining the flow cross-section area and estimating an average velocity for the region above the highest operating acoustic path. The uncertainty can be minimized by adding acoustic paths (i.e., average velocities) at additional elevations and by averaging redundant level measurements.

For very low flows where the water level is below the lowest acoustic path, the meter can automatically switch to the Manning method (where applicable) to compute flowrate using level data only. Typically, however, an acoustic path is placed very low in the conduit to ensure that velocity data becomes available early in a rain event.

An additional advantage of the acoustic transit-time technique is that the system is "dry calibrated", based on measurement of as-built path lengths and angles at the time of transducer installation. Because the transducers are typically permanently installed, once these path lengths and angles are known and are entered into the flowmeter console as parameters, there is no need to recalibrate the system over time. The multiple-path method also obviates the need for flow profile calibrations that are required for single-point or single-path flowmeters.

Another feature of the multi-path transit-time technique is that it measures bi-directional flow, which can be particularly important in tidally influenced CSOs. For example, at New York City's Fresh Creek CSO, negative velocities occur on the lowest path during the periods of incoming tide while velocities on the higher paths indicate an outward flow. The meter determines the net flow through the CSO even during these periods of bi-directional flow profiles. A single-point, single-path, or acoustic Doppler-type velocity flowmeter cannot resolve true net flowrates under these conditions and can even indicate the wrong direction of flowage! This is of critical concern for control of tide gates or other CSO flow diversion mechanisms.

A general arrangement drawing showing a multiple-path flowmeter configuration installed in the City of Philadelphia's Cottman Avenue CSO is shown in Figure 2.

Transducer Selection for CSO/Stormwater Applications

Important considerations in choosing flowmeter transducers for CSO applications are cost, conduit shape, protrusion into the flow, ease of installation, and whether the transducers need to be certified for use in a hazardous location. Any transducer selected for CSO monitoring use should be constructed of durable, non-corrosible components for trouble-free, long-term operation.

A variety of ultrasonic transit-time transducers have been developed for use in a wide range of measurement applications, including buried and exposed steel pipes, concrete pipes and trapezoidal channels, and open channels. Internal mount transducers are often used in CSO and wastewater applications (Figure 3). Accusonic has developed a dual-element, internal-mount transducer providing a completely redundant back-up capability to the primary sensor. Low-cost, array-mount PVC transducers and explosion-proof transducers are also available. Transducers for mounting on the inside of pipes or channels have generally been designed to minimize protrusion and to direct flow around the transducer. At sites where large items of debris might be expected to damage anything mounted on the channel walls, transducers have been recessed in blockouts in the channels walls, or protective "deflectors" have been mounted upstream of the transducers to prevent damage.

Several different types of water level sensors can be used with the flowmeter--an acoustic "downlooking" transducer, which is mounted above the flow and measures level by the time it takes to receive an acoustic signal bounced off the water surface, an acoustic uplooking transducer (mounted on the channel bottom and reflecting an acoustic pulse off the water surface), or a submerged pressure sensor. Because of the possibility that debris could settle on an acoustic uplooking transducer and obscure the signal, a downlooking sensor is often recommended in CSO applications, with an uplooker or pressure sensor used for redundancy. The downlooking transducer is often recessed in a manhole for continued operation during surcharged conditions.

Recent Flow Monitoring Installations

Massachusetts Water Resources Authority

Accusonic flowmeters are currently operating for the Massachusetts Water Resources Authority (MWRA) in the Somerville, Commercial Point, and Constitution Beach CSOs. All three sites are instrumented with redundant internal mount transducers. The Somerville and Commercial Point sites are large rectangular box conduits (15' x 7' and 15' x 15', respectively) configured with three or four acoustic paths, and both are instrumented with an uplooking transducer for water level measurement. The flowmeter at Constitution Beach CSO is located in a 36-inch-diameter buried concrete pipe. Two acoustic paths and an uplooking level sensor are used here because of space constraints. The flowmeters at all three MWRA sites are used to pace chemical metering pumps for treatment of CSO discharges.

New York City Department of Environmental Protection

An Accusonic flowmeter was installed in one of four 9' x 15' rectangular outfalls at the New York City DEP's Fresh Creek CSO Flow-balanced Storage project as part of a flow study in the early 1990s. The multi-path transit-time method was ideally suited to this site because of the capability to measure simultaneous bidirectional flow at various levels. This site often experiences salt water flowing upstream on the incoming tides near the bottom of the outfalls while fresh runoff flows downstream at

higher elevations. In 1993 the remaining three outfalls were instrumented with 3-path Accusonic flowmeters using low-cost array-mount transducers and an uplooking level sensor.

City of Philadelphia

A 3-path Accusonic flowmeter was installed in the City of Philadelphia's Cottman Avenue CSO in mid-1993 as part of an extensive CSO flowmeter intercomparison study. Low-cost array-mount transducers were installed in this rectangular 9' x 6'9" conduit. Four separate level sensors were included in the flowmeter configuration to measure water level at various locations in the CSO regulator, influent, and interceptor lines. Flow data is logged on a diskette in the flowmeter computer and is downloaded to the City's computers via dial-up modem. Data from several rain events exhibit rapidly changing flow conditions and demonstrate the need for simultaneous multiple-path measurement throughout the channel to provide accurate flow data (Figures 4, 5). Review of the velocity data simultaneously collected at the different levels in the flow during these events has demonstrated the superior flowrate accuracy and resolution provided by the multi-path technique. Flowrates derived from single-path velocity measurements, via use of a "meter factor" to calculate an average velocity representing the flow profile, are found to result in significantly greater uncertainties for flowrates measured over the wide range of conduit flows observed.

Summary and Conclusions

Multiple-path acoustic flowmeters provide capabilities for acquiring high-accuracy flow data in wide-ranging CSO system monitoring applications. New CSO control policies and regulations are increasing the need for flow monitoring by municipalities to meet the new regulatory requirements. Major features and advantages offered by multiple-parallel-path, transit-time flowmeter systems for CSO monitoring applications are summarized below.

- Capability to continuously measure, record, and transmit flow data
- Superior accuracy over complete range of changing flow and water levels
- Compound flow profile integration for free-flow or surcharge conditions
- No required "flow profile" calibration or recalibration over time
- Rugged, streamlined transducer design with minimal flow intrusion
- Multi-level, bi-directional flow measurement capability
- Remote system data access and control via telemodem
- Field-proven, long-term operating performance

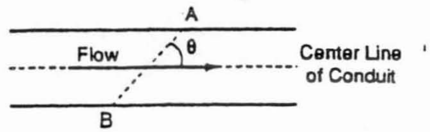

Figure 1 - Transducers mounted diagonally across a pipe or channel create an acoustic path (A-B).

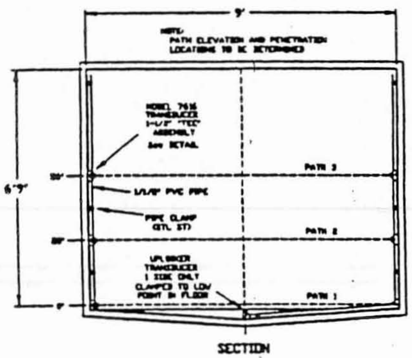

Figure 2 - Three-path acoustic transit-time configuration with water level sensors

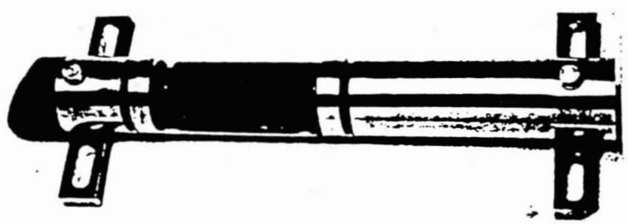

Figure 3 - Internal mount transducer and mounting assembly for long-term CSO monitoring applications

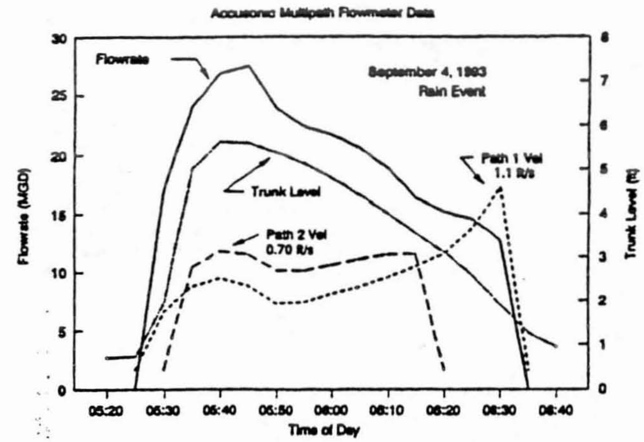

Figure 4 - Individual path velocities with measured stage (water level) and calculated flowrate information during a rain event at Cottman Avenue CSO, City of Philadelphia

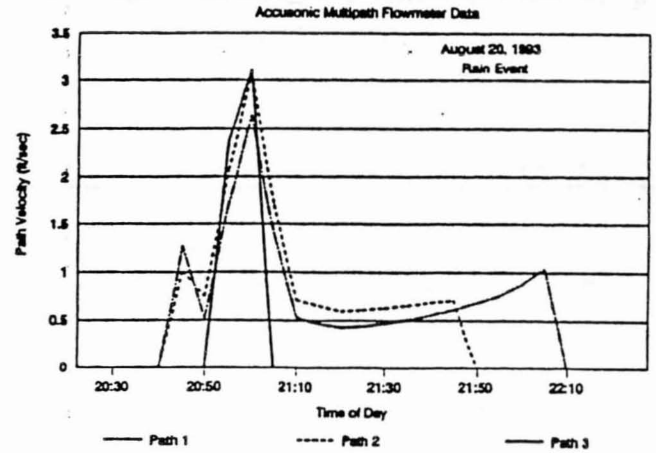

Figure 5 - Individual path velocities during a separate rain event at Cottman Avenue CSO

KEY WORD LIST
for
HIGH-ACCURACY CSO AND STORMWATER FLOW MONITORING

Accusonic

Acoustic Flowmeter

Compound Flow Measurement

CSO Monitoring

Flow

Flow Measurement

Flowmeter

Flow Modeling

Flow Monitoring

Flowrate

Flow velocity

Open Channel Flowmeter

Stormwater Monitoring

Transit-Time Flowmeter

Ultrasonic Flowmeter

Tuesday, August 9, 1994 (continued)

SESSION IV: NPDES COMPLIANCE MONITORING

1. **"Improved Methods for Stormwater Data Collection"**
   George C. Chang, William Burd, Thomas Brown, and James E. Lewis
   City of Austin

2. **"Biological and Chemical Testing in Stormwater"**
   William T. Waller, Miguel Acevedo and Eric Morgan
   Tennessee Technical University;
   Kenneth Dickson, James Kennedy and Larry Ammann
   University of Texas at Dallas;
   Joel Allen and Paul Keating
   University of North Texas

3. **"Blackstone River Wet Weather Monitoring Initiative Experience"**
   Raymond Wright, Roy Chaudhury and Makam S.
   University of Rhode Island

Methods and Procedures in Stormwater Data Collection

Thomas Brown, William Burd,
and George Chang, P. E.[1]

Abstract

This paper presents methods and procedures developed to ensure the quality of stormwater monitoring data produced by the City of Austin's Stormwater Monitoring Program. Since 1975, the City has monitored stormwater runoff to produce data used in many studies, to develop structural-control design criteria, and to develop watershed ordinances. These ordinances have minimized the impact of urban development on water quality and resulted in effluent limitations. Given this high visibility, the City has developed stormwater monitoring techniques and experimental designs to improve the processes of flow measurement, sample collection, data management, and data analysis.

Monitoring Program Goals and Objectives

The goal of the City of Austin's (COA's) Stormwater Monitoring Program (SWMP) is the collection and analysis of water quality data to guide the development of watershed ordinances, manage the City's waterways, and fulfill federal requirements. Stormwater monitoring has been used to comply with U.S. Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) permit application requirements, review and improve the City's watershed ordinances and evaluate the pollutant removal efficiencies of structural and non-structural Best Management Practices (BMPs). The SWMP has monitored runoff from a spectrum of land uses ranging from pristine, undeveloped watersheds in the Hill Country west of Austin to highly-developed urban watersheds in the City's core.

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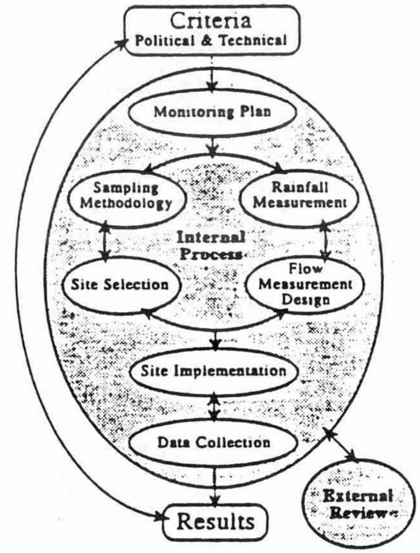

Figure 1. Stormwater Monitoring Process

Stormwater Monitoring as a Process

Stormwater monitoring can be considered as an expanded quality assurance--quality control (QA/QC) process (Figure 1). As in all integrated systems, errors occurring anywhere in the stormwater monitoring process tend to be translated into other components of the process--ultimately affecting the integrity of data. Therefore, careful planning at all stages of the stormwater monitoring process is the key element of the production of quality data (COA, 1993a; COA, 1993b).

a) Monitoring Plan

The monitoring plan defines the quantity and quality of data to be collected, the water quality parameters to be measured, the land use types and BMPs to be monitored, and the cost of data to be collected. The plan also specifies the type of monitoring equipment and software to be installed. The SWMP uses remote-controlled, automatic samplers that are operated from a central office (Figure 2).

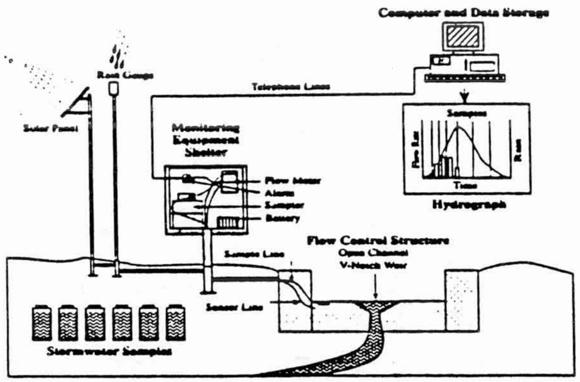

Figure 2. Remote-Controlled Stormwater Monitoring System

The number of storm events to be monitored at each site is determined mainly from the amount of rainfall and the number of dry days before storms. When the frequency distribution of storm sizes (Figure 3) is grouped according to storm-size class, the total average annual rainfall depths contributed by each storm-size class are roughly equal (Figure 4). According to previous data (COA, 1990), the event mean concentrations (EMCs) for all types of watersheds vary by storm size and the number of dry days between storms. In Austin, a range of 18 to 24 storm events should be collected at each monitoring station (Soeur, et al., 1994). The range of storm events to be sampled has been determined by experimental design factoring three or four storm-size classes with two antecedent dry day classes (Figure 5). In order to conduct statistical comparisons, there must be at least three storm events collected for each combination in the experimental design matrix.

The SWMP analyzes 15 standard non-point source water quality parameters representing five categories of pollutants, such as, suspended solids, oxygen-consuming constituents, nutrients, metals, and bacterial constituents. These parameters are commonly used in other studies to characterize point and non-point source pollutants (EPA, 1983).

b) Rainfall Measurement

Rainfall data are used to relate rainfall amounts to the runoff volumes recorded at a monitoring site. All stormwater monitoring stations use tipping-

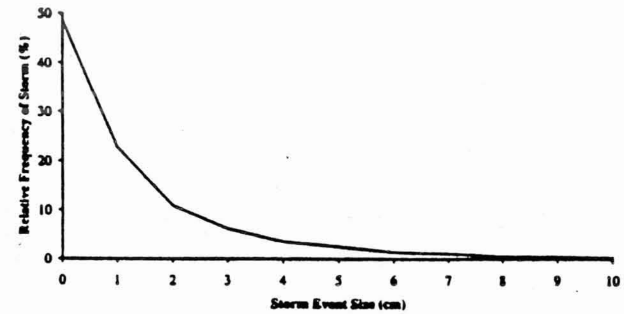

Figure 3. Relative Frequency of Storm Event versus Storm Event Size
Austin, 1950 to 1992

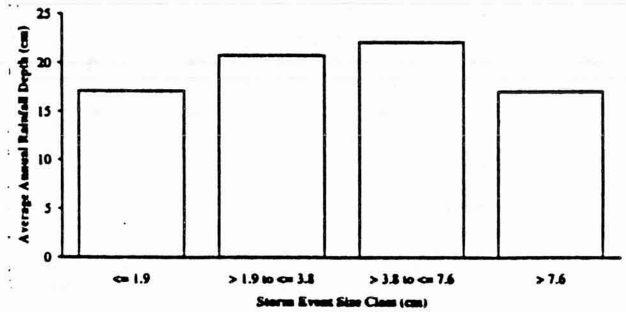

Figure 4. Average Annual Rainfall Depth per Storm Event Size Class
Austin, 1950 to 1992

	Storm Event Size Class (cm)				
Dry Days before Storm Event	<= 1.9	> 1.9 to <= 3.8	> 3.8 to <= 7.6	> 7.6	TOTAL
< 48 hours	3 storms	3 storms	3 storms	3 storms	12 storms
>= 48 hours	3 storms	3 storms	3 storms	3 storms	12 storms
TOTAL	6 storms	6 storms	6 storms	6 storms	24 storms

Figure 5. Recommended Number of Storms to Monitor by Storm Event Size Class and Antecedent Conditions

bucket rain gauges, which automatically record both rainfall amounts and rainfall intensities. The SWMP also uses rainfall data collected by the COA's Flood Early Warning System (FEWS) automatic rain gauges to supplement and verify the SWMP rainfall data. The high density of FEWS rain gauges (52 stations in Austin) is especially important during the summer months when highly-localized, tropical thunderstorms are common. Variations in rainfall within large watersheds are common during storm events.

c) Sampling Methodology

The SWMP uses the three standard sampling methods. Grab samples, when chemically analyzed, indicate water quality at a single moment in a hydrograph and are mandatory when manual or sterile sampling techniques are required. Flow-weighted composite samples are composed of a number of equal-volume aliquots collected at equal intervals of runoff volume throughout the hydrograph (Greenbery et al., 1992). When flow-weighted composite samples are chemically analyzed, the data directly yield an EMC for each water quality parameter. Discrete samples are sets of samples taken in some systematic manner throughout the hydrograph. Discrete samples show changes in pollutant concentrations throughout the hydrograph, but can be mathematically combined to yield an EMC for each water quality parameter (COA, 1983).

During runoff events, different watershed types have varying pollutograph characteristics. For example, in small watersheds (< 162 hectares, 400 acres) with medium to high impervious cover, the concentrations of TSS, total phosphorus (TP), total Kjeldahl nitrogen (TKN), and total organic carbon (TOC) are greatest during the first flush of runoff, and then decrease over time (Figure 6)(Soeur, et al., 1994).

In contrast, in large watersheds (> 162 hectares, 400 acres) with a high degree of channel erosion, the concentrations of TSS, TP, TKN, and TOC correlate with flow rate and are greatest at the peak of the hydrograph (Figure 7)(Soeur, et al., 1994). In Austin, this example corresponds to larger urban creeks draining mixed land uses.

A refined method for discrete sampling collects samples more frequently when pollutant concentrations are changing most rapidly. In a small watershed, sampling events should occur during the rising stage of the hydrograph while retaining sample coverage of the tail on the falling stage of the hydrograph. In a large watershed, sampling coverage should be concentrated around the peak of the hydrograph while retaining coverage on the tails of the hydrograph. During flow-weighted composite sampling, EMC's in a small watershed are best represented if many aliquots of small volume are collected during smaller intervals of runoff volume.

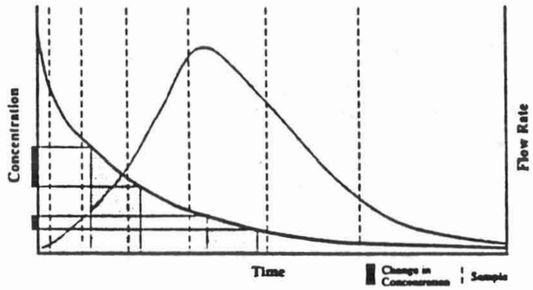

Figure 6. Small Watershed Pollutograph with Hydrograph

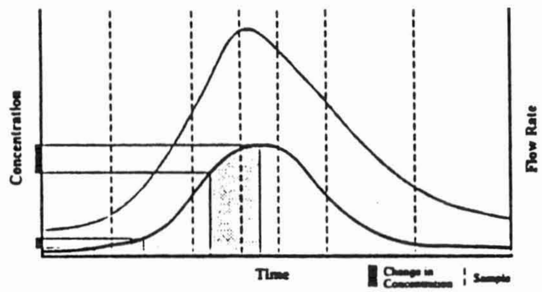

Figure 7. Large Watershed Pollutograph with Hydrograph

Each water quality parameter requires a certain sample volume for analysis (EPA, 1992). Automatic samplers provide a limited number of sample bottles. The number of water quality samples collected for any monitorable storm event range between three and sixteen samples, depending upon the complexity and size of the hydrograph. To accommodate the need for more sample coverage of both the hydrograph and sample volume for the analysis of 15 water quality parameters, two automatic samplers can be used at each site.

Automatic sampling has certain inherent advantages and drawbacks. An automatic sampling system can be remotely controlled and programmed, reduce human sampling error, and reduce the danger to field personnel during storm conditions. Automatically-taken samples, however, may not be representative because of holding-time limitations of some parameters and sample contamination by the equipment. True duplicate samples cannot be taken with standard automatic sampling equipment. If the sample water is being transported over a relatively long distance (> 15 m. or 50 ft.) or up a steep gradient (approximately > 4.5 m. or 15 ft.), TSS may settle in the line during transit. Automatic sampling may be inappropriate for the collection of volatile organic compounds (VOCs)(which require zero head-space sampling) and fecal coliform and fecal streptococci (which have a short holding time and could be cross-contaminated by the Teflon sample line)(EPA, 1992).

In contrast, manual sampling performed by trained staff does not require expensive equipment, always results in representative samples, allows duplicate QA/QC sampling, adjusts sampling for changing conditions, and provides information on flow conditions from field observations. Manual sampling is limited by safety concerns, the ability of personnel to respond in a timely manner, and the number of sites that can be handled in a given storm event (EPA, 1992).

d) Site Selection and Watershed Documentation

Monitoring site selection requires much planning to achieve characteristic water quality data for a given land use. Ideally, a watershed should be selected that does not have significant point-source discharge (e.g., toxic waste dump, land fill, problematic industrial source, etc.) and is largely covered by the targeted land use or research objective. The selection of a monitoring site is also influenced by the nature of the channel at the proposed monitoring location. To most accurately characterize flow rate and calibrate the rating curve without a flow control structure, a channel should be straight, have uniform cross-sectional shape, and have a mild slope (e.g., slope < 0.02) over a relatively long stretch. The site must be safe for field personnel and secure for monitoring equipment. Ideally, the monitoring station should be accessible for maintenance and sample collection during storms and high water.

Once a prospective monitoring site has been identified, a watershed analysis and documentation process defines hydrographs (or peak flow versus time) for various types of storm events. This watershed information is determined largely by field survey and map study. In general, the channel should have enough capacity so that a two-year storm event can be monitored. The peak and average flow conditions help determine which flow control structure and flow monitoring procedure to use. Watershed documentation provides the quantitative information necessary to run computer simulations, such as Stormwater Management Model (SWMM) and Hydrologic Engineering Center models (HEC1 and HEC2), that create synthetic hydrographs and calculate flowrates.

e) Flow Measurement

Determining flow rate through an open channel is the most difficult aspect of stormwater monitoring. The accurate measurement of stormwater discharges at a monitoring station is vital in calculating the EMC's for various water quality parameters. The SWMP uses four basic methods for determining flow: (1) appropriate flow control structures, such as weirs and flumes; (2) cross section area-velocity measurements to generate a flow-rating curve; (3) application of Manning's equation; or (4) the runoff coefficient method for estimating runoff (EPA, 1992). During storm events, field observations and video supply additional information on flow that might not be predicted by preliminary studies.

The SWMP uses flow control structures, such as weirs and flumes to give accurate flow measurement. Flow rating curves are well-established for both weirs and flumes (Bos, 1978; Grant, 1972), and the appropriate flow control structure can be selected according to its sensitivity to a certain range of flow. Flumes allow water to pass freely, limiting sediment and trash (that can accumulate behind weirs), but flumes also tend to be more expensive and difficult to construct than weirs.

The SWMP uses the area-velocity measurement method in larger channels and creeks where no flow-control structures exist. The COA contracts with United States Geological Survey to generate flow rating curves in these cases (International Organization of Standards, 1983). The average velocity of flow is measured by a hand-held velocity meter.

The Manning's equation can be applied to pipe and channel flow, but accuracy depends on steady flow, straight channels, even and gentle slope, uniform roughness, and uniform channel shape over a long length of channel (Grant, 1992). Satisfaction of these conditions is rare in storm sewers. In a few cases when other methods are not appropriate, the SWMP calculates flow rate using a two-point measurement system based on the theory of gradually-varied flow (Figure 8)(Dalrymple, 1984; Chow, 1959). This method is subject to some error due to the unsteady flow conditions of stormwater runoff.

The runoff coefficient method develops hydrographs on information based on the watershed documentation. This method, used when no other option is available, can also be used as a check against other flow volume calculations.

f) Equipment Testing

The SWMP's flow meters were tested in a hydraulics laboratory flume to investigate equipment performance under a variety of controlled flow conditions. Bubbler, submerged probe, and ultrasonic probe flow meters were tested.

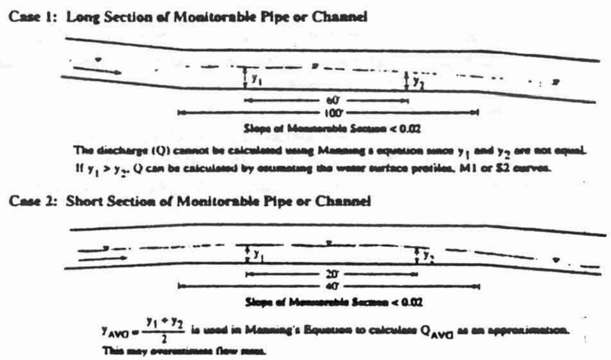

Figure 8. Flow Measurement with Two Points

Preliminary test results revealed that all flow meters accurately recorded depth at velocities lower than 1.5 m/sec (5 ft/sec). In the 1.5 to 2.1 m/sec (5 to 7 ft/sec) velocity range, 5% errors in depth readings were seen, and in the 2.4 to 3.0 m/sec (8 to 10 ft/sec) range, errors in depth of up to 20% were seen. These systematic errors are most likely produced by flow-induced pressure differentials around the exterior of the submerged sensors. The submerged pressure probes and bubbler lines must be oriented parallel to flow to minimize errors in depth readings at higher velocities. The bubbler sensor orifice must be pointed downstream for best accuracy.

g) Site Implementation

Monitoring site implementation is the culmination of an extensive planning process, which includes a sampling methodology, rainfall and flow measurement techniques, site selection, and watershed documentation. The typical monitoring installation consists of a modular equipment shelter, solar panel, rain gauge, buried conduits for various support systems, flow control structures, a system alarm, batteries, and phone lines or a cellular phone link (for isolated sites). All above-ground structures are modular in design for easy installation and removal, since most monitoring stations have an operational life span of three to five years.

Over the past two years, the SWMP's modular equipment shelters have been redesigned to improve ergonomics and security. The shelters have large interiors so that monitoring equipment is accessible for field operations and site maintenance. A

rain guard can be deployed to keep personnel, water quality samples, and monitoring equipment dry when access is necessary during storms.

Modular weir plates have been installed at several monitoring stations and can be inexpensively modified if the actual runoff is found to be different from the calculated runoff values used to size the original weir. Deviations in actual runoff versus calculated runoff may result from watershed mapping errors or from other complex phenomenon in the watershed. For example, a calculated runoff coefficient may not reflect local hydrologic variations caused by a karst terrain. This condition affects all monitoring sites located in the recharge zone of the Edwards Aquifer, which underlies western Austin.

At one location, accurate flow measurement was not possible without channel realignment because the storm sewer channel had a steep slope (slope > 0.043), and was curved. A SWMP field team straightened the pipe's existing alignment, reduced a section of the pipe's slope (slope = 0.004), and installed a rectangular weir near the location of the original outfall (Figure 10).

Data Collection

a) Storm Preparation

Weather conditions are closely watched by SWMP personnel when rain threatens. The local National Oceanic and Atmospheric Administration (NOAA) weather radar (shown continuously on local cable TV) is used to track storm development and movement. With advanced warning the SWMP field personnel cycle the equipment at the monitoring stations through a set of pre-storm preparations. Typical site maintenance includes checking bottle labels, icing sample bottles, checking system voltages, checking communication lines, cleaning rain gauges, and down-loading data stored in flow meters. Monitoring stations are also maintained on a weekly basis to accommodate surprise storms.

b) Data Collection and Verification

Rain and flow data are recorded at one minute intervals by a data logger inside the flow meter. During a remotely controlled operation, the data are transmitted from the flow meters to the office via telephone. The monitoring equipment can collect data independently. The down-loaded data are checked for errors by a computerized scanning program that detects outliers in rainfall data, and manual scanning of graphical flow and sample event data to verify data integrity. This verification process also identifies maintenance problems and double-checks sample-event data before sample bottles are sent to the laboratory.

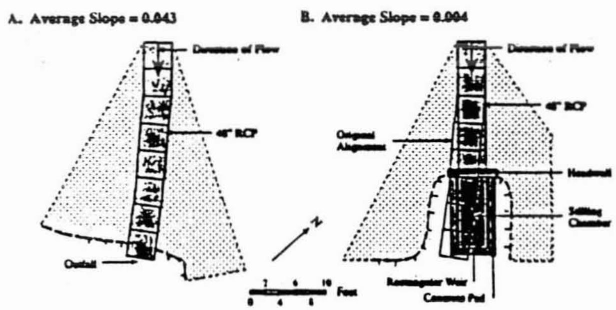

Figure 9. Realignment Plan for a Monitoring Site

c) Water Quality Sample Collection

When rain threatens, the automatic samplers at each monitoring station are programmed to automatically sample storm flow. This feature is useful should a storm hit without warning (e.g. in the hours before dawn). Even then, the monitoring staff can still be mobilized after a storm has begun to collect a balanced sample distribution across the hydrograph. A well-balanced sample distribution throughout any hydrograph is as much art as science, since there is no way to accurately anticipate runoff volume once a storm begins. The best way to achieve good sampling distribution at all monitoring stations is to watch the changing flow and rainfall conditions during a storm event and adjust the sample pacing accordingly.

The SWMP Chain of Custody documentation process has been extensively modified to facilitate sample documentation and communication between the field and laboratory. SWMP staff meet regularly with laboratory staff to coordinate sample collection and analytical QA/QC procedures.

d) Data Administration

The City's SWMP accumulates large amounts of flow, rainfall, and water quality chemistry data from each monitoring station for each storm event monitored. As additional monitoring stations become operational, the amount of data compiled will grow proportionally. Consequently, the data administration system must not

only deal with the current information flow but also be capable of accommodating twice as much information by 1996.

Automated data management and storage save time in processing and reducing human error. Water quality and flow data are stored on disk in an hierarchical file structure such that analogous data classes are stored at the same levels. Data identity labels, such as monitoring site ID codes, facilitate automated data processing. The goal of data management is to file data in a system that is appropriate for the way the data is used during analyses. Qualitative and hard copy data are filed in a restricted central location. Copies for general use are kept in an accessible location, so that if a copy is lost or misplaced the archives are not affected.

External Resources

The SWMP utilizes an external, independent group of engineers, that serve as a professional review board to cover all aspects of the SWMP. The COA is also a member of a group of regional water quality agencies called the Joint Water Quality Monitoring Program which is establishing a regional water quality data base.

Conclusions

During the COA's long term Stormwater Monitoring Program (SWMP), the City has refined and standardized stormwater quality monitoring methods and techniques. These practices have improved the accuracy of flow measurements and led to the collection of representative stormwater quality samples. The complexity of natural phenomena remains a large focus with the SWMP despite the fact that emerging monitoring technology and less expensive information systems have improved the ease of the stormwater monitoring process. The collection of comprehensive hydrologic data ensures a more appropriate sample distribution. Design utilizing principles of hydraulics is critical, especially to benefit from the use of automated flow measurement equipment and flow control structures. From careful planning and implementation of a monitoring project to the field calibration of each site, the SWMP endeavors to develop and utilize methods and techniques to achieve data with consistent accuracy and significant statistical validity.

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Ten Keywords for Brown et al.'s paper "Methods and Procedures in Stormwater Data Collection."

Composite sample
Discrete sample
Event Mean Concentration
Flow measurement
Flumes
Grab sample
Manning's equation
Pollutograph
Sample Distribution
Weirs

Use of Biological and Chemical Testing in Storm Water NPDES Monitoring

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The 1972, amendments to the Federal Water Pollution Control Act, referred to as the Clean Water Act (CWA), prohibited the discharge of any pollutant to navigable waters from point sources unless the discharge was authorized by a National Pollutant Discharge Elimination System (NPDES) permit. The principal focus of the NPDES program has traditionally been to reduce pollutants in discharges of industrial process wastewater and discharges from municipal sewage treatment plants. This program emphasis developed because many industrial and municipal sources were not controlled or poorly controlled at that time and were easily identified as contributing to water quality impairment. Nonetheless, within the framework of the law, channelled storm water was classified as a point source. The passage of the CWA led to a long and intense debate over storm water regulations. The Water Quality Act of 1987 added section 402(p) to the Clean Water Act (CWA). Section 402(p) requires the Environmental Protection Agency (EPA) to establish phased and tiered requirements for storm water discharges under the NPDES program (Federal Register, 1992).

The application for NPDES permits for storm water discharges consists of two parts. Part 1 of the permit application includes a description of legal authority to address separate storm sewer systems; an inventory of outfalls and details about drainage areas; a field screening program to detect illicit discharges; a plan for a representative sampling program to be implemented in Part 2 of the application; and a description of existing storm water controls. Part 2 of the storm water permit application includes a list of industrial dischargers to the municipal separate storm sewer system; quantitative data from the representative sampling program developed in Part 1; and a storm water management plan to be implemented during the term of the permit. An assessment of the effectiveness of the storm water management plan and a fiscal analysis of necessary capital and operations and maintenance expenditures are also included in Part 2 (Oakley and Forrest, 1991).

As part of the response to the Part 2, NPDES storm water permit application requirements, seven major cities in the Dallas-Fort Worth (DFW) metroplex participated in a comprehensive storm water sampling program. Thirty sampling sites representing different land uses (residential, commercial, industrial, and highway) were sampled for seven storm events. Approximately 185 parameters including nutrients, metals, pesticides and organics were analyzed.

Results of the local storm water sampling program are being compared with historical findings of the Nationwide Urban Runoff Program (NURP), as well as historical local data. NURP was a five-year program during the period 1978-1983. NURP collected data for ten constituents at 81 sites in 22 cities for over 2300 storm events at acceptable "loading sites" where no devices modifying runoff were upstream. Runoff was characterized by land use and for all urban sites combined. NURP values included BOD, COD, total Kjeldahl nitrogen, nitrite+nitrate, total phosphorus, TSS, total copper, total lead, and total zinc. In addition to these "standard pollutants", special priority pollutant and metals studies were conducted at many of the sites.

One use of the data collected from the recent Phase 2 sampling program carried out in the Dallas-Fort Worth metroplex is to determine the local event mean concentration (EMC) values for the calculation of the pollutant loads for local watersheds. An EMC value is defined as the flow-weighted mean pollutant concentration for a given or typical storm event. Choosing the correct local EMC value could result in different pollutant loadings than those predicted by the national average NURP EMC values. The regional program is being coordinated by the North Central Texas Council of Governments (NCTCOG) (Young, et al., 1993) and had as its objectives:

1) Satisfy the U.S. Environmental Protection Agency requirements for Part 2 NPDES storm water permit applications.

2) Determine the constituent loads from representative watersheds in the area.

3) Characterize the land use impacts on water quality.

4) Provide basic information to develop management alternatives for permit compliance.

Much of the data collected in storm water sampling programs have focused on chemical constituents and loadings because of the emphasis on the reduction of loadings characteristic of most Best Management Practice (BMP) goals, and concerns over the realism of traditional toxicity tests when used to measure episodic toxicity. Nonetheless, concerns exist about the toxicity of storm water, and toxicity tests are the only adequate way of characterizing the toxicity. Poor correlations between conventional contaminant measures and toxicity indicate that toxicity should be measured directly to assess the biological impacts of storm water runoff instead of inferring toxicity from chemical measurements. With chemical specific measurements you only find what you are looking for; what you do find is not always biologically available; the toxicity of all the chemicals that can be measured is not always known; and our understanding of the interaction of toxicants (synergism, antagonism, and/or addition) is poor at best. The need for the use of toxicity tests to determine toxicity has been stated best by Cairns and Mount (1990);

> "No instrument has yet been devised that can measure toxicity! Chemical concentrations can be measured with an instrument but only living material can be used to measure toxicity."

As a supplement to their participation in the Phase 2 storm water study, the City of Fort Worth applied for and received a 104(b)(3) grant from EPA to test the practical use of biotoxicity tests as screening tools in storm water programs. The City of Fort Worth contracted with the Aquatic Toxicology Laboratory of the University of North Texas (UNT) to perform acute toxicity tests on selected storm water samples collected in the Phase 2 storm water program. Acute toxicity tests using *Ceriodaphnia dubia* and *Pimephales promelas* were performed on these samples according to EPA methods (EPA, 1991a). City of Fort Worth personnel performed Microtox™, test methods on some of the same samples. In addition, UNT tested selected samples for chronic toxicity and some acutely toxic samples were characterized using Phase I, Toxicity Identification Evaluation methodologies (EPA, 1991b).

Acute toxicity tests were performed on thirty-one storm water samples collected from eighteen storm events. Sixteen stations representing industrial, commercial, residential, and mixed landuses were included in the analysis. Of the thirty-one acute toxicity tests performed on storm water samples from the Phase 2 study there was no significant mortality to *P. promelas* in any of the tests. In 12 of the thirty-one tests the no observable effects level (NOEL) for *C. dubia* was 50% or less. There were 23 tests for which both *C. dubia* and Microtox™ tests were performed. In eight of these tests *C. dubia* showed toxicity when Microtox™ did not, while there were three tests for which a 15 minute EC50 could be calculated for Microtox™ for which there was no measurable *C. dubia* response. There were 11 tests for which neither *C. dubia*, Microtox™, or *P. promelas* showed a significant response. In one test both *C. dubia* and Microtox™ showed a significant response. These

results suggest that *C. dubia* was the most sensitive indicator of toxicity tested, although strictly speaking comparing Microtox™ EC50's with *C. dubia* NOELs is not a good comparison. A better comparison would have been a comparison between percent light loss for Microtox™ and NOELs for *C. dubia*. Not unexpectedly, the finding that *C. dubia* is more sensitive to a broad range of toxicants is consistent with our findings for effluent tests and ambient toxicity tests.

The data from the Phase 2 study that will be focused on in this analysis involves two different but important toxicants, diazinon and zinc. The chemical specific data from all the samples collected during the Phase 2 study are not as yet available. The results for the chemical specific summaries reported in this paper are based on data from 19 stations represented by eight residential sites, seven industrial sites and four commercial sites. The data are not as yet considered final and are subject to revision. Zinc and diazinon are concentrated on because they were common to most of the samples collected in the Phase 2 study regardless of land use and they were identified through Phase I, Toxicity Identification Evaluation (TIE) procedures as being the likely causative agents responsible for acute toxicity to *C. dubia*, in some of the samples. Fifty-seven percent of the parameters analyzed for, and reported in the Storm Water Discharge Characterization Final Summary Report--Task 2.0 (1993) were not found at the analytical detection limits employed in the Phase 2 study.

Toxicity Reduction Evaluations (TRE), of which Phase I, Toxicity Identification Evaluation methods are an integral part, are an important part of the Water Quality Based approach to toxics control (EPA, 1984). Facilities which fail the toxicity portion of their NPDES permits are required to determine the causes of toxicity and develop methods to remove the toxicity. Phase I of the TIE procedures involves the physical and chemical manipulation of a toxic sample. The toxic sample is fractionated into seven fractions; pH adjustment, filtration, aeration, C_{18} solid phase extraction, oxidation reduction, EDTA chelation and graduated pH. The filtration, aeration, and C_{18} solid phase extraction steps are all performed on the sample at its initial pH and after the pH has been raised to pH 11 and reduced to pH 3. After the sample is fractionated, each fraction is returned to the initial pH, if necessary and tested for toxicity. Those fractions which remove and/or reduce toxicity are further tested to determine causative toxicants. The process of fractionation and toxicity testing focuses the search for the toxic components by reducing the number and types of chemicals one has to deal with by only concentrating on those fractions which reduce or remove toxicity. Phase II and III of the TIE procedures involve verifying the causes of toxicity.

Diazinon is an important toxicant in the southern part of the US. Many municipal wastewater treatment plants in the southern part of the country are failing their NPDES permit requirements for toxicity and frequently the indicated toxicant is diazinon. Diazinon is a very popular broad spectrum pesticide and is used extensively in residential settings. It is also extremely toxic to aquatic organisms. The 48-hour LC50 of diazinon to *C. dubia* is 0.350 ug/L (Norberg-King, *et al.*, 1989). Arthur, et al. (1983) recommended that diazinon in aquatic environments not exceed 0.080 ug/L. The 48-hour LC50 for the midge *Chironomus tentans* has been reported as 0.100 ug/L and development of the larvae of this midge have been inhibited by continuous exposure (80 days) to concentrations as low as 0.0006 ug/L (Morgan, 1976). Diazinon is sold in a variety formulations by numerous companies. One liquid formulation of diazinon sold in quart containers contains 25% diazinon by weight. It would take 247 football field size containers, exclusive of the endzones, three feet deep to dilute the amount of diazinon in a quart container of 25 diazinon to the 0.080 ug/L concentration recommended by Arthur, et al. (1983).

Table 1 shows there is a widespread occurrence of diazinon in storm water samples regardless of the landuse from which the samples were collected. The percentage of events and concentrations of diazinon were highest from residential sites and the median concentration in these samples was greater than the 48-hour LC50 for *C. dubia*.

Landuse	Percentage of Sites with Diazinon	Percentage of Events with Diazinon	Median Concentration of Diazinon ug/L
Residential	100	97	0.55
Commercial	100	85	0.20
Industrial	83	39	0.00

Table 1. The relationship between diazinon and its occurrence in samples collected during the Phase 2 study from residential, commercial and industrial sites in the Dallas and Fort Worth metroplex.

Figure 1 shows the distribution of diazinon concentrations from the 31 samples from residential sites for which diazinon concentrations were available. While the concentrations found in different rainfall events were highly variable, twenty of the values reported were in excess of the 0.350 ug/L LC50 values for *C. dubia*. The second most frequently measured pesticide

was total chlordane which was found at seven sites, five residential and two commercial.

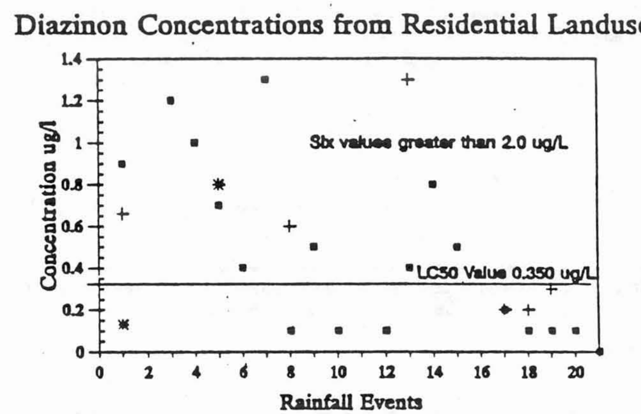


Figure 1. Diazinon concentrations from residential landuse and their relationship to the acute toxicity of diazinon to *Ceriodaphnia dubia*. Symbols associated with rainfall events represent different sites.

A recent California Regional Water Quality Control Board memorandum (March 17, 1994) reported diazinon concentrations found in storm water samples collected in Stockton, California from residential and mixed landuse. Two rainfall events were monitored at thirteen sites. The diazinon concentrations measured in these samples ranged from 0.160 to 1,050 ug/L. Eleven of the 13 sites had diazinon concentrations greater than the acute LC50 value for *C. dubia* (0.350 ug/L) and 100% *C. dubia* mortality was observed at most of the sites which were sampled. Clearly, as far as pesticides are concerned, diazinon is a widespread toxicant in storm water runoff and is especially prevalent in samples from residential landuses. Two of the toxicity identification evaluations which were performed on acutely toxic samples from residential sites showed that non-polar organic chemicals were the likely causes of the toxicity and while it was not established without doubt that diazinon was the causative toxicant, all the available information points in that direction.

Zinc is ubiquitous in its distribution, but was not included in the analysis for that reason. Rather, zinc was included because of the manner in which the collected data were treated in the Phase 2 study and because zinc is a significant toxicant in aquatic systems. One of the uses of the data collected in the Phase 2 study is to calculate EMC concentrations and to compare these with those observed in the NURP studies as well as other local studies. Therefore, it is important that all data which are collected and represent real values be included in the calculation of the EMC concentrations.

The percentage of sites, events and the median concentration of zinc collected during the study showed, as one would expect, zinc was found at all stations and every event (Table 2).

Landuse	Percentage of Sites with Zinc	Percentage of Events with Zinc	Median Concentration ug/L
Residential	100	100	65
Commercial	100	100	130
Industrial	100	100	110

Table 2. The distribution and median concentration of zinc amongst the landuses studied.

The landuse with the highest median zinc concentration was commercial (130 ug/L) followed by industrial (110 ug/L) and residential (65 ug/L). Thirty-six percent of the samples collected in the study contained zinc concentrations greater than the acute water quality criterion of 112 ug/L calculated based on an average water hardness of 28 mg/L as $CaCO_3$ (Figure 2). The concentrations reported for the same rainfall event were, as was true for diazinon values, highly variable.

In the Storm Water Discharge Characterization Final Summary Report—Task 2.0 (1993) from the Phase 2 study, the zinc concentration collected from one of the industrial sites was reported as 1,400 ug/L. In the report, this value

was marked as an outlier which was defined as a data value which is obviously out of the expected range of the parameter being evaluated. In addition, in the analysis of data collected in the study the following rule was applied to evaluate outliers. If the value of a parameter falls more than three standard deviations away from the average for that parameter, the value is scrutinized more closely and replaced with a blank if no other measured values are close. The 1,400 ug/L value was not included in the calculation of EMC concentrations presented in the report.

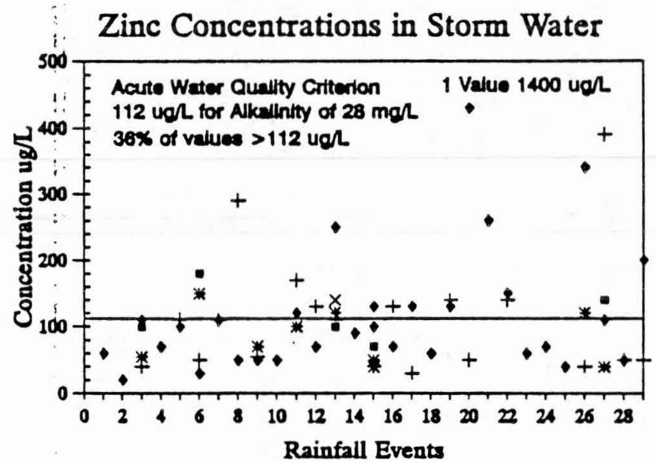


Figure 2. Zinc concentrations from storm water runoff and their relationship to the toxicity of zinc to *Ceriodaphnia dubia*. Symbols associated with different rainfall events represent different sites.

Subsequent to the sample for which the 1,400 ug/L zinc value was reported as an outlier another sample was collected from the same industrial site but in this case, acute toxicity tests were performed on the sample. The sample was determined to be acutely toxic to *C. dubia* with an NOEL of <50%. This was the single sample mentioned previously for which both a significant *C. dubia* response and a significant 15 minute EC50 for Microtox™ was calculated. A Phase I, TIE was performed on the sample. The EDTA chelation fractionation step was the only fraction which removed toxicity. Further independent analysis of the sample showed that the concentration of both zinc and copper were present at acutely toxic levels and lead was present at chronically toxic levels. The zinc concentration was 1,720 ug/L while the copper concentration was 54 ug/L. An examination by City of Fort Worth personnel revealed the presence of a galvanizing company in the area drained by the storm drain. Working with the galvanizer the City should be able to remove the toxicity associated with the facility. Organisms respond to extremes; not averages.

These examples show the usefulness of the toxicity and TIE methods in sorting through toxicity. However, the toxicity methods which were employed in this study are not without weaknesses when applied to the analysis of episodic toxicity events. Foremost amongst these weaknesses are concerns about how well, if at all, these methods mimic exposure of aquatic organisms during episodic events. Collins et al. (1992) state that exposure is a function of several factors including discharge volume, duration, frequency and mixing; receiving stream flow; and pollutant concentration. In 1982, EPA recognized that water quality criteria based on continuous exposure of organisms to constant concentrations of toxicants were probably overprotective when applied to episodic storm water samples. EPA (1982) published a procedure to adjust water quality criteria for exposures which were more in line with those observed in storm water runoff events. The Virginia Pollutant Discharge Elimination System permits for storm water discharges contains a toxic management program which integrates acute toxicity testing, chemical specific monitoring and a toxicity reduction evaluation component. Virginia's toxic management plan uses EPA recommended acute toxicity test methods for *C. dubia*, *Daphnia pulex*, and *P. promelas* but recognizes that exposure is a problem with this methodology (Collins, et al., 1992). If traditional toxicity methods do not mimic episodic toxicity exposure what methods might be used to evaluate episodic toxicity?

Aquatic animals have been shown to induce bioelectric signals into surrounding water which can be recorded as rhythmic analog signals representative of specific movement activities (e.g., gill beats, heart rates, etc.). In addition, gape measurements (the degree to which a bivalve is open or closed) have been successfully used with clams and mussels as a means to determine the status of this organism. Utilizing appropriate statistical techniques and accompanying electronics, changes in bioelectric action responses and gape can

be detected, processed, and continuously recorded, and have been used in detecting water quality induced stress in aquatic organisms.

The concept of using bioelectric action potentials to monitor the well being of aquatic organisms is not new. In the early 1970's Cairns *et al.* (1970, 1972, and 1975) proposed a biological monitoring system for watershed drainage that would provide an early warning of water pollution. In addition to stream surveys, Cairns and his co-workers described a unique system for automatically recording fish breathing and swimming activities in response to developing toxicity in effluents and ambient receiving waters. Since the early 1970's numerous attempts have been made to use remotely sensed bioelectric action potentials to detect adverse conditions (Morgan *et al.*, 1981, 1986, 1987a, 1987b, 1988a, 1988b, 1989). Morgan *et al.* (1986) have used signals generated by individually monitored trout to asses environmental conditions. The signals from the trout were accumulated for a 15-minute interval each half-hour. The data were held in memory of a data collection platform and transmitted to the National Oceanographic and Atmospheric Administration, Geostationary Operational Satellite System on six occasions each day. Broadcast data received by satellite were transmitted to a direct-readout ground station at the Tennessee Valley Authority. Ham and Peterson (1994) have evaluated the effect of low level chlorine concentrations on the valve movement of the Asiatic clam (*Corbicula fluminea*).

Europeans have also been involved in the use of remotely sensed bioelectric action potentials as a means of detecting adverse environmental conditions for aquatic organisms (Caspers, 1988; Matthias and Puzicha, 1990; Slooff, *et al.*, 1983). Specific biomonitors evaluated include the rheotaxis of fish (Juhnke and Besch, 1971) the respiration of rainbow trout (Slooff, 1979) and the electric field alteration of the tropical fish *Gnathonemus petersi* among others (Geller, 1984). A more recent European study used the mussel *Dreissena polymorpha* as a biological monitor (Borcherding, 1992).

Managing aquatic ecosystems at the watershed/drainage basin level has long been an objective of environmental managers. Watershed management by its very nature dictates that loadings to an aquatic ecosystem and their sources be understood. The storm water studies which have been and are being undertaken as part of the NPDES permitting process are making significant contributions to our understanding of loading. It is equally important that the impact of these loadings on the system be understood. The rapid evolution of computers, communications links, geographical information systems, remote sensing, and the information highway have, or will contribute toward advancing the tools necessary to achieve this objective.

The biomonitoring system we are developing and testing is concentrating initially on clam gape to continuously monitor, in near real time, the status of clams (*Corbicula fluminea*) at remote sites. Physically, the non-invasive system uses industrial proximity sensors aimed at foil targets located on the clams to record the gape of the animals. The prototype systems we have built and are testing monitor the gape of ten clams simultaneously.

Conceptually the system we are developing and testing includes the following components and approaches and is part of an overall strategy to manage watersheds:

1. The biomonitoring system which consists of the continuous monitoring of clam gape at each site within the drainage basin being monitored.

2. A means to telemeter the data collected on the status of the clams back to a central receiving station.

3. An alarm system which is activated by the behavior of the clams. When the behavior of the clams is determined by a resident computer program to be out of range of normal a series of samplers will be notified to begin taking samples and an event signal will be sent to the receiving station notifying the operator of an event.

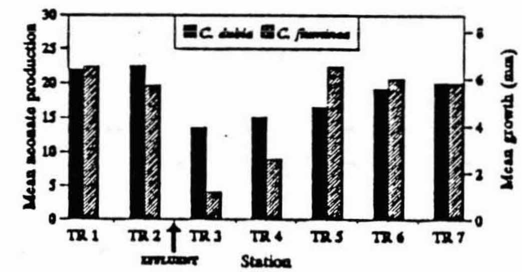
4. The samples are retrieved from the samplers and toxicity is verified using *C. dubia* as the test organism. If the samples are verified as toxic a Phase I, TIE procedure is initiated using *C. dubia* as the test organism. The data from the complete TIE process should be sufficient to identify the causative toxicants. Based on information from the TIE the likely sources of toxicity can be identified and management actions can be undertaken.

Clearly for this monitoring system, or one with similar components, to be effective several important operational conditions must be established. The most important condition is the reliability of the monitor. One consistent problem we have encountered with the monitors we have used in the past is that the volume of information and the complexity of the bioelectric signals being monitored (fish EKG's, breathing, etc.) have been so great as to be nearly overwhelming. This

does not mean they have not functioned well for the purposes they were intended, only that it would be advantageous to simplify the signals for this application. The signals we are monitoring from the clams are greatly simplified. However, we must still establish the frequency of false positives and false negatives before the system can be considered useful. We are in the process of doing this now.

The monitoring system must be sensitive to the presence of toxicants but not so sensitive as to falsely indicate damage to the system one is trying to protect. We have been using *C. fluminea* as an *in situ* biomonitor for some time. In this application caged young *C. fluminea* for which initial length and weight measurements had been taken were used. After an incubation time of approximately a month the cages were retrieved and length and weight determinations were made. Figure 3 shows the relationship between the growth

Comparison of *Ceriodaphnia dubia* & *Corbicula fluminea*
Dechlorination



Sample period 11/90 to 9/92
C. dubia n=17 monthly grab samples; C. fluminea n=4, in situ 28 day exposure

Figure 3. Relationship between *C. dubia* productivity and *C. fluminea* growth.

of *C. fluminea* and the productivity of *C. dubia* collected from the Trinity

River in the DFW metroplex above and below a municipal WWTP.

C. dubia productivity is based on grab samples collected from the Trinity River at the same sites the *C. fluminea* were incubated. In this example the exposure of the organisms were different, but the responses were similar. The suspected toxicant causing depressed *C. dubia* productivity and the reduced *C. fluminea* growth was diazinon. These data support the use of *C. fluminea* as a reasonably sensitive organism. Additional data collected during this and related studies suggest that the Trinity River was impacted beyond that observed for *C. dubia* and *C. fluminea*. The responses of *C. dubia* have been shown to be predictive of in-stream impact (Dickson, *et al.*, 1992).

The data on clam behavior can be telemetered back to a central receiving station from remote sites. We have done this in the past by collecting and transmitting fish breathing rates to an over-passing N.O.A.A. GOES satellite and then to ground stations. We envision coupling the biological monitors with the network of continuous monitoring gauging stations which record stage height, flow, and selected physical chemical factors which already exist (USGS, ORSANCO, TVA, etc.). While the system we are evaluating does not prevent toxicity from occurring it should distinguish between toxic events and non-toxic events thereby reducing the time and effort spent on non-toxic events (35% of the samples tested for toxicity by UNT for the City of Fort Worth in this study showed no toxicity to any of the test organisms used). Since the organisms are continuously exposed *in situ* the exposure regimes should be more realistic than those based on traditional toxicity methods. The exception to this will be the exposure for those organisms that might be entrained and move with the storm water as it travels down the receiving system. Coupling the biomonitors with TIE methodologies should permit the identification of causative toxics and provide the basis for reductions in those toxics. These methods plus the advances in remote sensing, GIS, computer technology, the information highway, file transfer protocol (FTP) sites and the internet should provide the technical basis for managing watersheds.

Acknowledgements: We wish to thank the City of Fort Worth, Mr. Gene Rattan and Mr. Brian Boerner; and the Texas Water Resources Institute, Dr. Wayne Jordan for their support with these projects.

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Experiences from the Blackstone River
Wet Weather Initiative

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Abstract

A program, initiated by the U.S. EPA, to study the Blackstone River under dry and wet weather conditions was conducted to pinpoint and rank major sources degrading water quality. The river was monitored at 13 locations along 48 miles, in addition to, six tributaries and five point sources. Three storms were monitored for 23 constituents with at least ten samples at each of the stations. Methods of interpreting the water quality data and isolating the sources into dry and wet weather sources are presented. The wet weather component is studied to establish loadings from point sources, new materials (runoff related) and old materials (bottom sediment resuspension). A procedure to estimate annual loading rates is presented.

Introduction

Pollutants enter coastal waters either through direct discharge or via a tributary as an integrated watershed load. Water quality studies are typically done under dry weather, steady state conditions. In general, those types of studies are successful and pollution is readily measured and modeled. On the other hand, wet weather sources are more difficult to characterize and predict. Wetweather sources include storm water runoff, bottom sediment entrainment and combined sewage

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overflows.

The Narragansett Bay (Bay) is one of the most important natural resources in Rhode Island (Figure 1). As an estuary, the Bay is the spawning grounds for many aquatic species and a major fisheries and recreational water course, and yet, it is continually under pressure to assimilate significant additions of pollutants. In 1989-90, a study was completed which identified and ranked the sources to the Bay (Wright et al. 1991). The study concluded that the Blackstone River watershed was the major source of both nutrients and trace metals.

In 1991, the U.S. Environmental Protection Agency (EPA) reviewed and summarized all water quality data pertaining to the Blackstone River. As a recommendation of this report, a program was proposed to conduct interstate steady state and wet weather water quality monitoring surveys, to identify and characterize the major water quality problems in the watershed and to calibrate and validate steady state water quality models for application in developing waste load allocations.

Following this recommendation EPA, along with the Massachusetts Department of Environmental Protection (MADEP) and the Rhode Island Department of Environmental Management (RIDEM), developed the Blackstone River Initiative (BRI).

Blackstone River Initiative

Phase 1 of the BRI was conducted jointly by the EPA, MADEP and RIDEM and included a comprehensive dry weather water quality sampling program on the river, tributaries and discharges. The results of the three surveys are summarized in Hartman et al. (1992).

The water quality data were used by the Civil and Environmental Engineering Department at the University of Rhode Island (URI) (Wright et al. 1993; 1994) to calibrate and validate both QUAL2E (Brown and Barnwell 1985), a dissolved oxygen model, and Pawtoxic (Wright and McCarthy 1985), a trace metals model . These models are being used by both MADEP and RIDEM in their waste load allocations.

Phase 2 was a joint program by the EPA, MADEP, RIDEM, URI and the U.S. Geological Survey (USGS). The summary of the field program is reported in this paper. The program included

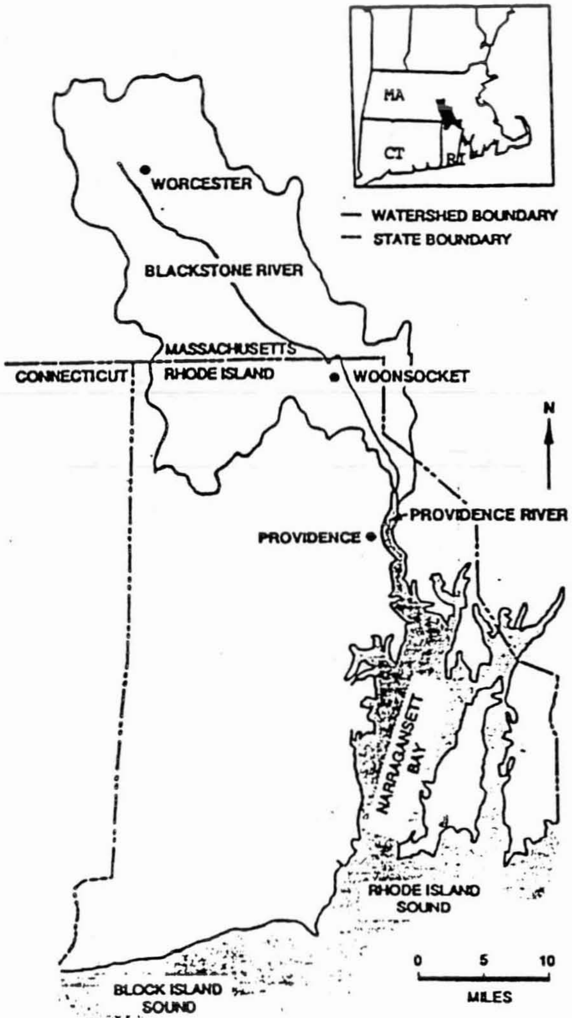

Figure 1. Blackstone River Watershed

the monitoring of the river under wet weather conditions for selected parameters including nutrients, trace metals, microbiological indicators and toxicity. The specific objectives of this study include the following:

1. To determine the spatial and temporal changes to water quality due to wet weather;
2. To identify and rank river reaches relative to wet weather loads and identify major wet weather pollutant sources;
3. To determine the relative importance between wet weather and dry weather loadings; and
4. To forecast annual wet weather loading rates.

System Description

The Blackstone River is an interstate waterway with its headwaters in Worcester, MA. It flows south through Pawtucket, RI into the Providence River and finally, Upper Narragansett Bay. The watershed area covers 1230 km^2 (480 mi^2) and its length is approximately 76.8 km (48 mi). The major tributaries to the river are the Quinsigamond, Mumford, West, Branch, Mill and Peter's Rivers.

The sampling stations are indicated on Figure 2 and listed in Table 1 for both Phase 1 and Phase 2 of the BRI. River mile points are listed from the mouth of the river starting with mile point 0. Only minor station modifications occurred between the dry and wet surveys.

Worcester is the second largest city in Massachusetts and historically has been identified as a major pollutant source to the river (Tenant 1973). The city's wastewater is treated at the Upper Blackstone Water Pollution Abatement District's (UBWPAD) wastewater treatment plant which is a secondary facility with average flows of 1.6 m^3/s (36.6 MGD) providing seasonal advanced waste treatment in the form of nitrification. Worcester also has a combined sewage overflow (CSO) facility which provides settling and disinfection. The CSO facility discharges between BWW00 and BWW01 while the UBWPAD discharges between BWW01 and BWW02.

The other significant urban areas along the river are the cities of Woonsocket, Pawtucket and Central Falls in RI. Woonsocket is serviced by a secondary wastewater plant, with a design flow of

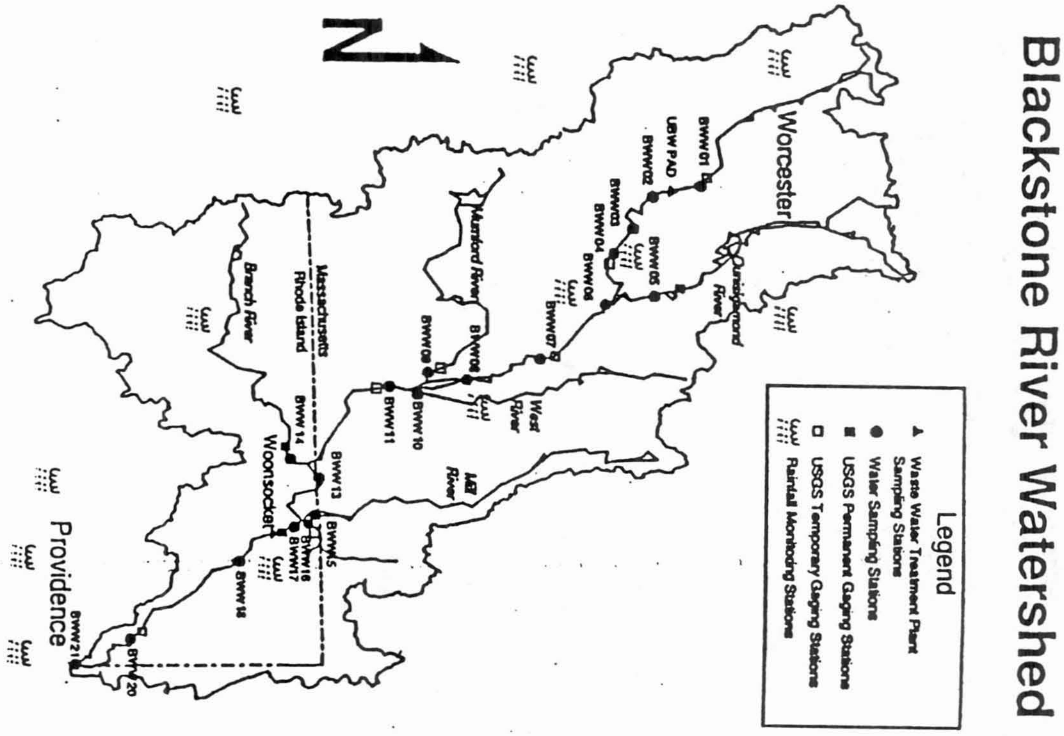

Figure 2. Water Quality Stations for the Blackstone River Initiative

Table 1. Blackstone River Initiative Sampling Locations

Station ID		Location	Drainage Area		River Mile	
Dry Weather	Wet Weather		sq. km	sq. miles	km	miles
		Blackstone River				
	BWW00	Worcester, MA				
BLK01	BWW01	Worcester, MA	194.3	75.9	73.1	45.7
BLK02	BWW02	Millbury, MA	210.2	82.1	70.2	43.9
BLK03		Millbury, MA	233.0	91	66.1	41.3
BLK04	BWW04	Sutton, MA,	252.9	98.8	63.7	39.8
BLK06	BWW06	Grafton, MA	382.7	149.5	58.1	36.3
BLK07	BWW07	Northbridge, MA	398.1	155.5	51.0	31.9
BLK08	BWW08	Uxbridge, MA	413.7	161.6	44.5	27.8
BLK11	BWW11	Uxbridge, MA	690.7	269.8	37.1	23.2
BLK12		Millville, MA	709.1	277	30.6	19.1
BLK13	BWW13	Blackstone, MA	963.3	376.3	26.6	16.6
BLK17	BWW17	Woonsocket, RI	1103.1	430.9	20.5	12.8
BLK18	BWW18	Cumberland, RI	1134.3	443.1	15.8	9.9
BLK19		Cumberland, RI	1143.6	446.7	13.0	8.1
BLK20	BWW20	Lonsdale, RI	1169.2	456.7	5.9	3.7
BLK21	BWW21	Pawtucket, RI	1228.8	480	0.0	0
		Tributaries				
BLK05	BWW05	Quinsigamond River, Grafton, MA	87.6	34.2	58.7	36.7
BLK09	BWW09	Mumford River, Uxbridge, MA	175.4	68.5	40.8	25.5
BLK10	BWW10	West River, Uxbridge, MA	95.7	37.4	38.7	24.2
BLK14	BWW14	Branch River, Slatersville, RI	238.3	93.1	27.8	17.4
BLK15	BWW15	Mill River, Woonsocket, RI	58.9	23	21.3	13.3
BLK16	BWW16	Peter's River, Woonsocket, RI	29.7	11.6	21.0	13.1
		Point Sources				
	WORCSO	CSO Facility, Worcester, MA			75.5	47.2
UBWPAD	UBWWTF	UBWPAD Facility, Worcester, MA			74.6	46.6
Woonsocket	WNWWTF	Woonsocket WWTF, Woonsocket, RI			19.8	12.4
	BUCWTF	NBC BP, East Providence, RI			-3.2	-2
	BUCBYP	NBC BP Byp, East Providence, RI			-3.2	-2

CSO - Combined Sewer Overflow; UBWPAD - Upper Blackstone Water Pollution Abatement District; WWTF - Wastewater Treatment Facility; NBC BP - Narragansett Bay Commission's Bucklin Point Facility; NBC BP Byp - Narragansett Bay Commission's Bucklin Point Bypass

0.70 m^3/s (16 MGD), that discharges directly to the Blackstone River between BWW17 and BWW18. Wastewater from the Pawtucket and Central Falls area is transported below BWW21 for treatment and discharge at mile pt. -2. Both Pawtucket and Central Falls have CSO's which discharge into the Blackstone River between BWW18 and BWW20.

The Blackstone River watershed has a significant industrial and manufacturing history. As a result, there are 20 river impoundments initially built for industrial water supply or hydropower. These impoundments are typically 40 - 60 years old, run-of-the-river, and no longer in use. Three of the largest impoundments are at Fisherville Pond above BWW06, Riverdale Dam at BWW07 and the Rice City Pond above BWW08.

Rainfall Criteria

Establishing rainfall criteria was critical to the success of the monitoring program and the interpretation of the data. The goal was to isolate the effect of a discrete event to permit the characterization of runoff and the determination of the impact on receiving water quality. Rainfall criteria were set in advance of the field program, consisting of a minimum duration of six hours, a minimum of 0.5 inches of total rainfall, an antecedent dry period (ADP) of 3 days and a post storm period of three days. The criteria is designed to sample storms associated with frontal systems that provide uniform rainfall over the watershed. Storm development and movement were tracked by meteorologist with the final decision for the call of the storm provided by URI.

A rainfall monitoring network was established to cover the study area, consisting of six gages maintained by the National Weather Service, 4 URI gages and 2 gages maintained by municipal wastewater treatment facilities (Figure 2). Three storms were successfully monitored on 9/22/92, 11/2/92 and 10/14/93, meeting all rainfall criteria with total rainfalls of 14 mm (0.55 inches), 23 mm (0.92 inches) and 20.3 mm (0.8 inches), respectively. The rainfall coverage for storms I and II were relatively uniform. Storm III ranged from 33 mm (1.3 inches) in the north at Worcester, MA to 14 mm (0.55 inches) in the south.

Sampling Protocol and Frequency

A total of thirteen water quality stations were sampled along the Blackstone River, as well as six tributaries and five point sources discharges. Stations were selected to isolate wet weather problem areas such as point sources, impoundments, combined sewer overflows and junk yards and to provide sufficient spatial detail in the system. The stations were compatible with previous water quality studies along the river.

A prestorm sample was collected 3-4 hours in advance of the storm to define the baseline dry weather loads. Initially, sampling was set at a higher frequency to identify the local stormwater and first flush contribution to the receiving water. A total of 15 samples were taken for each location starting at 3 hour intervals from time 0 (observed runoff) and continuing through 12 hours (5 samples), followed every 4 hours for the next 36 hours (9 samples) with one sample on the third day to define the end of storm. Samples were transported to a field lab centrally located in the watershed for processing and distribution. The list of constituents analyzed is given in Table 2.

Flow Measurements

Three permanent USGS gaging stations located at BWW05, BWW14 and BWW17 provided continuous flow information in the watershed (Figure 2). Additional information was derived from two stations maintained by the Army Corps of Engineers and stage measurements taken at each station during each sampling interval. These stage measurements were converted to flows from rating curves developed by USGS and URI.

Figure 3 illustrates the track of the storm for Storm II starting in Worcester at point A and increasing in magnitude as it progresses south to point D. Major increases in flow associated with tributaries are seen at points B and C.

Spatial and Temporal Changes

The concentration profiles for each event are evaluated by station. Some pollutant concentrations increased indicating significant sources of wet weather loads (ie. TSS, copper and lead)

Table 2. List of Constituents for the Wet Weather Program

Parameter	Units	Detection Limit	Methodology	Reference
Dissolved Oxygen	mg/L	0.1	DO Probe	1
Temperature	deg C	1	DO Probe	1
Conductivity	umhos/cm	10	Conductivity Meter	1
pH		0.1	pH meter	1
Total Suspended Solids	mg/L	0.5	Gravimetric	1
Volatile Suspended Solids	mg/L	0.5	Gravimetric	1
Biochemical Oxygen Demand	mg/L	1	DO Probe	1
Chloride	mg/L	5	Orion Probe	1
Dissolved Ammonia	ug/L	5	Spectrophotometer	1
Dissolved Nitrate	ug/L	20	Auto Analyzer	2
Dissolved Phosphate	ug/L	20	Auto Analyzer	2
Sodium	mg/L	5	Flame AA	3
Calcium	mg/L	0.05	Flame AA	3
Magnesium	mg/L	0.05	Flame AA	3
Zinc	ug/L	10	Flame AA	3
Cadmium	ug/L	0.05	Graphite AA	3
Chromium	ug/L	0.2	Graphite AA	3
Copper	ug/L	0.5	Graphite AA	3
Lead	ug/L	0.5	Graphite AA	3
Nickel	ug/L	0.5	Graphite AA	3
Fecal Coliforms	md/100 mL	1	mTEC	4
Enterococci	md/100 mL	1	mE	4

AA - Atomic Absorption Spectrophotmeter; 1- APHA, AWWA and WPCF (1989); 2 - MERL (1985); 3 - USEPA (1979); and 4 - APHA, AWWA and WPCF (1992)

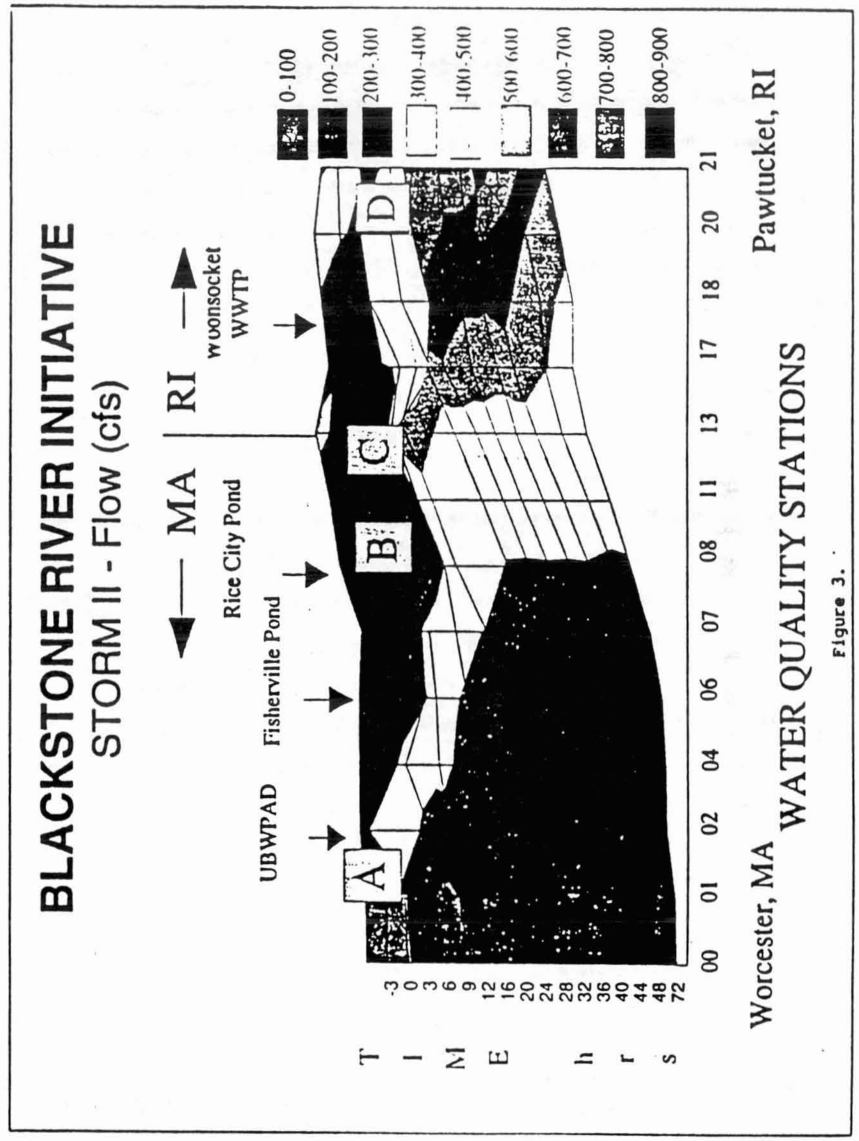

Figure 3.

while other pollutants concentrations decreased, a result of dilution (ie. Ca and Mg).

An example case where the combination of the increase and decrease of individual constituents causes a greater environmental impact is seen with respect to the potential toxicity caused by trace metals. The EPA has established acute and chronic concentrations for trace metals using relationships based on hardness. When hardness decreases, the potential toxicity increases. Thus, in the Blackstone River, under wet weather conditions, the decrease of calcium and magnesium, and thus hardness and the increase of trace metal concentrations, results in violations of a greater magnitude (Figure 4).

The evaluation of wet weather concentrations for each event for the entire watershed also enables the identification of the major wet weather sources. For example, copper concentrations in Figure 5 indicate that the major sources occur at the headwaters between BWW00 and BWW04 (Point A). The CSO discharge between BWW00 and BWW01 and the UBWPAD discharge between BWW01 and BWW02 are contributors and were monitored. However, no major source was identified between BWW02 and BWW04, yet sharp increases of trace metals were observed. The land use in to this reach ranges from suburban to rural, without significant sources of runoff related trace metal inputs.

It appears that the wet weather observations are supported by the results of the dry weather surveys. Earlier observations related to the dry weather data (Phase I), indicated significant increases in metal concentrations due to UBWPAD inputs at BWW02. This was followed by a rapid loss of metals between BWW02 and BWW04. The mechanism of removal is not clear but appears to be either a result of settling or biological uptake. The reappearance of metals in this reach under wet weather is most likely a result of either resuspension or sloughing of biological material. The importance of evaluating the system under both dry and wet weather conditions is evident. Clearly, the results of the dry weather survey suggests UBWPAD is the original source.

Additionally, the concentrations decrease at BWW06 and BWW07 (Point B). This is due to the removal of pollutants in the impoundments above these stations. Below BWW07, the river enters Rice City Pond. Sharp increases in copper can be seen at BWW08 (Point C) at the Pond's outlet with

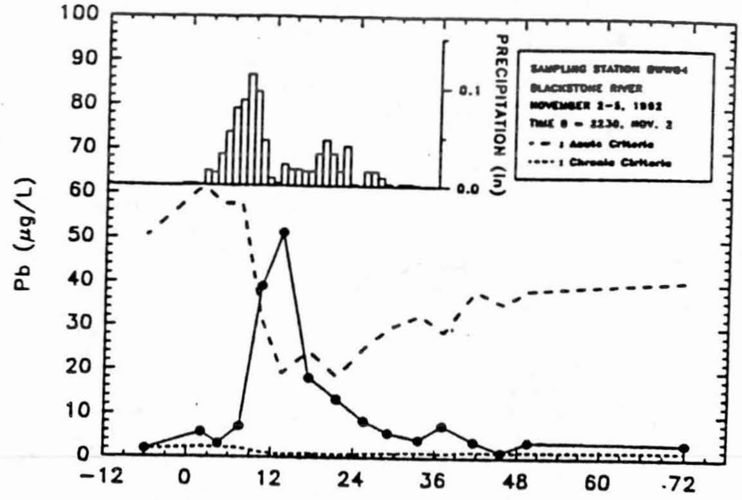

Figure 4. Concentration Profile at BWW04 - Lead

concentrations translating further downstream. This source is a result of sediment resuspension. Unlike the impoundments upstream, Rice City Pond has seen a lowering of the dam height in recent years exposing historic sediments. As the river carves channels through the soft sediments of the impoundment, even moderate flows cause resuspension.

Wet Weather Loadings

The water quality data coupled with stream flows allow for the calculation of mass loading curves. These have been interpreted to define dry weather baseline loads as prestorm conditions and, for comparison, wet weather loads from the integration of the mass curves (Figure 6).

The wet weather mass loads for TSS, lead and copper are presented in Figure 7. The net gain or loss of mass by reach can be observed in Figure 8. These figures provide a spatial view of the river under wet weather conditions. Increases like that occurring between BWW01 and BWW04 are obvious while reductions in wet weather mass loadings are noticed between BWW04 and BWW07.

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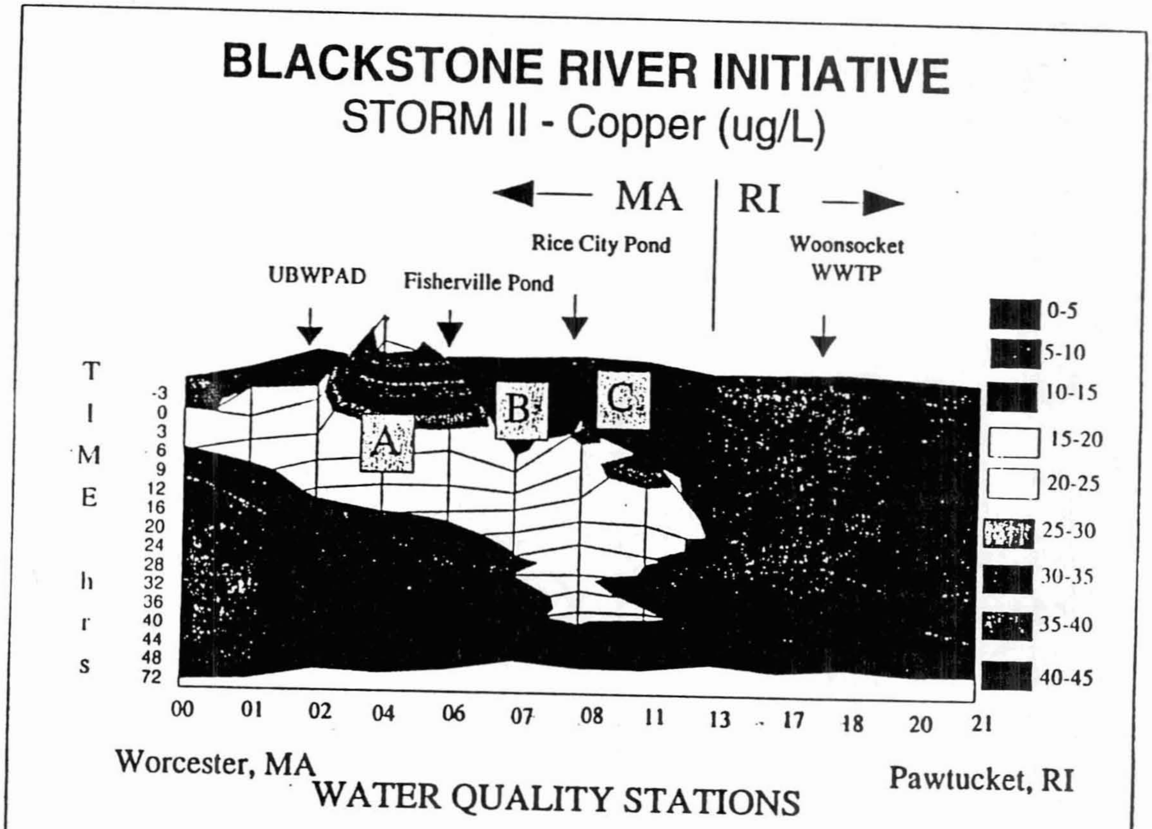

Figure 5.

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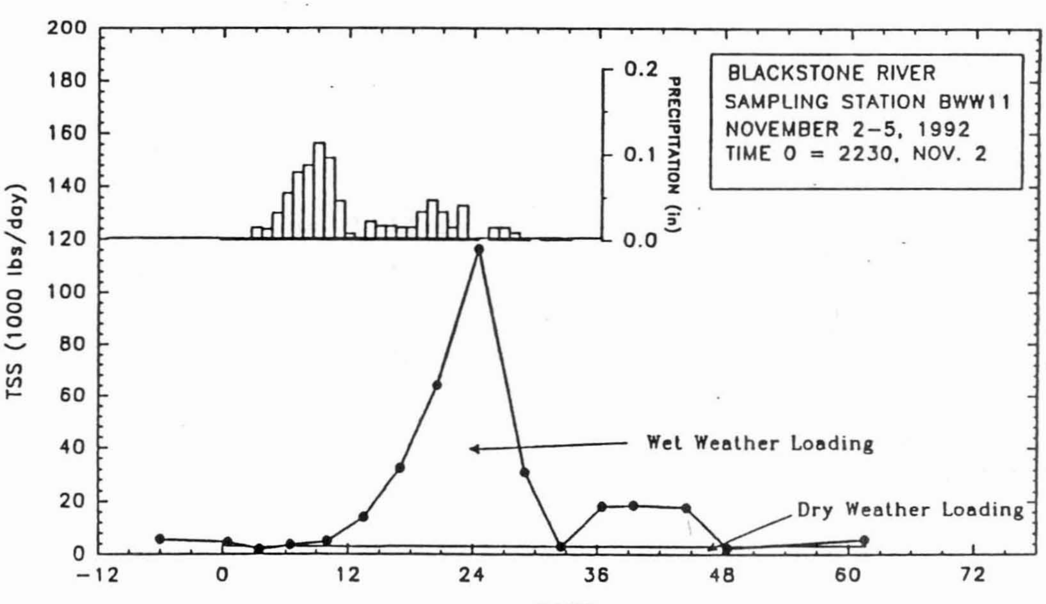

Figure 6. Separation of Dry and Wet Weather Loadings

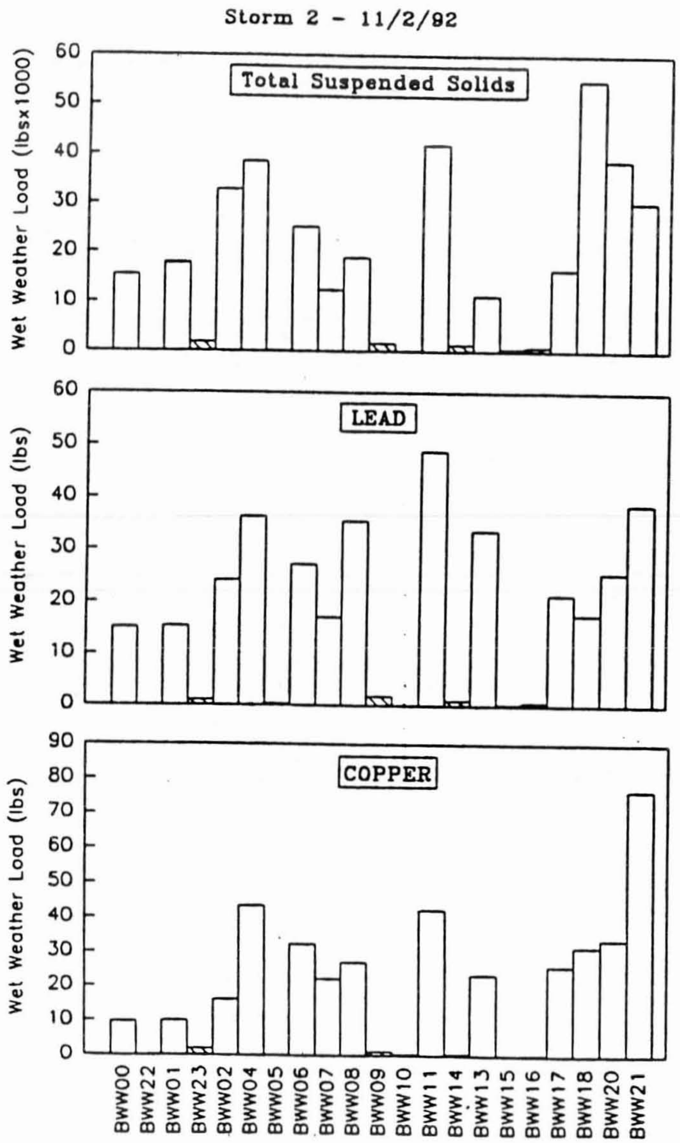

Figure 7. Wet Weather Loads by Station

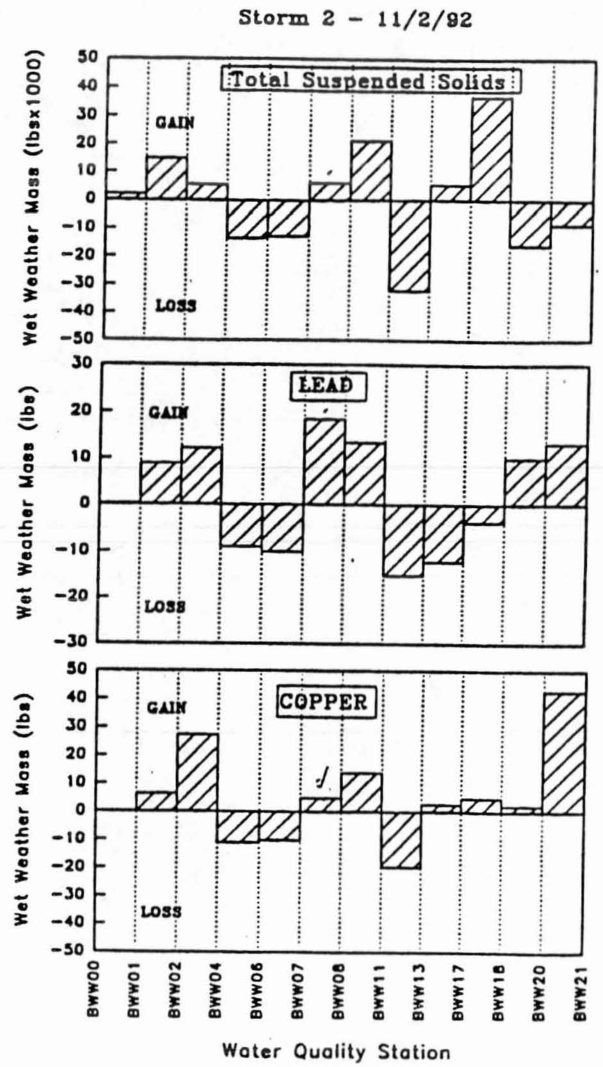

Figure 8. Gains and Losses by Reach

Pollutants associated with wet weather may come from either new sources (runoff induced) or old sources (river sediments). It is important to note that the former may be easier to control and regulate than the latter. The wet weather component was separated into its new and old sources by estimating the resuspension component with the trace metal model, Pawtoxic (Roy Chaudhury 1991; Roy Chaudhury et al. 1993). Through application of the model for a range of flows, relationships were developed for each reach between net mass transported and flows. Resuspension is then estimated from these relationships for the observed flows during each of the wet weather sampling runs. The gain in the resuspension load between stations can be deducted from the wet weather load for an estimation of the new source. Figure 9 illustrates this application for the reach between BWW07 and BWW08. The results of this analysis for TSS, copper and lead is summarized in Table 3. With this method, the wet weather loads of Figure 7 may be refined further to provide an estimate of the resuspended and runoff loads as shown in Figure 10. Since the relationships are based on net mass transported, if net settling occurs within a given reach, a similar procedure can be followed to estimate the runoff component.

Figure 11 illustrates the movement of the mass loading of copper as a result of the wet weather event. The sharp increases in the Upper Blackstone at BWW02 and BWW04 (Point A) occur for samples taken between 6 and 36 hours with the peak at hour 6, while at BWW21 (Point B), the increases are noted between hours 20 and 72, with a peak at hour 20. The progression of the storms impact downstream can be clearly tracked through the hydrograph (Figure 3) and pollutant (Figure 5) and the mass loading (Figure 11) curves.

Figure 11 also supports the partial removal of materials by BWW07 (See also Figure 8) with increases at BWW08 and BWW11. Further downstream it is evident that partial settling occurs by BWW13 and BWW17. The 3-dimensional plots also provided the opportunity to view smaller impacts like localized impacts of the CSOs in Pawtucket (BWW20 and BWW21) seen at hours 3, 6 and 9. Unlike the impacts on system flows, the tributary contribution to the mass loading appears minimum (Figure 7).

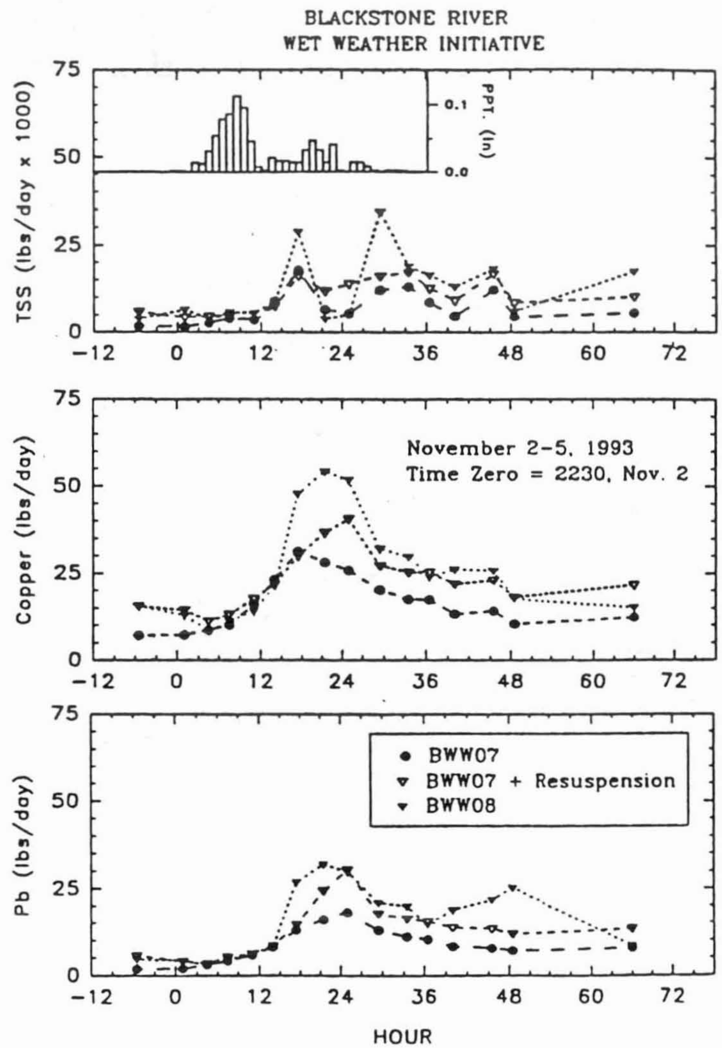

Figure 9. Estimation of Runoff and Resuspension

Table 3. Runoff and Resuspension Loads Between BWW07 and BWW08.

Constituent	BWW07	BWW08	Loading Between	Resuspension		Runoff	
	lbs	lbs	BWW07 and BWW08	lbs	%	lbs	%
TSS	21600	38300	16700	6400	61.7	10.3	38.3
Cu	47.2	72.2	25	15	60	10	40
Pb	26.7	49	22.3	12.6	55	9.7	45

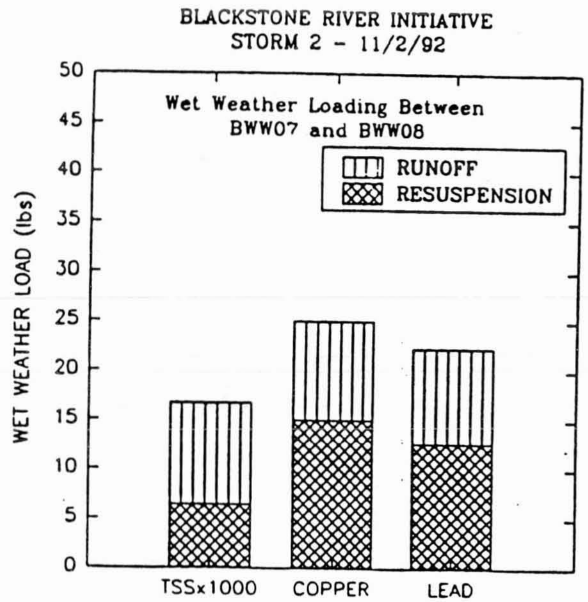

Figure 10.

Pollutants associated with wet weather may come from either new sources (runoff induced) or old sources (river sediments). It is important to note that the former may be easier to control and regulate than the latter. The wet weather component was separated into its new and old sources by estimating the resuspension component with the trace metal model, Pawtoxic (Roy Chaudhury 1991; Roy Chaudhury et al. 1993). Through application of the model for a range of flows, relationships were developed for each reach between net mass transported and flows. Resuspension is then estimated from these relationships for the observed flows during each of the wet weather sampling runs. The gain in the resuspension load between stations can be deducted from the wet weather load for an estimation of the new source. Figure 9 illustrates this application for the reach between BWW07 and BWW08. The results of this analysis for TSS, copper and lead is summarized in Table 3. With this method, the wet weather loads of Figure 7 may be refined further to provide an estimate of the resuspended and runoff loads as shown in Figure 10. Since the relationships are based on net mass transported, if net settling occurs within a given reach, a similar procedure can be followed to estimate the runoff component.

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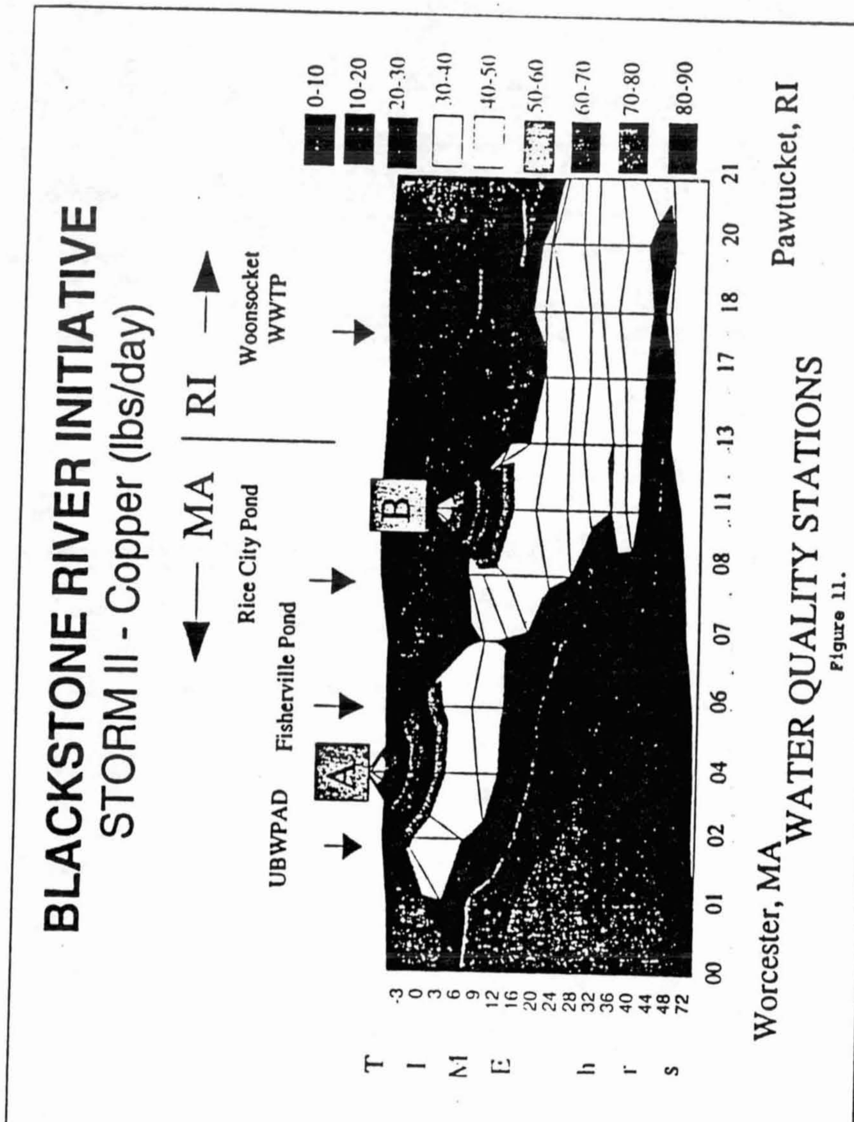

Figure 11.

Annual Loading Rates

Empirical relationships between the wet weather pollutant mass and rainfall characteristics were evaluated initially by Wright et al. (1991) at BWW21, the mouth of the Blackstone River. These relationships when coupled with the historic rainfall records provided an estimate to annual loading rates. Projections of annual wet weather pollutant loadings at the mouth of the Blackstone River will be important to the restoration of the Blackstone River and to the ongoing Narragansett Bay study. A preliminary assessment of this relationship is presented for BWW21 (Figure 12) that includes the loadings calculated from the BRI.

The dry weather models are utilized to predict annual dry weather loadings which are combined with the annual wet weather loadings to provide the total load by station as well as to the Bay. This enables the permitting process to encompass the impacts of runoff in the river as well as to the Bay.

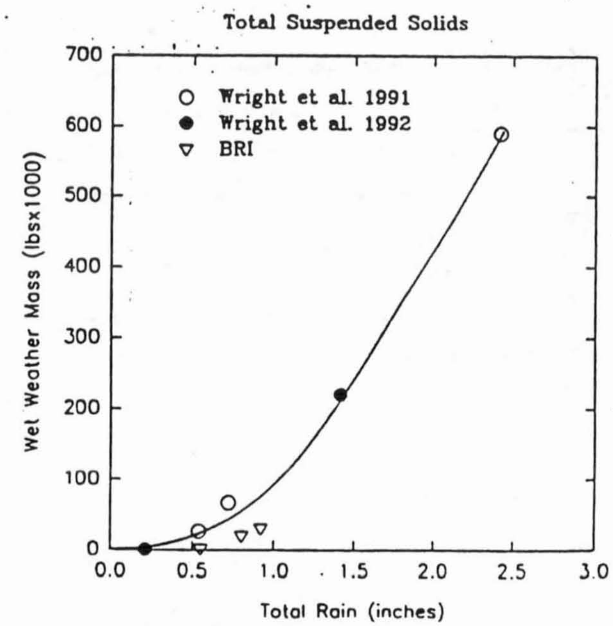

Figure 12. Wet Weather Mass and Total Rainfall Relationship

Conclusion

A comprehensive wet weather monitoring program of an interstate river has been successfully completed. The program consisted of sampling at locations along the river, point sources and tributaries for three storm events to identify and rank sources.

Changes in the river were assessed for impacts from point sources, runoff and resuspension of bottom sediments to water quality and water quality based toxic criteria. For initiating and focussing management alternatives, wet weather loadings are determined to identify and rank the various sources. River reaches may also be ranked to isolate locations for optimizing the institution of best management practices for nonpoint sources. Methods of determining annual wet weather loadings using rainfall characteristics are also discussed.

In systems such as the Blackstone River, gains and losses of wet weather materials due to resuspension and settling are a function of the existing physical attributes of the channel, baseflow and rainfall characteristics. Design solutions to remedy adverse wet weather impacts need to account for the conditions that would result in no losses (worst case), also including natural and man-made changes to the channel. Improvements instituted by waste load allocations for dry weather conditions should also be accounted for during the wet weather permitting process.

Acknowledgements

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Wednesday August 10, 1994

SESSION V: POLICY & INSTITUTIONAL ISSUES OF NPDES MONITORING

1. **"An Industry's Perspective on Stormwater Monitoring"**
   Charles Beck
   Coors Brewing Company

2. **"EPA Use of Stormwater Monitoring Data"**
   William Swietlik and William Tate
   US Environmental Protection Agency;
   Eric Burneson
   SAIC

3. **"Local Municipal Perspective on Stormwater Monitoring"**
   Doug Harrison
   Fresno Metropolitan Flood Control District

4. **"What Congress Should Do About Stormwater"**
   Howard Holme
   Fairfield and Woods, Denver

STORMWATER PERMIT PROGRAM
AN INDUSTRIAL EXPERIENCE

P. Charles Beck[1]

ABSTRACT

The impact of the NPDES stormwater permit program on a Fortune 500 company located in the semi-arid west is discussed. The results of a stormwater outfall sampling program are presented. Modifications to the facility were made as a result of the sampling and site inspection program. The problems and successes of the stormwater permit program from an industrial environmental manager's perspective are presented. Concerns about the future direction of the program and economic impact on industry are raised. A balanced cost-versus-benefit analysis of the program before the enactment of additional regulatory requirements within the stormwater program is needed. An understanding of the basin-wide impacts of non-point discharges is needed. Industry must be an active participant in the development of future stormwater regulations.

INTRODUCTION

The following paper will offer the perspective of a heavily regulated fortune 500 company located in the semi-arid west. It will address a company's experiences with the stormwater permit program and briefly discuss some positive and negative aspects of the current stormwater program. It will also offer thoughts about the future of the program. The views are those of the author and do not necessarily represent the those of Coors Brewing Company.

First some background information for those not familiar with the Coors Brewing Company. Coors Brewing Company, America's third largest brewer, is located in the foothills of the Rocky Mountains just west of Denver, Colorado. The company also has operations in Memphis, TN and Shenandoah Valley, VA.

[1] Manager, Environmental Engineering, Coors Brewing Company, CE 200, Golden, Colorado 80401

The Golden plant is the largest single brewery in the world with a plant brewing capacity of over 20 million barrels of beer per year. To put this in Civil Engineering terms, this is the equivalent of around 0.0745 cms (2.63 cfs) or 74.5 liters per minute (1,180 gallons per minute)...24 hours per day, 365 days per year.

The physical plant straddles a river known as Clear Creek, a major tributary of the South Platte River. Clear Creek is a heavily allocated river supplying seven major water supply and irrigation canals. The Clear Creek headwaters are located within the historic mining districts of Central City and Blackhawk and the Eisenhower Tunnel-Loveland Pass region near I-70. The old mining districts have been identified as potential CERCLA Superfund sites due to the extensive mineral production and processing activities. The area is literally dotted with old tailings piles, mine shafts and mills. As a result, Clear Creek suffers from acid mine drainage problems plus other water quality problems associated with the boom town growth from the revitalization of gambling in the Central City area.

Water flow in the river is highly seasonal and dependent upon winter snowpack and rainfall. During a normal year, flow can range from 22.7 cms to 28.3 cms (800 to 1,000 cfs) to less than 1.42 (50 cfs) in parts of the river. This year the peak flow at the mouth of Clear Creek Canyon was 23.2 cms (820 cfs). The average annual rainfall in the Golden area is approximately 330 to 356 mm (13 to 14 inches).

The brewery has been located in the same area for its entire 120 year existence. Besides the brewing and packaging facilities, Coors' operations in the area include three coal-fired power boilers, two waste water treatment plants, a can manufacturing facility (5 billion cans per year), a can lid or end manufacturing facility and a glass bottle plant.

Coors' has additional property holdings that include an abandoned landfill and an operating gravel mine and asphalt batch plant. The gravel mining and asphalt plant is operated by others.

CURRENT PERMIT STATUS

The NPDES stormwater permit program is a delegated program administered by the Colorado Department of Health, Water Quality Control Division. Coors has been issued six general stormwater permits for both Light and Heavy Industry General Stormwater Discharge activities. The permits cover approximately 180 outfalls to either Clear Creek or tributary irrigation canals. Currently the NPDES discharge permit for the waste water treatment plants is a renewal process with a final draft expected by mid July 1994. The new NPDES permit incorporates a complete section on stormwater for the brewing and can manufacturing plant operations. Coors' will then operate under four general stormwater permits and the NPDES discharge permit.

SAMPLING PROGRAM

1991 Program.

Along with other major industrial concerns Coors' was caught up in the initial permitting frenzy in 1991. Coors, by virtue of having one of the largest ammonia based refrigeration systems in the world, was and still is a "313" industry or heavy industry. The decision was made to pursue an individual industrial permit using the "Form F" application.

Coors was well into completing the "Form F" when the decision to issue general permits was made just weeks before the individual applications were due. Considerable effort and resources were spent assembling the maps and data required for the Form F.

Maps and Surface Areas.

Some twenty-five five-size maps have been assembled on CAD using field data that required some 16 person-weeks to gather. The total area surveyed included approximately 300 hectares (742 acres). Two hundred three (203) hectares (501 acres) are pervious land which includes railroad staging yards and equipment staging areas and undeveloped land. There are 72 impervious hectares (178) acres that includes parking lots, truck aprons and roads. Twenty Five hectares (63 acres) are under roof. At the time of mapping in 1991 the total number of outfalls was 182.

Sampling Data.

Form F required sampling all outfalls unless a case could be made to group essentially identical outfalls together under the provision of similar activities and physical characteristics. This was done as the cost to sample and analyze 182 outfalls for up to 25 chemical analysis methods was prohibitive. The 182 outfalls were grouped into five major categories and the number of samples was reduced to twenty-two. The twenty-two outfalls were selected based on access safety and on their being representative of the industrial activity in the area. Both manual sampling and "automatic" sampling techniques were tried. Manual sampling was the most effective. The automatic samplers did not work satisfactorily particularly in collecting composite samples during storms of short duration. A team of six people was formed to manually sample assigned outfalls.

Sixteen of the twenty-two outfalls were sampled during the summer and fall of 1991. Both grab and composite samples were obtained and analyzed for up to twenty-seven different parameters.

Rainfall was, and still is, measured using a standard tipping bucket rain gauge connected to a Campbell Scientific datalogger. During the sampling period of June to October the Golden site received 198 mm (7.8 inches) of rain in 50 storms. Of the 50 storms 28 were greater than the 2.54 mm (0.1 inches) required for sampling. The maximum storm occurred in August and produced 41.7 mm (1.64 inches of rain). The maximum rain rate was in June and was 69.3 mm/hr (2.73 inches/hour).

The parameters measured included the standard nutrient suite (pH, TSS, Oil & Grease, BOD5, COD, TKN, Total P, etc), metals (Cu, Cd, Pb, Ag, Cr, Zn, Fe) and special organics (600 series).

Figures 1 and 2 summarize the results for the grab samples for selected nutrients and metals during the 1991 sampling. The results for the composite samples were similar but slightly lower in values. Note that the value scale (y-axis) for both figures is logarithmic. The value scale for the nutrients is in parts-per-million (ppm) or mg/l and the value scale for the metals is in parts-per-billion (ppb) or ug/l. The averages shown are skewed by the maximum values. Typically the maximum values are for one or two outfalls. For example, the average for BOD5 is reduced to 42 mg/l when two high values are not included.

Metals Discussion.

To give some perspective to the numbers for the metals please consider the following chart (Table I) which compares the numbers with some existing water standards. The average stormwater values fall within the requirements for both bottled and/or drinking water and RCRA Health Based Standards. The metals values are in some cases above the Warm Class II stream standards as established by the Colorado Department of Health (CDH). Given that the data are for single point samples from different outfalls under different storm conditions it would not be good practice to draw too many conclusions from this data comparison. The data do suggest that additional work would be needed to fully assess the normal distribution of the data for any given outfall for any given parameter.

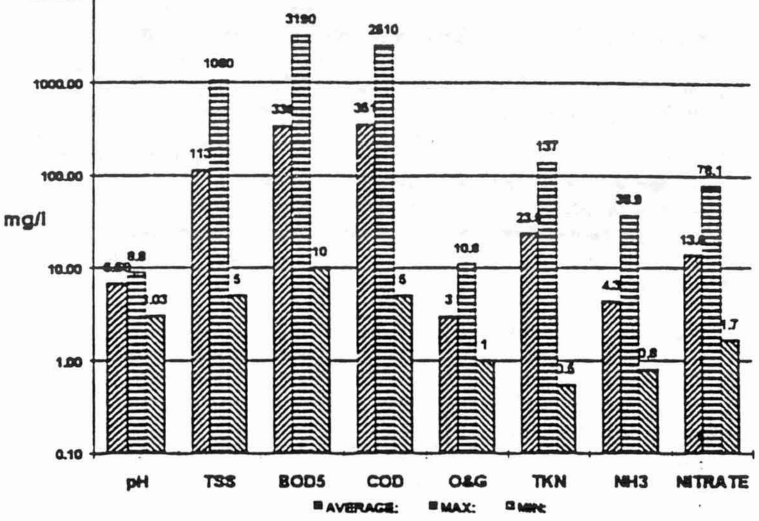

Figure 1. Stormwater Sampling Results for
1991 Grab Sample Nutrients Summary

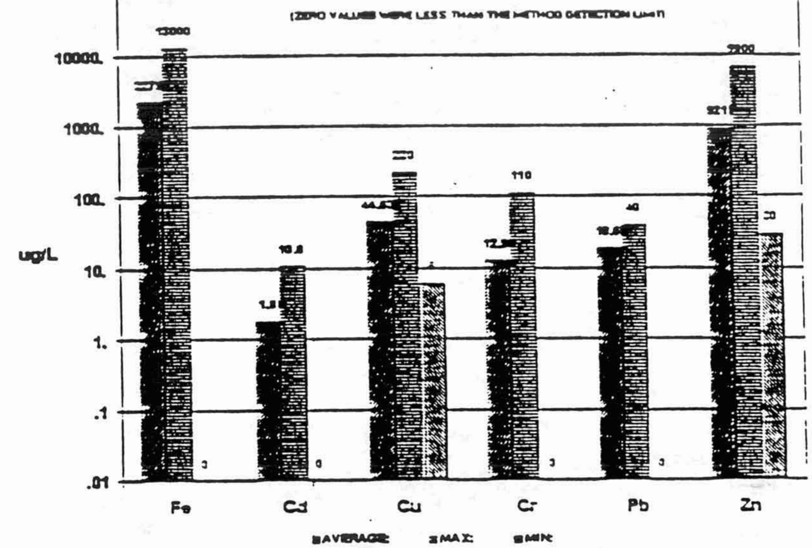

Figure 2. Stormwater Sampling Results
or 1991 Grab Sample Metals Summary

METAL	Health Based Std RCRA 40CFR260.2 ug/l	Bottled Water 21CFR103.3 5 ug/l	Stormwater Max ug/l	Grab Sample Average ug/l	CDH Stream Standard (Warm II @ 116 ppm Hardness
IRON (Fe)	NA	NA	13.000	2.30	NA
CADMIUM (Cd)	5	10 *	11	2	1.3
COPPER (Cu)	NA	100	220	45	13.5
CHROMIUM (Cr)	100	50 *	110	13	234
LEAD (Pb)	15	50 *	40	19	4.8
ZINC (Zn)	7000	5000	6900	920	120
SILVER (Ag)	50	50 *	4.9	.33	.4

* —Also a drinking water standard per CDH 5CCR1003-1.

Table 1. Stormwater Metals Values

Nutrients Discussion.

The nutrients show a wide range in variation in Figure 2. is typically skewed by one or two outfalls with very high values in comparison to the other data. For example the average BOD5 drops from 336 mg/l to 42 mg/l with exclusion of the maximum value of 3190 mg/l. The 42 mg/l value is within the NPDES discharge 7-day average limitation of 45 mg/l. Likewise, the average suspended solids value drops from 113 mg/l to 41 mg/l which is within the NPDES 7-day average of 45 mg/l. The oil and grease values are nearly within the NPDES discharge limitation of 10 mg/l.

Follow-up Actions.

The outfalls which had unusually high parameter values were examined and modified to reduce the source or sources of the problem. For example, the outfall with the 3190 mg/l BOD5 was near a spent yeast drying facility and spilled yeast was responsible for the high value. This prompted a review of the storm drains around the yeast drying facility. Modifications were made to reroute the storm drains to a process waste water drain in the high risk areas around the yeast plant.

The review of the sampling data resulted in modifications of several other potential problem areas within the plant. Roof drains on fermenting buildings ere rerouted from a Clear Creek discharge to the process waste water collection system. Storm drains in high traffic garage areas were modified to collect up to a five year storm event into the sanitary sewer system. Lean-to roof structures have been installed over waste material collection bins and over above ground fuel storage facilities. Manual valves have been installed on outfalls with a high potential for substance spills.

Coors has been under no direct order from a regulatory agency to correct any of the problem outfalls other than the guidance in the general permit. The installation of corrections and modifications have been voluntary and done willingly in the spirit of good corporate citizenship. Coors will continue to make minor improvements in the physical plant which will directionally improve the quality of stormwater.

The current sampling program for Coors calls for sampling of ten outfalls a single time for four parameters (pH, Oil and Grease, TOC and BOD5) and for sampling three additional outfalls twice for the four parameters plus selected metals. An estimate of the discharge volume is also requested. The requirements are for 1994 and 1995 only. This sampling program does not place an undue burden on Coors. However, it is not clear how this stormwater sampling program will address measurable changes in stream quality.

The sampling data is to be included in an annual report to the regulatory agency. It has not yet been stated by the regulatory agency how this data is going to be used in the future. Will the data form a basis for numeric limits or mandatory BMP installation and performance standards. Based on previous experience, industry becomes concerned when reporting numbers to a regulatory agency about how the data will be used and what future culpability may exist from the data.

Additional Comments.

Other topics besides sampling within the stormwater permitting program are of interest to the industrial community. The current stormwater permit program is, overall, a reasonable program. There are, however, some other issues to be considered about the NPDES Industrial Stormwater Program now that the first phase has been implemented for industry.

Regulation Burden.

American industry, particularly manufacturers, is surrounded by environmental regulations. The flow of all significant materials into and out of any manufacturing/industrial complex is now controlled in one fashion or another. Under the Community Right to Know 312/313 program, industry is required to maintain a mass balance for the listed chemicals at all times.

The stormwater program and its permit requirements are considered to be either redundant and of a relatively minor consequence within the industrial environmental regulation arena. From the regulatory manager's perspective it overlaps the RCRA, Community Right to Know and the Spill Prevention and Emergency Response Planning and other programs. This redundancy does create some unnecessary costs for industry. This cost is carried by industry and ultimately by the public through higher product prices.

Program Cost.

The cost to prepare either the individual permit application or the Stormwater Management Plans was much higher than originally estimated by the EPA. This was aggravated by the switch from the EPA Individual Permit program to the State General Permit Program. Coors has spent over $250,000 in the mapping, sampling and administration effort over the last three years. The EPA estimated cost of $15,000 to $20,000 to complete the individual industrial permit application was off by a factor of ten. It is not known if the EPA has developed any figures relating to the on-going costs of the program in terms of annual report preparation, sampling and BMP installation. The Coors experience is not unique. In comparing notes with other major industries in the Denver front range area, Coors' cost was not unusual or out-of-line. Cities may have experienced similar discrepancies between the EPA cost estimates and the actual cost of the application and plan preparation.

Poorly Defined Program Goals

The understanding of the Stormwater problem and the long term goals of the program is limited. The specific lasting effects on the river system from non-point source runoff have not been widely discussed in the trade literature. The benefits of the stormwater program have not been effectively communicated to industry and the true costs appear to be much higher than original estimates.

The NURP study demonstrated that there were elevated levels of contaminates in the stormwater over and above stream standards. The study did not address, in depth, the acute or chronic effects on the receiving waters from the contaminates originating from the urban and industrial environment versus background levels from non-agricultural land sources.

Because of the lack of a clearly defined problem, the industrial environmental manager tends to be less than enthusiastic about committing

resources toward an equally poorly defined solution. Particularly when the NPDES point source, RCRA waste handling and CAA air emissions programs are better defined, more visible and supported with very active regulatory staffs.

Minor Inconsistencies.

Lastly the general permits contain inconsistencies in the application of industrial activity restrictions. For example, in the Colorado General Permits irrigation return flows are allowed but air conditioning condensate flows are not allowed. Irrigation flows are often cited as being major sources of suspended solids, pesticides and phosphates. Fire fighting activity water is allowed, but water from the code required hydrant testing is not allowed. The reasons cited being chlorine levels in the testing water. Building foundation water can be discharged if it is not contaminated, but no standard is cited for defining contamination...is it stream standards, drinking water standards or existing point source standards.

Successes.

The NPDES Stormwater Program is also successful on several counts. Although the improvements to water quality resulting from the program will not often be as dramatic as the point source program, but should be positive for receiving water quality. The permit program is raising the awareness of the effects of outdoor industrial activities on water quality within the industrial community.

System Understanding.

The preparation of the Stormwater pollution prevention plans required by both the light and heavy industrial permits have caused the industry to closely examine its external work activities and the relationship of those activities with the physical layout of the facility.

The initial mapping and site inspection activities revealed areas where simple, inexpensive changes could be made right away. These areas were prioritized and included in the Pollution Prevention Plan and in the budget planning process for the company. If more complex and costly changes are required in the future then the planning and design process will be facilitated by the mapping program.

Illicit Discharge Elimination.

Both the inial and on-going inspection and mapping programs have identified illicit connections and discharges that were previously either ignored or forgotten. For the Coors facility, the most common illicit connections were groundwater collection systems under and around production buildings and HVAC condensate drains. The ground water drains were repiped to the waste water system. As HVAC condensate drains are identified they are rerouted to the waste water collection system.

Spill Reduction.

The three-year spill history review called for in the Pollution Prevention Plan (called the Swamp Plan in our state) placed emphasis on the correction and modification of areas that had a history of repeated spill events. Coors had experienced repeated discharges from process roof vents in the beer fermenting area and periodic spills from the loadout system for waste beer and related byproducts. In each case the system was modified to reroute the discharges to the waste water collection system.

In other cases, where the spills are more random and much less frequent but the activity concentration was high, the drains were equipped with some sort of valving to control the discharges to the local waters.

Improved Storage Practices.

Material handling and storage practices have been inexpensively modified to reduce exposure to stormwater. Simple roof structures over material storage areas and material handling areas have reduced stormwater contact with these operations.

Scrap material hoppers used to collect segregated construction debris, such as wood, mild steel, etc., have been either relocated under roof or have had simple covers installed.

Outdoor housekeeping practices have received renewed interest from the Environmental Specialists in each operating area thanks to the semi-annual inspection program. Housekeeping activities as simple as street sweeping are monitored more closely.

The annual inspection program focuses attention on the activities and site conditions which would affect the quality of stormwater leaving the property.

Employee Awareness.

The Stormwater program requires employee training. At Coors the stormwater training program has been incorporated into an existing mandatory OSHA program. This is given once a year to all Coors Brewing Company

employees and contract employees working on site. The impact for the stormwater program from training program is an increased awareness that spills and careless material handling can affect more than just the immediate area. An unrealized side benefit might be the employee thinking twice before dumping pesticide wastes or radiator fluid on the street at home and finding an alternate means of disposal. This is an area where the local municipalities and industry could work together.

Constructive Regulators.

A final success is the approach taken by the regulators within our state. They have recognized the inherent limitations and pitfalls that exist within the regulation. But, more importantly, they have recognized the intent of the current regulation is pollution prevention. As a result, they have provided a constructive and positive framework for most industry to work in. The enforcement focus has been on the recalcitrant industries which make no positive effort to correct overt problems or industries that could pose a significant risk to the public or are politically sensitive and highly visible.

FUTURE DIRECTIONS

What is the future for the Industrial Stormwater Program? The Clean Water Act Reauthorization, which will dictate the future, is in process and the status the stormwater portion of the act is not defined at this point.

Historically, new regulations demand an improvement in the quality of the regulated media, be it air, water or solid waste controls. It is reasonable to expect that the new CWA will require improvements in stormwater quality from both the municipal and industrial sectors of our economy. The timing and level of improvement is still an open question.

It should be recognized that industry has made significant strides in improving the overall quality of the environment in this country. The costs for the improvements have been distributed relatively painlessly throughout the economy in terms of a modest increase in the cost of goods. There is a desire on the part of many for industry to bear yet a greater portion of the burden of environmental improvement in the foreseeable future....but at what cost?

In the author's view, a point of diminishing returns for the environmental dollar for industry is very close. The benefit versus the cost ratio is shrinking rapidly as major pollution problems are solved and level of control is ratcheted down ever tighter.

The current stormwater regulation is primarily a pollution prevention program and does not, generally, mandate the installation of major (and expensive) structural controls for existing industrial facilities. Will the new stormwater regulations mandate numeric standards to control the quality of stormwater discharges? Will the new stormwater regulations mandate major structural changes to control the quality of stormwater discharges?

Either case is likely given the current stormwater quality monitoring requirement for the heavy industry category. The current approach to monitoring from the regulators is that it is for information only and for the use of the industry to correct obvious problems under the provisions of the Stormwater Pollution Prevention Plan.

It is left to the best judgement of the industry and regulator as to what is acceptable and what is not acceptable. This is a reasonable approach providing industry is proactive and takes visible action to correct problems.

As the spill control, material handling and housekeeping practices are implemented within a facility under the current program the major pollutant components will be reduced and controlled for a relatively small cost. The next increment of control could involve major modifications to the infrastructure of a facility. The resultant incremental cost per kilogram of pollutant controlled could be quite high.

Basin Paradigm.

The air pollution arena provides some insight to a possible future program. The attainment or non-attainment status of a regional air basin determines the level of control required for a discharging industry. The RACT (Reasonably Available Control Technology) and LAER (Lowest Achievable Emission Rate) criteria are used for determining a "reasonable" cost per ton of pollutant controlled against the local pollutant reduction requirements for the air basin.

A similar program could be used for stormwater discharges. The RACT/LAER approach would be used if a receiving water was not achieving a given stream quality criteria within a drainage basin. Based on the quantity and quality on the discharge water certain Best Management Practices could be required if an existing facility is modified or a new facility is built within a given attainment or non-attainment drainage basin.

If a form of the air permit paradigm is used then a valid and enforceable algorithm which balances area of the country, individual stream flow and recovery factors, rain event factors, discharge flow and pollutant concentrations

against a new stormwater stream standard would be required. All sources, municipal, industrial and agricultural, contributing to the basin must be included and the control burden should be prorated on a mass/volume basis. This is an extremely complex problem. Creative and innovative solutions will be required. Water pollutant trading between industry, sanitation districts and non-point dischargers could play an important role in resolving the problem.

The cost and time to then establish and implement an equitable and enforceable program nation wide will be tremendous. The subsequent monitoring and enforcement costs to both regulated community and regulators will also be very high. These costs must be balanced against the economic and quality of life benefits of the program.

Pressure and inflammatory rhetoric could be generated by others to force a rapid implementation of numeric standards. Particularly, if the monitoring data is taken out of context and used, without a sound scientific base to develop unreasonable numeric standards for stormwater. The direction and intentions of the program could be become lost in a fog of chemophobic emotionalism.

The economic impact of a rapidly implemented program that had a minimal rational base would be more severe than a thoughtful and well considered program. It would prove to be extremely costly for industry, the regulatory community and the country as a whole. A recent editorial (6/13/94)in the Washington Post called for "..a careful balancing of costs and benefits.." for environmental programs.

Industry, through trade organizations and professional societies, must be an active participant in the development of any future stormwater discharge standards. For industry, the creator of value added hard goods and the engine of the national economy, the costs associated with government regulations and mandated programs are increasing daily.

The current stormwater program being an integral part of a general pollution prevention program is successfully reducing the pollutant loading to the nations rivers and streams. If the United States is to maintain its competitive position in the world market then a very hard look must be given to the cost versus the true economic benefit for all new and reauthorized environmental programs. Industry must work diligently within our political framework toward the establishment of a rational and economically feasible stormwater program for the country in the future.

STORMWATER PERMIT PROGRAM
AN INDUSTRIAL EXPERIENCE

P. Charles Beck[1]

Key Words

- Industrial
- Stormwater
- Outfalls
- Sampling
- Metals
- Regulation
- Costs
- Nutrients

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STRATEGIES FOR USING STORM WATER MONITORING DATA

William F. Swietlik[1], William D. Tate[2], Robert Goo[3], Eric Burneson[4]

ABSTRACT:

This paper discusses monitoring requirements in the National Pollutant Discharge Elimination System (NPDES) storm water permitting program and reflects upon what has been learned since November 16, 1990, when the NPDES storm water program regulations were promulgated.

The monitoring required of regulated municipal separate storm sewer systems (MS4) and of storm water discharges associated with industrial activity are summarized. Examples of municipal separate storm sewer system monitoring are highlighted along with EPA's experience with the storm water monitoring data reported by industries for the group application process.

In general, for municipalities, the illicit discharge monitoring and outfall characterization conducted during the NPDES permit applications have generated useful data for some municipalities, but in other cases there are clearly ways to improve upon the purposes for storm water monitoring and the methodologies employed. The flexibility afforded municipalities and regulatory authorities in establishing storm water monitoring requirements under the terms of an NPDES permit, on a case-by-case basis, should accommodate more useful and effective monitoring efforts in the future.

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Under the industrial storm water group application monitoring effort, approximately 3,500 industrial facilities conducted monitoring of their storm water discharges and submitted this data to EPA Headquarters. This database represents the most comprehensive collection of industrial storm water data assembled to date. EPA used the data to develop a proposed multi-sector industrial storm water permit to cover 44,000 industrial facilities. In developing the permit, EPA used the data to identify pollutants of concern for each industrial sector, to help identify high priority industries for future monitoring under the terms of the permit, and for selecting the most appropriate pollution prevention measures and BMPs. Monitoring under the proposed permit is designed as an incentive for industry to implement more effective storm water pollution prevention plans.

In conclusion, possible future directions for storm water monitoring for municipal and industrial NPDES storm water discharges are discussed.

INTRODUCTION:

The 1987 amendments to the Clean Water Act added Section 402(p) to the Act which directed EPA to establish and implement a two phase National Pollutant Discharge Elimination System (NPDES) storm water point source permitting program. To initiate this permitting effort, EPA published regulations on November 16, 1990 which defined the types of municipal and industrial storm water discharges that would be regulated under the first phase of the program, and which laid out specific permit application requirements. Storm water discharge monitoring requirements were an important part of the permit application process and will be an important component of NPDES storm water permits.

During the permit application process, storm water monitoring was required for regulated municipal separate storm sewer systems (MS4s) and storm water discharges associated with industrial activity. In general, the monitoring efforts yielded important information for NPDES storm water permit writers as well as for the permittees.

As a result of the monitoring efforts, EPA and the NPDES authorized States will be able to write tailored storm water discharge permits. Such information will also enhance dischargers' ability to target pollutant sources when designing storm water management programs and pollution prevention plans. However, a number of other important lessons have also been learned that should allow permitting authorities and the regulated community to simplify and strengthen storm water monitoring in the future.

For example, many of the monitoring efforts conducted during the permit application process may not provide cost-effective feedback to adjust management strategies. EPA is looking at ways to improve municipal storm water monitoring to be more efficient and to derive the greatest benefits, especially under the terms of NPDES permits.

In addition, such improvements can be incorporated when the second phase of the NPDES storm water program is implemented. For storm water permits issued to MS4s, storm water monitoring needs to be carefully planned and designed to accomplish useful purposes both in the short-term and in the long-term for the regulated municipality, its citizenry, as well as for the permitting authority and for national trends monitoring purposes.

On the industrial side, storm water monitoring must be emphasized as a valuable tool for assessing the effectiveness of an industry's storm water pollution prevention plan and for examining possible receiving water impacts. With reliable storm water data, an industrial operator should be able to determine if current pollution prevention measures are adequate, or if additional measures, and possibly treatment controls, will be necessary.

BACKGROUND:

The NPDES program provides three major tools for requiring and collecting monitoring data: permit applications; permit requirements; and information requests made pursuant to Section 308 of the Clean Water Act. Permit applications are generally national requirements which can provide a snapshot of the discharger once every five years. (NPDES storm water permits are usually issued with a five year term.) Monitoring data in permit applications is generally used for the purpose of supporting the issuance of the permit.

Although some monitoring requirements for NPDES permits are established in national regulations, such as the effluent guidelines, most permit monitoring requirements are established by permit writers on a permit-by-permit basis. This provides a great deal of flexibility to tailor monitoring requirements to each individual discharger. In addition, since permits are written for a five-year term, they can be used to require comprehensive monitoring programs that have the potential to evaluate discharge trends. Requests for information under Section 308 of the CWA are usually done more on an as necessary basis, and can provide a mechanism to fill some of the gaps associated with applications and monitoring requirements in permits or to answer other necessary permitting questions.

The NPDES program takes two very different approaches to controlling pollutants in storm water discharges. Under one approach, storm water requirements for industrial facilities are established in permits issued by EPA or by an authorized NPDES State. The second approach to storm water controls is through the involvement of municipal governments. Under this second approach, EPA or authorized NPDES States issue permits for discharges from municipal

separate storm sewer systems which require the municipal permittee to develop and implement municipal storm water management programs.

One of the major differences between the industrial and municipal approaches is the programmatic flexibility available to develop monitoring programs. As discussed below, the NPDES program relies heavily on the use of general permits to authorize storm water discharges associated with industrial activity. In addition, industrial sites may be one of many sites in a watershed, or within a State, that discharges storm water. These factors tend to limit monitoring efforts to evaluating the nature of storm water discharged from a site and evaluating the effectiveness of the pollution prevention measures implemented at the site.

On the other hand, permits for municipal separate storm sewer systems have a much broader scope which allows consideration of more comprehensive monitoring approaches. As originally intended, storm water monitoring during the term of the NPDES permit for regulated municipal separate storm sewer systems was to be a flexible plan developed by the municipality, and approved by the permitting authority, to meet and support the purposes for the monitoring that the municipality itself identifies as important.

Monitoring for Municipal Separate Storm Sewer Systems (MS4s):

For municipal separate storm sewer systems (MS4) serving a population greater than 100,000, monitoring requirements were established as part of a two-part permit application. For the part 1 permit application, MS4s were required to report the results of field screening efforts to detect the presence of dry-weather discharges, e.g., illicit connections or illegal dumping. Visual observations, including simple colormetric tests, of dry weather flows were used to assist in identifying illicit connections. These were conducted at up to 500 major storm sewer system outfalls, depending on the size of the municipality. The part 2 permit application focused on reporting the results of wet-weather monitoring from representative municipal storm sewer outfalls in a plan approved by the appropriate permitting authority.

Wet-weather monitoring requirements for the part 2 permit application included submittal of quantitative data on physical and chemical characteristics of the discharge taken from at least 5 to 10 representative outfalls during 3 storm events; estimates of the annual pollutant load and event mean concentration of the cumulative discharges from all known municipal outfalls, and proposal of a schedule to provide seasonal loading and event mean concentration estimates for constituents detected during sampling for each major outfall.

Permits for discharges from municipal separate storm sewer systems will require the municipal permittee to develop and implement municipal storm water management programs which focus on implementing non-traditional control measures for priority sites and areas. The nature of these programs presents a number of opportunities that well-designed monitoring programs can support.

Monitoring for Storm Water Discharges Associated with Industrial Activity:

The NPDES regulations provided three different options for industrial facilities with storm water discharges to apply for permit coverage: individual applications; group applications; and submittal of a notice of intent (NOI) to be covered by a storm water general permit. Each option represents a distinct approach to collecting monitoring data.

Individual applications for most types of storm water discharges associated with industrial activity require site-specific narrative information, as well as monitoring data from a representative storm event. Individual industrial permit applications required monitoring for;

- Any pollutant limited in an effluent guideline to which the facility is subject
- Any pollutant listed in the facility's NPDES permit for its process wastewater (if the facility has an existing NPDES permit)
- O&G, pH, BOD_5, COD, TSS, total phosphorus, TKN, and nitrate plus nitrite nitrogen
- Any pollutant known or believed to be present [as required in 40 CFR 122.21(g)(7)]
- Flow measurements or estimates of the flow rate, the total amount of discharge for the storm events sampled, and the method of flow measurement or estimation
- The date and duration (in hours) of the storm events sampled, rainfall measurements or estimates of the storm event (in inches) which generated the sampled runoff, and the time between the storm event sampled and the end of the previous measurable (greater than 0.1 inch rainfall) storm event (in hours). In addition, individual applications must contain a certification that all storm water outfalls have been tested or evaluated for the presence of non-storm water discharges.

The Agency developed the group application process to lessen the monitoring burden on industrial facilities and to provide a large, nationally consolidated database of monitoring data from classes of industrial facilities. The

group application process was intended to encourage similar types of industrial facilities to participate in one data collection effort, thereby compiling information on the class of facilities. EPA provided an incentive for industrial facilities to participate in a group application by only requiring a small percentage of the facilities in the group to monitor, provided the facilities were representative of the members in the group.

- Designated samplers in group applications were required to monitor for;
  - Oil and grease
  - Biochemical oxygen demand, 5-day (BOD5)
  - Chemical oxygen demand (COD)
  - Total suspended solids (TSS)
  - Total kjeldahl nitrogen (TKN)
  - Nitrate plus nitrite nitrogen
  - Total phosphorus
  - pH
  - Any pollutant listed in an effluent guideline to which a facility is subject
  - Any pollutant listed in a process wastewater permit to which the facility is subject
  - Any pollutant from a list of conventional, toxic and hazardous pollutants that the operator of the facility had reason to believe would be present in the discharge from the facility.
- Separate analyses were required for both a grab sample and a flow-weighted composite sample. Grab samples, only, were required for oil and grease and pH.

Over 65,000 industrial facilities representing 1250 groups initially participated in the group application process. Approximately 3,500 of these industrial facilities provided storm water monitoring data. This database represents the most comprehensive collection of storm water data from industrial facilities assembled to date.

The Agency is in the process of finalizing an innovative monitoring approach proposed in the multi-sector industrial storm water general permit based on the data received during the group application process. EPA used the data to identify pollutants of concern for each industrial sector, to help identify high priority industries for future monitoring under the permit, and for selecting the most appropriate pollution prevention measures and BMPs. Under the proposed multi-sector industrial permit, monitoring for the high priority sectors is designed as an incentive for industry to implement more effective storm water pollution prevention plans. Under this incentive, if storm water monitoring shows that pollutant concentrations are below specified levels, the industrial facility no longer is required to monitor under the permit.

Most storm water general permits for industry do not require monitoring data to be submitted during application for coverage. General permits for storm water may identify targeted classes of facilities to conduct monitoring as a condition of the permit. Several factors have helped shape the approaches to developing monitoring requirements in permits for storm water discharges associated with industrial activity, including the large number of facilities that need to be covered by permits, difficulties in sample collection, and variability of data.

The NPDES regulations provide that permits for most types of storm water discharges associated with industrial activity must, at a minimum, require dischargers to conduct annual site inspections to identify sources of pollutants to storm water and evaluate pollution prevention measures. This requirement does not preclude the establishment of additional monitoring requirements on a case-by-case basis by the permit writer.

The baseline storm water general permit issued by EPA for industrial activities provide that most types of facilities do not have to conduct monitoring, but must conduct the annual compliance site evaluation. Under this permit, priority facilities that are thought to present higher risks have been required to conduct chemical monitoring of their storm water discharges in addition to conducting the annual inspections.

EPA has initially targeted classes of industrial facilities that need to conduct storm water monitoring on the basis of available information and best professional judgement. Monitoring requirements are intended to help regulators and permittees identify sources of pollution at facilities, evaluate the risk posed by the storm water discharges, evaluate the effectiveness of control measures and establish a database to support more applicable and effective permit requirements in the future.

For any NPDES permittee monitoring their storm water discharge, data collection procedures described in 40 CFR §122.21(g)(7) are required to be followed. Analytical methods are required to be conducted in accordance with 40 CFR Part 136.

Under 40 CFR §122.21(g)(7), specific storm event criteria were defined within which storm water sampling was required to be conducted:

- The depth of the storm must be greater than 0.1 inch accumulation
- The storm must be preceded by at least 72 hours of dry weather

- Where feasible, the depth of rain and duration of the event should not vary by more than 50 percent from the average depth and duration.

These additional technical criteria were established to: (1) ensure that adequate flow would be discharged; (2) allow some build-up of pollutants during the dry weather intervals; and (3) ensure that the storm would be "representative," (i.e., typical for the area in terms of intensity, depth, and duration).

Collection of samples during a storm event meeting these criteria also ensures that the resulting data will portray more consistent conditions at each site. However, the permitting authority was authorized to approve modifications of this definition, especially for applicants in arid areas where there are few representative events.

To support storm water monitoring requirements, EPA published a storm water monitoring guidance document that describes in detail the methods used for storm water discharge monitoring (5).

MUNICIPAL STORM WATER MONITORING RESULTS:

To illustrate potential uses of wet-weather monitoring data in support of municipal storm water management programs, highlights from the cities of Austin, TX, and Charlotte, NC and the counties of Santa Clara Valley, CA and Montgomery County, MD are discussed below. In addition, a brief discussion is provided on the use of monitoring data to support watershed planning activities in the State of Wisconsin. These examples illustrate how storm water monitoring has been put into practice at various levels. It should be emphasized that these are not the only approaches that may be adopted. Recent studies using biological and habitat assessments suggest that there a number of cost-effective techniques to accurately assess the extent of impacts associated with storm water discharges (19, 20, 23, 25, 27, 28).

Storm Water Monitoring in Austin, TX:

Austin, TX has maintained a storm water monitoring program for over 10 years. The purpose of the program is to collect information on the quality of urban runoff, evaluate the performance of structural controls, and to support the development of design guidelines for storm water quality controls (16). The impetus for this program was to support efforts at protecting several environmentally sensitive watersheds. These watersheds serve as a source of groundwater recharge to the Edwards Aquifer which discharges to Barton Springs (an important recreation resource) or to two lakes that serve as the primary drinking water supply for the city. The storm water monitoring program in these watersheds also coincides with the city's most stringent watershed protection ordinances.[5]

In a five year summary of results (1984 to 1988), the city monitored at seven sites corresponding to watersheds or catchments ranging from 3 to 371 acres in size (16)[6]. The percentage of impervious cover at these sites ranged from 3% to 95%. With the exception of the control watershed and a low-density residentially developed site, all other watersheds or catchments had structural controls that provided detention and/or filtration.

A separate study of sampling data (17) resulted in a number of findings including:

- Typically, first flush concentrations were notably higher as compared to average concentrations from a subsequent series of sampled runoff intervals;
- Austin's experience revealed that a majority of pollutants are not washed away from impervious surfaces during the first 1/2 inch of runoff. As the amount of impervious surface increases, there is a generally negative trend in the percent removed in the first 1/2 inch of runoff as the volume of runoff increases; and,
- A significant pollutant loading will continue to exist if storm water controls are designed to only treat the first 1/2" of runoff. The proportion of untreated runoff increases as the percentage of impervious cover increases.

In addition, analysis of rainfall and sampling data resulted in the development of percent annual pollutant loading curves expressed on the basis of runoff amount and degree of impervious cover. An additional study of monitoring data (1984 to 1989) yielded estimates of removal efficiencies for various structural controls (18). The study also examined the effects of design and maintenance on removal efficiency. The results are used as a basis of maintaining design guidelines for storm water quality control structures (15).

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[5]Austin's storm water monitoring program is also augmented by a cooperative monitoring program with USGS.

[6]The sites monitored included one undeveloped watershed serving as a control, four catchments coinciding with either low or medium density residential development, one high-developed mix between residential and commercial and one highly developed commercial. Five of the seven sites were substantially below 100 acres in size.

Charlotte, NC In-Stream Water Quality Problem Rating Scheme:

The City of Charlotte, NC has developed a stream problem rating system which is designed to characterize and prioritize stream segments based on a series of pollutant parameters believed to reflective of the water quality conditions in the stream segment (14). More specifically, the City has developed limiting concentration ranges for a number of indicator pollutants which are segregated into three action rating levels; No Action, Watch, and Action. In order to develop a reliable rating system, the City consulted numerous information sources currently in existence, e.g., NC Sanitation Foundation Index, NC Water Quality Index, 305(b) reports, and water quality standards for the State of North Carolina. Specific range limits were established for dissolved oxygen, fecal coliform, PO_4-P, NO_3-N, BOD_5, total solids, pH, turbidity, lead, and zinc. An exceedance frequency was then developed for each pollutant which established the number of times a limiting concentration could be exceeded before a stream segment was classified by an action level. Using the database capabilities of a Geographic Information System (GIS), monitoring data were then sorted in order to establish an action level for each stream segment.[7]

The City also developed an action-level correlation matrix for each indicator pollutant based on typical pollutant sources or activities. These sources or activities include; construction runoff, sanitary sewers, fertilizer application, industrial facilities, transportation, illicit connections, agriculture runoff, wastewater treatment plant discharges, residential runoff, and animal waste. The matrix can then be used to investigate the most likely source of a problem based on the action level produced for an individual stream segment. The matrix does not provide sufficient information to exactly determine the problem source(s), however, the matrix does provide a starting point for further investigation.

Santa Clara Valley Non-point Source Pollution Control Program:

Santa Clara Valley Water District (SCVWD) is the lead or managing agency working in cooperation with 14 other California municipalities addressing issues related to non-point source pollution control. The purpose of monitoring focuses largely on collecting data necessary to assess compliance with a copper waste- load allocation established for the San Francisco Bay (a 304(l) listed waterbody) and to monitor for pollutants that have caused frequent exceedances of numeric water quality objectives (WQO) (24).

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[7]Analysis of data from Charlotte's Part 2 Permit Application indicate that for 27 individual stream segments, that the majority of the monitored stream segments were rated as either Action or Watch for all indicator pollutants except for total solids and pH.

In their FY92-FY93 Annual Report, Santa Clara Valley reported that acute water quality objectives are frequently exceeded for total copper and total zinc, and sometimes for total lead. Similarly, chronic water quality objectives are frequently exceeded for total copper, total zinc, and total lead. The Report further notes that acute exceedances were not observed for the dissolved metal concentrations and infrequent chronic exceedances were observed for dissolved metals. Chemical analyses were performed on flow-weighted composite samples collected from several in-stream monitoring stations. The results of the toxicity testing revealed that collected samples were toxic to *Ceriodaphnia*, however, test results were variable based on period of the season that samples were collected.

Statistical analysis of the data revealed that long-term trend analysis could be performed for a number of pollutants at two stream stations (one in the Guadalupe River and one in Coyote Creek). Conversely, data variability was observed to be much greater at two other in-stream stations (Calabazas Creek and Sunnyvale East Channel). The Annual Report noted that statistical methods would allow for grouping of the data for long-term trend analysis from Calabazas station with that of Guadalupe River and Coyote Creek stations. However, extensive channelization in the Sunnyvale East Channel is believed to be a reason that monitoring data cannot be used with other stations for long-term trend analysis (24).

In concert with their monitoring strategy, Santa Clara Valley has instituted a comprehensive source identification program to identify potential sources and land uses suspected of contributing significant amounts of toxic metals. For example, Santa Clara Valley recently completed a study of the contribution of heavy metals from automotive brake pads (Woodward-Clyde 1994). The results of this study suggest that brake pads could potentially contribute on average between 53%, 3%, and 6% of the total annual loads for copper, lead, and zinc, respectively[8]. Santa Clara Valley has also instituted a toxicity control program (TCP) in an effort to identify appropriate measures to reduce toxicity.

Montgomery County, MD's Alternative Monitoring Strategy:

Montgomery County, MD is a MS4 regulated under Phase I of the NPDES Storm Water Program. The County is proposing an alternative to the historical emphasis on accumulating chemical and physical water quality data (29). The County has noted that focusing exclusively on traditional monitoring approaches, i.e., chemical-specific monitoring, is not necessarily the most appropriate means for accurately assessing impacts associated with storm water. In particular, the County recognizes that the effects of storm water discharges are cumulative in

[8]Estimates for copper ranged from approximately 19% to 75% of the total annual load to South San Francisco Bay. Similarly, the range for lead and zinc were estimated to be approximately between 1% to 4% and 2% to 9%, respectively.

nature (e.g., anthropogenic enrichment of streambed sediments, degradation of aquatic habitat, and loss of benthos and fish species diversity) and cannot be exclusively attributed to urban runoff quality alone. Consequently, the County is proposing to use bioassessment techniques, complemented with physical and stream habitat assessments.

The County's strategy includes the collection of baseline data necessary for the development of biological water quality criteria and envisions the eventual development of aquatic life use classes that contain biological, chemical, and physical attainment criteria. This approach is expected to provide the basis of conducting long term trend assessments of receiving water quality (29).

For example, the County suggests that the degree of impairment could be plotted along the entire reach of a stream segment, similar to an approach currently in practice by Ohio EPA. Those areas which indicate significant impairment would be specifically targeted for further investigation and would also serve as a basis of documenting management program effectiveness. The County's proposed monitoring program is intended to reflect the movement towards holistic approaches to ecosystem protection.

Wisconsin DNR Priority Watershed Planning:

In recent years, numerous States and municipalities have instituted comprehensive watershed planning processes for storm water management. Wisconsin DNR has established a watershed approach as part of its Priority Watershed Planning Program (21). The program consists of three major components; a priority watershed plan, an engineering feasibility study, and an implementation phase.

There are a number of elements contained within the priority watershed plan, they include:

a. **Identification of Current and Desired Beneficial Uses:** This element includes results of fish and benthos surveys that quantify existing levels of use. Other habitat surveys may also be included.

b. **Problem Evaluation:** This element includes evaluation of problems that are contributing to impairment of the water resource and, therefore, preventing the attainment of designated uses. Evaluations have included habitat and streambank inventories to determine the suitability of resources to support different aquatic life beneficial uses. This information in conjunction with fish/benthos surveys can then be used to determine the extent of impairment and to identify possible sources contributing to the impairment[9].

c. **Sources of Problems:** This element addresses specific problem sources that are believed to be contributing to receiving water impairment. A distinct aspect of this element of the program is its extensive use of the Source Loading and Management Model (Pitt 1991). Unlike many other urban runoff models in practice, SLAMM was specifically designed as a planning tool for storm water quality management and did not originate as a flood control planning and design tool.

Since storm water impacts are principally cumulative in nature, SLAMM data inputs focus on watershed and land use development characteristics. Consequently, SLAMM is intended to provide information on the significance of different sources, control measures, and drainage characteristics on urban runoff quality[10].

d. **Identification and Evaluation of Suitable Source Area, Drainage System, Outfall, and Receiving Water Controls:** Once problem sources (pollutants and flows) have been identified, this element focuses on the selection of different control strategies. In particular, selecting the individual or mix of controls effective in removing the types of pollutants found, e.g., particulate vs. dissolved metals. SLAMM model output includes pollutant concentrations (particulate & dissolved), flow, and estimate control costs on an areal basis.

e. **Selection of Urban Runoff Control and Habitat Improvement Program:** In this element, the most effective control strategy is selected after considering other programmatic factors including cost.

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[9]For example, the inability of urban resources to meet their designated uses was frequently attributed to periodic flooding and poor water quality. The results of these evaluations could lead to the adoption of goals to reduce streambank erosion, including establishing flow reductions in order to prevent flushing of spawning areas and protection of fish refuge areas (22).

[10]SLAMM represents a tradeoff between the cost of extensive data collection and providing information to support planning level decision-making. It also provides an opportunity to quickly consider the costs and benefits of many different control strategies. The development of SLAMM's specifically focuses on the hydrological characteristics of frequent small storm events which are critical in storm water quality investigations (21, 22).

The second major component of the Wisconsin Priority Watershed Planning program is the engineering feasibility analysis which follows the completion of the watershed plan. Since, the watershed plan is structured around general land use categories, the engineering feasibility analysis allows for consideration of site specific conditions within a particular watershed or basin that may limit or prohibit the use of control strategies identified in the watershed plan.

a. **Site Specific Area Availability, and Groundwater and Infiltration Conditions:** This element considers potential options for locating controls, including retrofit opportunities. Other considerations include identification of sites to promote infiltration provided infiltration rates and groundwater conditions satisfy established standards.

b. **Flooding and Drainage Benefits of Water Quality Controls:** SLAMM cannot be used to perform hydraulic analyses, therefore drainage or local flooding conditions may be required to determine the potential benefits of selecting locations for storm water quality controls.

The final component of the planning process is the implementation phase which entails the development of a cost-sharing agreement. Using information from the previous planning steps, the agreement specifically identifies types of cost-sharable projects that may eligible for matching State funds.

EPA also reviewed available sampling data and information from 23 municipal part 2 permit applications located throughout the U.S. The purpose of this review was to obtain a greater appreciation of the efforts involved in collecting storm water sampling data and to gain some insights on the results. Of these 23 municipalities, at least 14 provided some sampling data which could be used for further analysis. Due to the substantial differences in the amount of sampling data between municipalities and gaps in data, this paper does not attempt to draw conclusions about national trends with respect to the pollutant concentration values. However, sufficient information was available from permit applications, to support some general observations:

- Residential and commercial areas represented an estimated 31% and 27% of sites sampled, respectively[11];
- Approximately 96% of the sampled sites corresponded to a single land use classification;

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[11]Information on land use type was provided for 36 sampling sites.

- The median size of the catchments or watersheds sampled was estimated at 47 acres and ranged in size from 8 to 2,252 acres[12].
- The median value for sampled watershed impervious area was estimated at 47%.
- The average number of sampled sites was estimated to be 6, and ranged from 3 to 10.
- The median and average number of sampled storm events was estimated to be 7 and 12, respectively. An estimated 80% of the municipalities sampled more than the minimum 3 representative events required. Approximately 47% sampled more than 10 storm events.
- Approximately 8 municipalities reported that storm event characteristics were consistent with EPA criteria or satisfied modifications in the criteria by State permitting authorities. Most municipalities reported difficulties with start-stop events, meeting the 72 hours of dry-weather, and/or achieving a total rainfall accumulation greater than 0.1 inch.

RESULTS OF GROUP APPLICATION MONITORING:

The discharge data collected under the NPDES Storm Water Group Application process is perhaps the largest and most comprehensive industrial storm water discharge data set compiled to date. The data set includes the monitoring results from approximately 3,500 industrial facilities which were selected as representative of their larger industry groups. The data includes results collected from a wide variety of industrial activities. It includes data submitted by manufacturing facilities with little exposure of activities to storm water such as electronic manufacturing facilities to facilities with high degrees of exposure such as scrap recycling facilities. Table 1 lists the sectors of industrial activities for which data was received and analyzed.

Limitations of the Group Application Data:

There are, however, a number of limitations to the data set which should be considered when analyzing and reviewing the data. The following paragraphs describe some of these limitations.

[12]This does not include several watersheds monitored by USGS which ranged in size from 4,032 acres (6.3 sq. mi) to 74,240 (22.3 sq. mi.).

TABLE 1

INDUSTRIAL SECTORS/GROUP APPLICATIONS	
SECTOR	ACTIVITIES REPRESENTED
1	Timber and Wood Products
2	Paper and Allied Products
3	Chemicals and Allied Products
4	Lubricants and Asphalt Products
5	Stone, Clay, Glass and Concrete Products
6	Primary Metal Industries
7	Ore Mining and Dressing
8	Coal Mining
9	Oil and Gas Extraction
10	Mineral Mining and Dressing
11	Hazardous Waste Treatment Storage or Disposal Facilities
12	Industrial Landfills, Land Application Sites and Open Dumps
13	Used Motor Vehicle Parts
14	Scrap and Waste Materials
15	Steam Electric Power Generating Facilities
16	Railroad Transportation Vehicle Maintenance Areas
17	Vehicle Maintenance Areas at Truck Terminals, Bus Terminals, Bulk Petroleum Stations, and Postal Service Facilities
18	Water Transportation Vehicle Maintenance Areas
19	Ship Building and Repairing, and Boat Building and Repairing
20	Air Transportation Vehicle Maintenance Areas
22	Domestic Wastewater Treatment Plants
23	Food and Kindred Products, and Tobacco Products
24	Textile Mill Products, and Apparel and Other Fabric Products
25	Furniture and Fixtures
26	Printing Publishing and Allied Industries
27	Rubber and Misc. Plastic Products
28	Leather and Leather Products
29	Fabricated Metal Products
30	Industrial and Commercial Machinery, and Transportation Equipment
31	Electronic and other Electrical Equipment and Components, Measuring, Analyzing, and Controlling Instruments; Photographic and Optical Goods; Watches and Clocks

Monitoring Facilities Were Not Selected Randomly:

The facilities which were designated as samplers in the group application process were not selected at random. The group application requirements established a number of criteria which the monitoring sub-group was required to satisfy. These criteria, which are described in the previous section, were designed to ensure geographic distribution, and representation of the various significant materials and material management practices. EPA required a group to satisfy these criteria prior to approving Part 1 of the application. EPA did not require the groups to randomly select their facilities, therefore once the application criteria were satisfied, a group organizer had discretion in the selection facilities to be monitored.

Monitoring and Analyses Were Typically Performed for Only One Storm Event:

The regulations require facilities to submit analytical results for samples collected from one representative storm event (see the previous section for a discussion of the representative storm event requirements). A significant majority of the facilities limited their monitoring to one storm event, therefore the data does not reflect any variation in concentration that may occur at a facility from storm event to storm event.

Only Half of the Designated Samplers Are Included in the Data:

There were over 6,800 designated samplers from the approved group applications, however, only about 3,500 of these facilities submitted data by the deadlines for EPA to incorporate their data into the analyses. The remaining facilities were not able to meet the application deadline primarily due to a lack of representative storm events during the time frame in which they intended to sample.

Monitoring and Analyses Were Performed by the Permit Applicants:

All data were submitted to EPA by the permit applicants. None of the monitoring or analyses were performed by the Agency. Applicants were required to collect samples in accordance with the regulations under 40 CFR Part 122.21 and analyses were required to be performed in accordance with approved methods under 40 CFR Part 136.

Permit Applicants Determined If They Were Required to Sample for a Portion of the Pollutants:

Within part VII.C of the Storm Water Permit Application form 2F there are a number of pollutants which an applicant is required to sample if he or she "'knows or has reason to believe'... are present in an effluent based on an evaluation of the expected use, production, or storage of the pollutant or on any previous analyses for the pollutant."

Analyses of the Group Application Monitoring Data:

Group application monitoring data were entered into a data base for analyses. Applicant's monitoring data were categorized into one of 31 industry sectors (See Table 1). Categorization was based upon the Standard Industrial

Classification (SIC) code of the facility when provided, or upon the narrative description of the industrial activities at the facility when an SIC code was not included in the application. Data within each sector was analyzed separately.

Prior to analyses, units for each of the pollutant data values were standardized to mg/L (except pH, fecal coliform and several other pollutants not measured in mg/L). Pollutant values reported as below detection limit, or not detected were assigned a concentration of 0.0 mg/L for the statistical analyses.

Analyses of the data were performed using the UNIVARIATE procedure of SAS (SAS is a statistical analyses software package developed by the SAS Institute). For each pollutant sampled at least once within each sector, the following statistics were calculated:

Total Number of Observations,
Total Number of Non-Detects Reported,
Total Number of Detects Reported,
Mean Concentration,
Standard Deviation,
Minimum Concentration,
Maximum Concentration,
Median Concentration (the concentration which was greater than half of the values reported),
95th Percentile Concentration (the concentration which was greater than 95 percent of the values reported), and
99th Percentile Concentration (the concentration which was greater than 99 percent of the values reported).

Statistics were calculated separately for the grab samples and for the flow proportional samples. Tables 2 and 3 present a portion of the results of the analyses. Table 2 lists median pollutant concentration of the grab samples for select pollutants. Table 3 lists median pollutant concentrations of flow proportional composite samples for select pollutants.

Use of the Group Application Data in Permit Development:

The results of the group application data analyses were utilized by the permit writers to develop targeted pollution prevention plan requirements and to select industries and pollutants for further monitoring.

Permit writers utilized the monitoring data to identify pollutants which are likely to be present in high concentrations for an industry sector. They then identified the potential sources of the pollutants and selected pollution prevention measures or structural controls which could be practicably implemented or installed at an industrial facility.

Development of Permit Monitoring Requirements:

The selection of industry sectors for monitoring under the terms of the permit was based in part upon the results of the group application monitoring data. Discharges from the following industries were identified as requiring analytical monitoring as a result of the prioritization analysis: facilities engaged in wood preserving or wood surface treatment, chemical and allied products manufacturing facilities, concrete and clay products manufacturing facilities,

Table 2 - Median Pollutant Concentrations (mg/l) in Grab Samples of Industrial Storm Water Discharges

Sect.	BOD_5	COD	TSS	TKN	NO_3 NO_2	Total P	Total Cu	Total Pb	Total Zn
1	13	131	242	1.6	0.32	0.29	0.03		0.37
2	8	61	41	1.8	0.50	0.18			
3	7	58	40	1.9	0.80	0.24	0.01	0.01	0.24
4	7	48	93	1.1	0.30	0.14			
5	5	51	200	1.2	0.60	0.28	0.02	0.01	0.14
6	11	71	72	2.0	0.68	0.17	0.10	0.02	0.45
7	9	71	403	2.6	0.75	0.30	0.14	0.00	0.59
8	2	6	150	2.6	0.40	0.04			
9	10	82	75	0.8	0.15	0.18			
10	5	33	181	1.1	0.65	0.20			
11	12	41	128	1.3	0.50	0.10			
12	7	31	633	1.1	0.50	0.50		0.08	
13	6	61	183	1.9	0.83	0.05			
14	9	120	148	2.1	0.61	0.29	0.26	0.21	1.40
15	4	33	44	1.3	0.36	0.29	0.00	0.00	0.05
16	6	118	172	1.5	0.92	0.54			
17	8	64	104	1.4	0.60	0.33	0.01	0.01	0.13
18	7	93	135	1.6	0.60	0.10		0.05	0.22
19	3	53	17	1.0	0.72	0.00	0.15	0.04	
20	8	44	29	1.6	0.41	0.20	0.03	0.02	0.08
22	12	69	68	1.5	1.09	0.50	0.01	0.00	0.07
23	14	77	73	2.4	0.56	0.56	0.04	0.01	0.21
24	8	44	36	1.7	0.39	0.15	0.01	0.02	0.19
25	9	83	130	1.7	0.90	0.20	0.04		0.78
26	9	49	30	1.5	0.82	0.14	0.03	0.03	0.37
27	7	53	44	1.4	0.58	0.19	0.00		0.19
28	11	82	49	4.3	1.20	0.16			
29	8	56	76	1.4	0.74	0.22	0.03	0.00	0.36
30	6	36	30	1.3	0.58	0.14	0.01	0.00	0.20
31	6	46	29	1.0	0.51	0.13	0.00	0.00	0.09

Table 3 - Median Pollutant Concentrations (mg/l) in Flow Proportional Composite Samples of Industrial Storm Water Discharges

Sect.	BOD_5	COD	TSS	TKN	NO_3 NO_2	Total P	Total Cu	Total Pb	Total Zn
1	17	122	230	1.5	0.33	0.30	0.03		0.30
2	8	51	13	1.8	0.47	0.16			
3	6	41	25	1.7	0.82	0.22	0.00	0.01	0.24
4	4	50	46	1.0	0.3	0.15			
5	4	44	149	1.0	0.60	0.25	0.04	0.01	0.18
6	8	60	69	1.6	0.77	0.14	0.07	0.02	0.43
7	6	160	330	3.2	0.86	0.38	0.09	0.05	0.66
8	4	14	251	1.5	0.61	0.00			
9	7	92	48	0.9	0.12	0.07			
10	5	37	296	0.8	0.76	0.24			
11	7	34	32	0.9	0.34	0.09			
12	4	28	370	1.0	0.50	0.38		0.18	
13	6	60	226	1.8	1.32	0.11			
14	9	110	85	2.2	0.80	0.29	0.22	0.22	1.70
15	4	39	40	1.0	0.45	0.27	0.02	0.07	0.06
16	6	89	90	1.4	0.78	0.45			
17	6	48	67	1.1	0.52	0.30	0.01	0.00	0.11
18	6	51	68	0.8	0.65	0.17		0.00	0.21
19	1	28	8	1.0	0.72	0.06	0.09	0.01	
20	5	36	22	1.4	0.43	0.20			0.04
22	8	61	56	1.3	0.87	0.44	0.02	0.00	0.06
23	11	63	54	2.0	0.55	0.48	0.03	0.01	0.24
24	7	37	22	1.5	0.40	0.11	0.01	0.03	0.21
25	6	73	91	1.3	0.68	0.19	0.00		0.40
26	6	39	28	0.8	1.05	0.13	0.03		0.52
27	7	43	30	1.2	0.67	0.16	0.05		0.24
28	10	50	86	3.5	0.9	0.18			
29	7	48	32	1.2	0.76	0.21	0.02	0.00	0.21
30	5	29	17	1.1	0.45	0.13	0.01	0.00	0.14
31	5	24	14	1.01	0.51	0.16	0.00	0.00	0.09

primary metals facilities, ore mining and dressing facilities, landfills and land application sites, scrap and waste material processing and recycling facilities, steam electric generating facilities, ship and boat building and repair yards, waste water treatment works, food and kindred products facilities, leather tanning and finishing facilities, and fabricated metal products facilities.

Observations Derived from the Group Application Data:

Despite the limitations discussed, the data collected through the NPDES storm water group application process contains a great deal of information regarding the quality of storm water discharges associated with industrial activity. The following two examples are illustrative of this given the analyses performed to date.

The concentration of pollutants in storm water discharges varies widely among facilities within an industry sector and between the different industry sectors. A number of factors influence the concentration of pollutants in storm water discharges associated with industrial activities, including: the amount and types of materials exposed to storm water; the amount and intensity of rainfall; and the types of best management practices employed at a facility. Given the number of factors influencing pollutant concentrations, and the wide variation in conditions at the facilities conducting sampling, it is not a surprise that discharge concentrations of pollutants vary a great deal. Figures 1 and 2 illustrate this variation for total suspended solids (TSS) concentrations in storm water discharges. Figure 1 is a plot of the cumulative distribution of TSS concentrations in discharges from all industry sectors. Figure 2 is a plot of the cumulative TSS concentration distribution for discharges only from scrap recycling facilities.

The highest pollutant concentrations were generally found at industries with the most industrial activity exposed to storm water. While industrial activity is not the only factor that influences the presence of pollutants in storm water, the data do show that there are generally higher concentrations of pollutants found in storm water discharges from facilities where the majority of activities are performed outdoors as opposed to facilities where activity generally takes place indoors. Figures 3, 4 and 5 compare the levels of pollutants from three high exposure industries (ore mining and dressing, industrial landfills and scrap recycling facilities) to three low exposure industries (furniture and fixture manufacturing, printing and publishing, and electronic equipment and instrument manufacturing). Figure 3 compares median concentrations for three conventional pollutants. Figure 4 compares median concentrations for nutrients and Figure 5 compares median concentrations of metals.

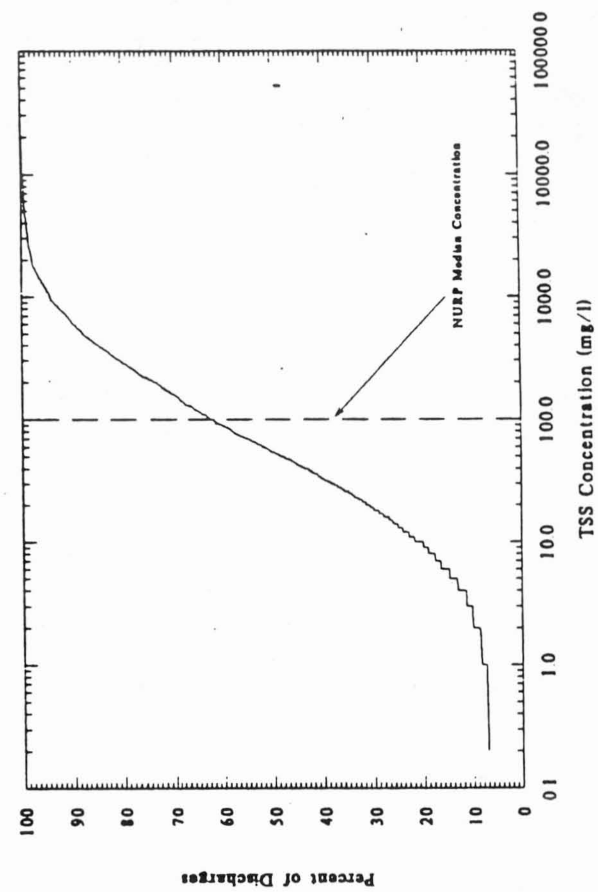

Figure 1. Cumulative Frequency Distribution of TSS Concentrations In Storm Water Discharges From ALL Industry Sectors

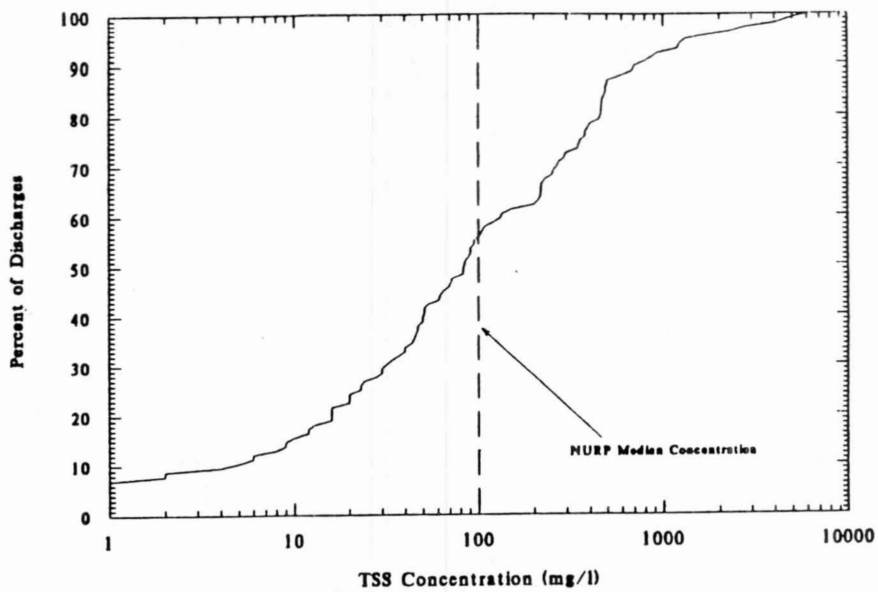

Figure 2. Cumulative Frequency Distribution of TSS Concentrations In Storm Water Discharges From Scrap Recycling Facilities

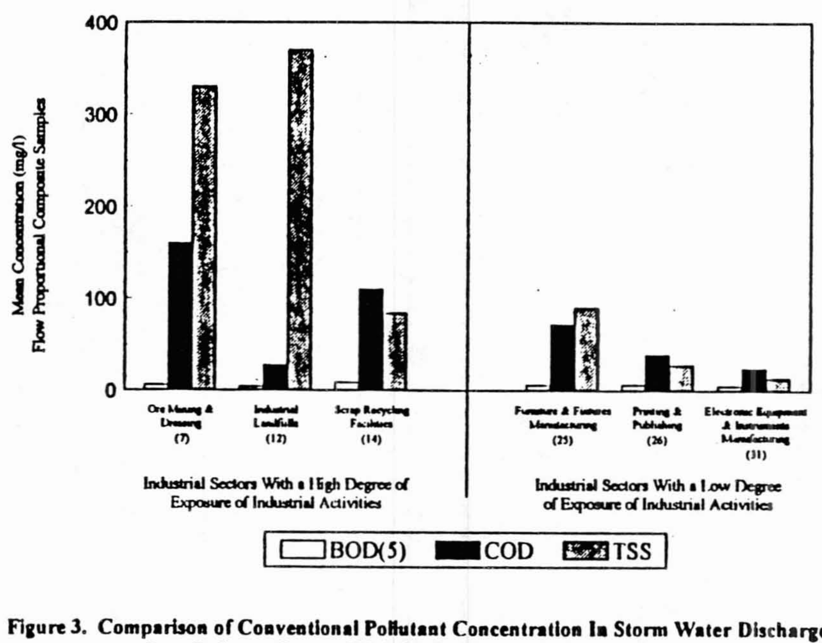

Figure 3. Comparison of Conventional Pollutant Concentration In Storm Water Discharges from Industry Sectors With High vs. Low Levels of Exposure

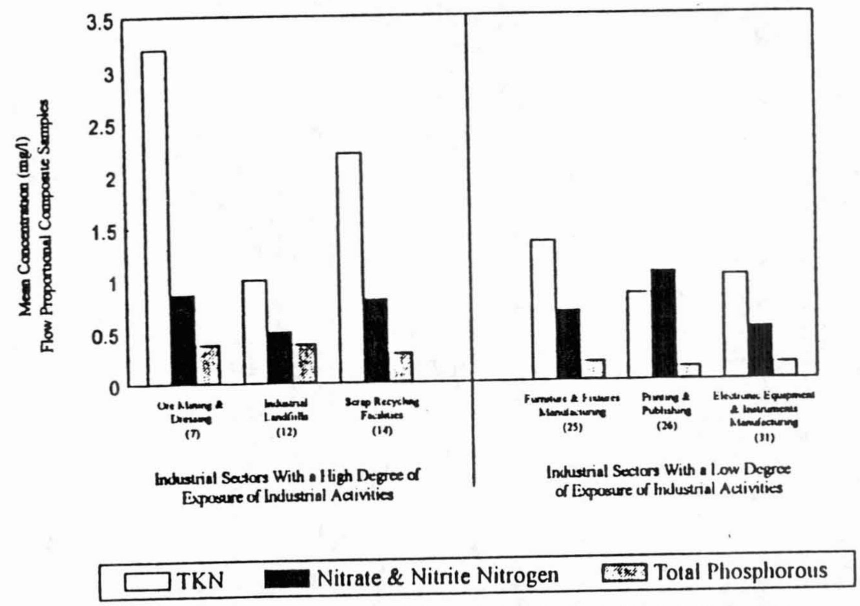

Figure 4. Comparison of Nutrients Concentration In Storm Water Discharges from Industry Sectors With High vs. Low Levels of Exposure

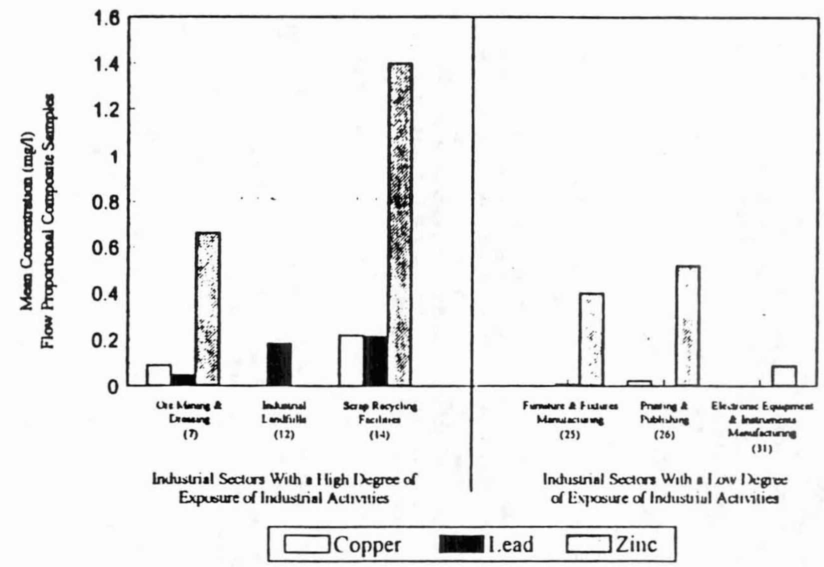

Figure 5. Comparison of Metals Concentration In Storm Water Discharges from Industry Sectors With High vs. Low Levels of Exposure

MONITORING NEEDS IN THE FUTURE:

Municipal Storm Water Monitoring:

Revision of Municipal Application Requirements:

The existing NPDES permit application requirements for discharges from municipal separate storm sewer systems serving a population of 100,000 or more were designed to provide information for first round permits. A major goal of these applications was to provide an initial description of the system and its discharges. The application used a number of sources of information to address this goal, including narrative descriptions of land use, rainfall data, site inspections of selected outfalls to screen for problems associated with non-storm water discharges and limited discharge monitoring data. As municipal storm water programs evolve, issues such as program effectiveness and identification of specific water quality problems become more important so that limited resources can be more effectively targeted to address these problems.

In addition, site-specific requirements for monitoring programs will give individual municipalities direction to their monitoring efforts. These factors will change the monitoring requirements in future municipal storm water permit applications. This change in emphasis may result in a shift from discharge monitoring to the use of alternative monitoring tools such as environmental indicators.

For many types of municipal storm water controls, municipalities will be required to identify priorities for implementation. Priorities for implementing controls will be based on a number of factors, including the potential for discharges to cause or contribute to water quality impacts, the nature of the discharge, and the effectiveness of potential management measures, the geographic location of the municipality, the size and type of receiving water body and the resources available to the municipality. Providing useful information to evaluate these factors should be a major consideration in the development of monitoring requirements in permits for municipal separate storm sewer systems (MS4s).

In addition, application requirements must be developed for any additional "Phase II" municipal separate storm sewer systems that are brought under the NPDES program in the future. One goal of the NPDES program for municipal separate storm sewer systems will be to strongly encourage municipalities to take regional and watershed approaches that involve interaction and coordination amongst municipalities. One critical programmatic step that can be taken to encourage regional/watershed approaches is to synchronize the resubmittal of applications for municipal separate storm sewer systems currently subject to the program with the first time submittal of applications for surrounding "suburban" Phase II municipalities. Failure to synchronize these submittals will greatly decrease opportunities for municipalities to coordinate storm water monitoring efforts, and may result in independent, uncoordinated efforts by individual municipalities.

Use of Biological Assessment Methods:

Given the complex nature of storm water impacts and attempts to put issues associated with urban runoff quality in the proper context with other runoff

related problems (e.g., flooding, aquatic habitat degradation, and sediment enrichment), one prevailing misconception is the need to focus exclusively on urban runoff quality.

Despite the emphasis in the permit application on pollution prevention and identifying potential pollutant sources, it is important to be aware of the significance of other contributing sources. More specifically, practices which produce excessive amounts of runoff, frequently result in substantial alterations to aquatic habitat, e.g., streambank erosion, streambed instability, loss of refuge areas, anthropogenic-enrichment of bed sediments, flushing of juvenile aquatic life forms, and siltation of spawning areas. An example from the State of Ohio illustrates this point.

Lessons from Ohio's Ecological Assessment Program:

Ohio recently adopted numeric biological criteria for its State Water Quality Standards (WQS). A comparison between measured biological impairment and chemical water quality criteria exceedance frequency revealed that biological impairment was evident in nearly 50% of assessed segments where no ambient chemical water quality criteria exceedances occurred (27). This result could suggest that chemical water quality criteria are not stringent enough, however, Ohio observed that in cases where only biological impairment was observed, the causes of impairment, principally low dissolved oxygen/organic enrichment, habitat alteration, and siltation, are not directly measured by chemical specific monitoring, with the exception of low dissolved oxygen.

Chemical causes of impairment were observed in 30.7% of assessed segments. However, the ability to detect chemical exceedances is heavily dependent on other factors such as adequate sampling frequency and the selection of monitoring parameters. More importantly, however, Ohio's experience underscores that both chemical and non-chemical causes can simultaneously contribute to biological impairment which is only evident using bioassessment techniques (27, 28).

Limitations of Chemical-Specific Monitoring:

As noted above, a prevailing misconception is that monitoring requirements during the permit term must focus exclusively on chemical-specific monitoring. Chemical-specific monitoring does not necessarily result in a good representation of receiving water impacts due to storm water discharges. Furthermore, relying extensively on chemical-specific monitoring data as a basis of prioritizing the investment of resources could lead to inadequate coverage of other areas that are greater sources of receiving water impairments. Numerous papers on this subject have noted the growing trend to use other techniques (e.g., bioassessments, habitat evaluations, and sediment analysis) for assessing receiving water impacts (19, 20, 23, 25, 27, 28).

Monitoring During the Permit Term:

The regulations, as they apply monitoring during the permit term, do not specifically require MS4s to perform chemical-specific monitoring only. The regulations provide flexibility to a MS4 to design a monitoring program to support the objectives of their storm water management program. However, MS4s should take into consideration three significant factors when designing a monitoring program:

1. Complying with the statutory provision that effectively prohibits non-storm water discharges into storm sewers;

2. Information to support a determination that pollutants are being reduced to the maximum extent practicable; and

3. Information to support a determination as to whether discharges from MS4s are or are not attaining applicable State water quality standards.

The implications of each of these points are discussed below.

Non-storm Water Discharges:

The statutory provision regarding the effective prohibition on non-storm water discharges to storm sewers is fairly specific. EPA expects that field screening for illicit connections and illegal dumping will continue during the permit term as a monitoring condition. However, it is also expected that MS4s will use the results of previous screening efforts to establish long term priorities based on some appropriate ranking criteria, e.g., proximity to sensitive receiving waters, extent of directly connected impervious cover, use of raw materials in industrial manufacturing, age of system, potential for inflow from sanitary sewers, and evidence of past problems.

Achieving the Maximum Extent Practicable Standard:

Monitoring programs can provide information to support a determination that the storm water management program is reducing the amount of pollutants to the maximum extent practicable. MS4s may elect to conduct long-term trend analysis as a basis of supporting estimates that pollutant are in fact being reduced. However, methods other than chemical-specific monitoring may be used as a basis of meeting the MEP standard.

MS4s may propose to use other alternative monitoring assessment techniques, e.g., bioassessments, habitat evaluations, sediment quality analysis, etc, to demonstrate long term trends. EPA recognizes that in many instances, MS4s do not possess the in-house expertise to perform such assessments. However, a number of States are already performing such assessments and may be ready source of information.

Some factors that should be considered in advance before adopting an alternative monitoring approach include:

- The type of assessment technique to employ, e.g., narrative bioassessment vs. multi-metric indices such as the Index of Biotic Integrity (IBI) or Invertebrate Community Index (ICI);
- Current State regulations and practices;
- The extent to which basins or watersheds are impacted by other stressors;

- Availability of applicable technical and scientific expertise;
- Limitations of assessment techniques;
- Experience of in-house personnel; and,
- Cost.

From the perspective of a MS4, cost of monitoring will be an important concern. However, experiences from Ohio's ecological assessment program reveal that the cost of using bioassessment techniques is very competitive with chemical-specific monitoring.

Attainment of Water Quality Standards:

The ability of storm water discharges from MS4s to meet applicable State water quality standards remains an important issue but is required under the current statutory framework. Numerous organizations and municipalities have asserted that such a goal is neither realistic or achievable because of the unique aspects of storm water discharges, while others maintain current water quality standards are not applicable to wet weather discharges. This is a complex issue and more complete answers will require further investigation. Given the cumulative effects of storm water discharges on receiving water quality and the significance of other factors such as runoff quantity, habitat alterations, geology, and hydromodifications, future storm water monitoring programs will likely evolve from an emphasis on chemical-specific monitoring alone, to one that more fully integrates other methods such as the use of environmental indicators.

Industrial Storm Water Monitoring:

Evaluating Effectiveness of General Permits for Industrial Facilities:

NPDES permits for storm water discharges associated with industrial activity are unlike NPDES permits for traditional sources such as sewage treatment plants and industrial process wastewaters in that they generally do not rely on the use of numeric effluent limitations. Rather, most NPDES permits for storm water discharges associated with industrial activity have required the implementation of pollution prevention measures and best management practices (BMPs). While the pollution prevention/BMP approach has a number of programmatic advantages, a major disadvantage of this approach is that it becomes more difficult to evaluate the effectiveness of the permit requirements. Ensuring that pollution prevention plans are effective should be a key objective of industrial storm water monitoring.

EPA is currently reviewing a number of methods to evaluate the effectiveness of permit requirements for storm water discharges associated with industrial activity and storm water monitoring results may play an important part in this effort. These include identifying measures, such as the number of industrial facilities that have obtained permit coverage and that have prepared pollution prevention plans to control their storm water, reviewing select pollution prevention plans to extract unique, innovative and creative techniques for storm water control, conducting pollution prevention plan audits of certain high priority facilities, working with industry trade associations and other groups to initiative cooperative efforts to assess the effectiveness of permits for industrial storm water, implementing environmental indicators, and possibly collecting and analyzing trends in storm water monitoring results for industrial dischargers across the country.

As more NPDES permitting is conducted on a watershed basis, monitoring of industrial storm water discharges will be necessary for developing State watershed strategies, identifying high priority sources within watersheds and for calculating wasteload allocations for permitting purposes.

SUMMARY:

Due to the nature of storm water impacts, it is expected that municipal storm water monitoring programs will evolve over time as MS4s gain greater familiarity with site-specific storm water problems. Given that many MS4s are dealing with issues of storm water quality for the first time, monitoring programs can be expected to vary in their complexity and NPDES storm water permitting can allow for this flexibility. EPA also recognizes that cost of monitoring will also be a significant factor, however, EPA encourages MS4s to design monitoring programs that yield useful information to support their storm water management program. To accomplish this, municipal storm water monitoring efforts must be carefully designed with a specific programmatic purpose in mind, and then the most appropriate monitoring tools should be selected to meet this purpose.

Municipal storm water monitoring programs can be designed to support specific goals, including:

- Identifying/evaluating pollutant levels of discharges from areas and sites;
- Evaluating hydraulic conditions;
- Characterizing the performance of specific controls and providing information to support site-specific BMP designs;
- Evaluating the overall effectiveness of a storm water management program;
- Identifying water quality impacts and/or trends in water quality;
- Estimating/refining estimates of pollutant loadings;
- Supporting watershed protection/planning efforts; and,
- Supporting physical, chemical and biological assessments of receiving waters.

With the initial implementation of NPDES requirements for storm water, a number of key questions and issues have arisen in relationship to the purpose and methods for monitoring. Underlying these questions and issues is the central goal of trying to find the appropriate mix of monitoring tools to get information in a cost-effective manner to successfully implement NPDES storm water programs. Monitoring approaches developed under the NPDES storm water program should consider a broad set of monitoring tools, including environmental indicators. This is particularly true due to the intermittent nature of storm water discharges; the significant variability of pollutants in storm water; and the difficulties in correlating end-of-pipe storm water discharge data directly to water quality impacts and benefits.

EPA anticipates that a number of monitoring approaches will play a part in municipal storm water monitoring strategies in the future, including: discharge

monitoring for chemical-specific parameters or toxicity, biosurveys, bioassessments, habitat assessments, instream monitoring, and sediment monitoring. Different goals for a municipal storm water management program can be best supported by different monitoring approaches.

For storm water discharges associated with industrial activity, storm water monitoring also plays an important role. Monitoring can, and should be, used at certain industrial activities to determine which pollutants are of concern and need to be addressed by the pollution prevention plan. Monitoring can also be used to assess potential environmental impacts of the storm water discharge. In addition, the ongoing effectiveness of the storm water pollution prevention plan can be assessed by tracking pollutant discharges over time and most importantly, where necessary, monitoring of high-risk facilities can be required to ensure compliance with applicable water quality standards.

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LIST OF KEY WORDS

for

STRATEGIES FOR USING STORM WATER MONITORING DATA

by

William F. Swietlik, William D. Tate, Robert Goo, & Eric Burneson

Key Words:
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pollutants
bioassessment
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POLICY AND INSTITUTIONAL ISSUES OF NPDES MONITORING:

LOCAL MUNICIPAL PERSPECTIVES OF STORMWATER MONITORING

Doug Harrison[1]

Abstract

This presentation reviews the stormwater program mandate imposed on local agencies, the role of monitoring in the mandate, deficiencies which can be expected in the monitoring results and the impact of these deficiencies on the administration of local stormwater NPDES permit programs.

Introduction

There was a time in the recent past when, as a stormwater agency administrator I was looking forward to the monitoring programs required by the stormwater NPDES permit regulations. Frustrated by the obligation to implement a water quality control program and to comply with pre-existing unrelated standards without benefit of supporting data, the pendency of a structured program of scientific measurement was encouraging.

Implementation of the mandated stormwater monitoring programs through the NPDES permits promised help in defining the physical and chemical character of urban stormwater. In addition, these monitoring efforts promised the ability to identify the long-term changes produced by the stormwater permit programs. Unfortunately, the optimism generated by anticipation of solid stormwater quality data is rapidly deteriorating.

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On the basis of an increasing body of work, it seems clear stormwater cannot, within the limits of existing resources, be characterized sufficiently accurately to determine the appropriateness or effectiveness of the stormwater quality controls local agencies are required to implement. Paradoxically, it is likely monitoring activities will divert critical funding away from activities which could actually improve stormwater quality.

The Stormwater Quality Mandate

The Congress, in enacting the Water Quality Act of 1987 attempted to clarify the stormwater obligations created by the Clean Water Act. In short, Congress imposed two basic mandates on municipalities that owned and operated stormwater systems.

1. " . . . effectively prohibit non-stormwater discharges into the storm sewers"; and

2. " . . . reduce the discharge of pollutants to the maximum extent practicable . . ." (emphasis added)[2]

To demonstrate "reduction", which is the obvious test of compliance with the Congressional mandate, a local municipality must first establish the current volume of pollutants being discharged. Secondly, the municipality must then determine, with accuracy at least equal to that in the initial determination, how much of the pollutants previously discharged are no longer being discharged. To arrive at this determination, the community must, of course, be able to distinguish between the changes in pollutant discharges caused by factors unrelated to the controls and those produced wholly by the controls.

To insure that these measurements are produced, the stormwater NPDES program regulation promulgated by EPA (November 16, 1990) added certain monitoring requirements to the congressional mandate. The regulation established a two-part application process which leads to an NPDES permit for the stormwater system. Monitoring requirements are contained in each of these three elements.

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[2]WQA, 1987

Part I Application Requires:

" . . . quantitative data describing the volume and quality of discharges from the municipal storm sewer . . ."

" . . . description of known water quality impacts."

" . . . a field screening analysis for illicit connectings and illegal dumping.

Part II Application Requires:

" . . . provide information characterizing the quality and quantity of discharges . . . from representative outfalls . . .;"

" . . . estimates of the annual pollutant load of cumulative discharges . . . and the event mean concentration of the cumulative discharges . . . from all identified municipal outfalls for [specified constituents]."

Permit Program Requires:

" . . . monitoring program for representative data collection for the term of the permit . . ."

" . . . monitor and control pollutants in stormwater discharges to municipal systems from . . . industrial facilities . . ."

"Assessment of Controls; estimated reductions in loadings of pollutants from discharges of municipal storm sewer systems . . ."

" . . . identification of water quality improvements or degradations . . ."[3]

In short, the regulation prescribing the elements of the permit program and related application process, outlined five questions local agencies are required to answer:

1. How much pollutant is being discharged?

2. Where is it coming from?

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[3]USEPA, November 16, 1990

3. What harm has it caused?

4. How do you propose to reduce it?

5. How much did you reduce it?

Given the assumption that it was possible to generate data which would provide answers to these questions, the requirement for local municipalities to produce answers was logical. What is now in doubt however, is the validity of the underlying assumption.

If, in fact, it is not possible to accurately answer these questions the municipality is left in pursuit of a mandate which devours resources without any means of determining results or benefits. Of even more concern, municipalities are left without a defense for allegations of violation of the CWA.

The Critical Role of Monitoring in the Stormwater NPDES Program

Because of the previous conclusion, the justification and the potential for success or failure of the stormwater NPDES permit program is anchored to the monitoring element of the mandate. Only with accurate quantification of the stormwater problem, its sources and the achievable results can the stormwater program maintain its political priority, justify the allocation of resources, and provide the necessary means of enforcement. Clearly, the Congressional mandate for business and local government to spend hundreds of millions of dollars annually on stormwater quality was sold on the basis that preliminary conclusions generated by NURP could be specifically confirmed and quantified by a nation-wide permit driven monitoring program.

The Multiple Objectives of Stormwater Monitoring

Because of the inherent dependency of the stormwater regulatory effort on the program's monitoring component, that component has been assigned a variety of diverse objectives by the many key parties of interest.

- Activists, regulators and legislators must use the monitoring process to demonstrate that stormwater pollution is, in fact, a major controllable source of adverse environmental impacts, warranting the massive expenditures required to achieve "clean-up".

- Enforcement interests must demonstrate that site and use specific sources can be accurately measured to support the civil and criminal actions brought against CWA violators.

- Municipalities and business require data which will support the diversion of financial resources to stormwater quality, and to differentiate between inefficient controls and those which are cost effective.

Many other interests also color the structure of the monitoring program. Some are involved for the pure delight of research; others have an interest shaped by a profit and loss statement.

The impact of such a diversity of interests is compounded by two additional factors which are most significant. The first is the absence of a national strategy for stormwater monitoring and data development. The second is the ad hoc nature of the stormwater permit, with the structure of each of the permit monitoring programs being determined at the discretion of a relatively independent permit writer.

Unlike NURP, which established clear objectives and guidelines toward the goal of a nationally significant data base, the stormwater NPDES permit program has as many different monitoring strategies as it has permits.

The result of this diversified interest in stormwater monitoring has been a predictable disjointedness among the various monitoring programs. Some are conducting research on beneficial use impacts; others are examining sources. Some are examining land use differences while others try to explain hydrologic impacts. Some are still trying to determine how stormwater discharges differ from traditional point source discharges, and others are evaluating available forms of pollutants in the stormwater. Some may even be trying to do it all. Certainly, because of its complexities, every municipality could conduct focused stormwater quality research unique to their locale, and many permit writers are appearing to require it.

Recognizing that much monitoring and research is now underway, the question that must be asked is whether the results will be sufficiently accurate to justify either the cost of the stormwater quality program – or the cost of the monitoring itself.

Relationship Between Monitoring Costs and Stormwater Program Costs

The matter of stormwater program costs has been hotly debated. Estimates to fully implement the congressional mandate have ranged from the absurdly low levels presented by EPA in its November 1990 regulation ($14.5 million annually)[4] to the fearfully high levels estimated by the APWA, Southern California Chapter in May 1992 ($542.0 billion annually).[5]

Cost estimates defining stormwater program needs have been as detailed as the use attainability analysis performed by the City and County of Sacramento ($2.0 billion, local need).[6] Others, like EPA's 1992 Needs Survey Report to Congress ($116.5 million, national need)[7] have excluded virtually all implementation costs associated with the stormwater NPDES permit program requirements.

The real issue buried in all of the rhetoric is "what do you get for what you spend?" It is in the satisfaction of this issue that monitoring again assumes the central focus of the entire stormwater quality program. Stormwater managers are being repeatedly asked by policy makers and administrators to demonstrate that the dollars invested will produce a verifiable result.

Unfortunately, a growing body of evidence is suggesting that, as currently structured, our stormwater monitoring program can do neither. More discouraging is that substantial increases in data usefulness cannot be achieved without massive increases in the resources allocated to the monitoring effort.

It has long been recognized that the variables associated with urban runoff, which include the limitless multiplicity of sources, the episodic nature of runoff events, the massive magnitude of source areas and flow volumes, and the unknown assimilative capability of receiving waters, prevented any hope of discreet cause and effect findings from stormwater monitoring. Expectations were high, however, that changes in the long-term stormwater quality trend lines produced by broadly based consistently applied control practices could be observed and measured, providing a form of program assessment and a measure of cost effectiveness.

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[4] USEPA, November 16, 1990
[5] Montgomery, May 1992
[6] Walker, December 1990
[7] USEPA, September 1993

However, recent work by Woodward-Clyde (which will be reviewed at this conference) has produced conclusions which create reservations about the validity of even this more conservative expectation. Specifically, Woodward-Clyde's work has produced the conclusion that significant increases will be required in monitoring program expenditures if changes in long-term stormwater quality trend lines are to be measured with any significant confidence.

The Woodward-Clyde analysis has determined that, for the Fresno California metropolitan area, 64 composite samples per year will be required over a ten year test period to detect with 80% confidence a 20% change in copper concentrations. This contrasts with the monitoring plan which was to be made a condition of the Fresno NPDES permit, that plan proposing 15 samples per year. However, we now know that at 15 samples, the Fresno program has only a 15% chance of detecting a 20% change over the 10 year test period.

Correspondingly, Woodward-Clyde's work indicates it will be much easier to detect large changes in the long-term stormwater quality trend lines. For example, again in the Fresno California case, the planned 15 sample per year program has a 48% chance of detecting a 30% reduction, and a 79% chance of detecting a 40% reduction.

The obvious caveat for program managers is the imperative of insuring that the control program creates a big change in stormwater quality. If not, your monitoring program is not likely to detect the impact at any significant confidence level.

The significance of this information to stormwater program managers can be seen in the following graph. The graph contrasts the monitoring program costs required under the pending Fresno area NPDES permit with the costs required to increase the confidence level of confirming a 20% change in stormwater quality from 20% to 80%.

As currently structured, the Fresno area NPDES stormwater permit program will expend $1.55 million dollars over the next ten years on monitoring (assumes annual expenditures of 1994 levels), but will achieve only a 20% probability of detecting a 20% change in stormwater quality. Based on the Woodward-Clyde work, to increase the confidence level to 50% the program must increase monitoring expenditures to $5.33 million; and to reach the 80% confidence level it must expend $5.84 million.

Stated another way, the permit program now allocates 21% of the program budget to monitoring. To increase the confidence level of the monitoring results to 50%, the percentage of the permit program resources allocated to monitoring must increase to 27%. To achieve the 80% confidence level, 41% of the program's resources must be directed to monitoring.

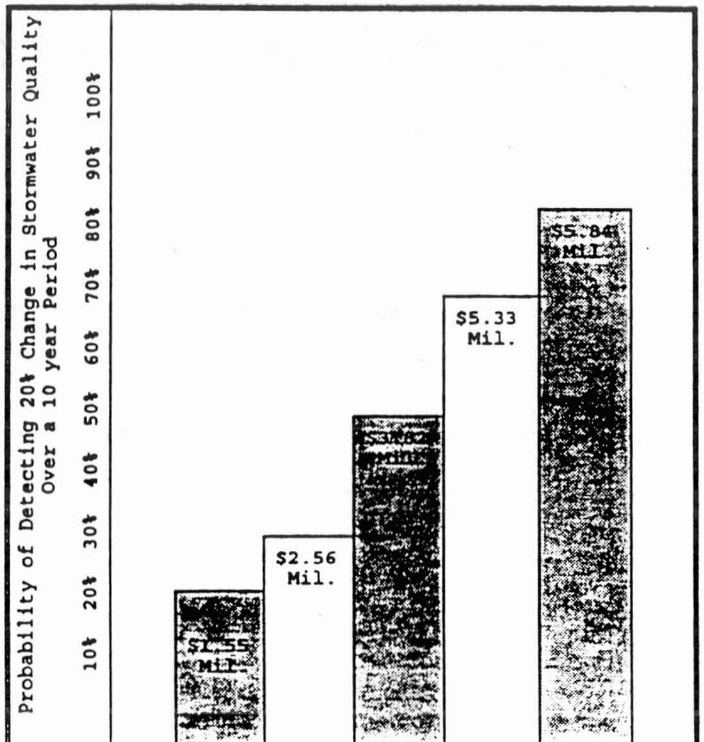
Correspondingly of course, increases in the monitoring budget decrease other elements of the stormwater program such as public education, legal enforcement, or – heaven forbid – annual reporting. This places before the local program manager the unique dilemma of maximizing expenditures that are likely to produce a change in stormwater quality, while pursuing a "low confidence" monitoring program; or, increasing the confidence level of the monitoring by reducing the things which are likely to improve stormwater quality. The other option, of course, is simply to divert more money from other municipal needs to invest more in stormwater monitoring.

Arguing strongly for restraint in inflating monitoring budgets, in addition to the resultant reduction in stormwater control practices, is the related difficulty in identifying the cause of an observed change in stormwater quality. Even at the 80% confidence level of detecting a change, it remains doubtful the monitoring program can identify with any confidence, the cause of the change detected. Whether it was the program itself, some specific element of the program, or some other series of events, that produced the observed change is likely to remain an important unknown.

The scope of this issue becomes more visible when statewide and nationwide impacts of raising the monitoring confidence level are considered. While an admittedly primitive approach, the Fresno program can be used to create such an estimate. If it can be assumed Fresno is relatively representative of the stormwater monitoring programs in California, it can be estimated that annual stormwater monitoring activity would have to increase from the $3.7 million actually expended statewide in 1993-94 to $9.1 million in order to achieve the 50% confidence level, and to $13.9 million to reach the 80% confidence level.

TABLE NO. 1

Monitoring Costs To Detect a 20% Change in Stormwater Quality (10 Year Test Period; Fresno CA)



Ten Year Monitoring Program Costs

(Annual costs in 1994 dollars; sampling, laboratory, and analytical costs only, excludes equipment and installation.)

Relatedly, if California bears the same permit program monitoring cost relationship to the rest of the nation as it does with respect to the total of all permitted municipalities (35.4% of all permitted communities are in California)[8], it is possible to estimate the confidence level cost impact on a national basis. On this basis, the nationwide cost to achieve the 20% confidence level will total $10.45 million per year. (This represents an estimate of the basic permit monitoring requirement cost which will be incurred by the total of all permitted municipalities assuming no substantive variances from the obligations imposed on California communities). To achieve the 50% confidence level, annual nationwide monitoring costs must increase to an estimated $25.75 million; and to achieve the 80% confidence level, the annual nationwide costs must increase to $39.4 million. (It is noted that monitoring costs, expressed in annual terms, must continue at the same level for ten years to produce the desired confidence level data base.)

Conclusion

The stormwater quality program is the object of intense scrutiny by political, environmental, municipal, and business interests. However, because the program's accountability to all of these interests is so completely dependent on reliable data, the program cannot achieve the objectives ascribed to it without an effective monitoring program producing dependable information.

It is this manager's opinion that the requisite information cannot be developed, and the ascribed objectives cannot be achieved without fundamental changes in the structure of the stormwater quality program.

First, we must change the presumption that stormwater quality problems and solutions can be as easily identified and quantified as other point source problems; and the presumption that given a little time, we can drive stormwater quality into compliance with traditional standards.

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[8] USEPA, October 1993

It seems a reasonable conclusion that, if we can't clearly measure how much stormwater quality has been changed, it is not likely we can measure how much pollution stormwater carried to begin with. Relatedly, if it is so difficult determining if all of the things we did caused a change, it is even more unlikely we can measure the change caused by any one thing we've done. The same conclusion also applies to accurately identifying the stormwater pollution sources.

Secondly, we must change our approach to defining the problem and testing for solutions. The weak repetitious characterization studies, haphazard source investigations and miscellaneous "nice to know" projects occurring through the permit process must be replaced with a national stormwater quality monitoring and research strategy. Specific goals and objectives must be developed and then implemented through the permit programs by means of specifically focused target/pilot studies. Only that duplication necessary for statistical confidence should be permitted and all efforts should be held accountable to rigid procedural guidelines and QA/QC standards.

The sampling, analysis and development of conclusions should be routinely supervised by a national data coordinating unit, and the data aggregated into a functional data base for use by the political, environmental and municipal interests. From such a data base, appropriate discharge standards for both end-of-pipe and receiving water conditions can then be extracted and useful measurements for assessing effective control practices can be developed.

Unless there is such a change in the structure of the stormwater monitoring program, we are destined to invest a major portion of the stormwater program finances in activity which produces dubious information and no stormwater quality improvement.

Given the magnitude of costs associated with the stormwater quality program, our nation's municipalities simply can not afford to have such a large percentage of its expenditures so unproductively used. Neither can we afford to impose such a devastatingly expensive standards compliance mandate on the basis of irrelevant or inaccurate data. Only with the proper structuring and conduct of a nationwide monitoring strategy can we produce the data necessary to insure successful attainment of the rightful objectives assigned to the stormwater program.

REFERENCES APPENDIX

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C. USEPA; "National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges", 40 CFR Parts 122, 123, and 124, November 16, 1990.

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F. Walker, Larry and Associates, "Urban Stormwater Controls Necessary to Achieve Water Quality Based Effluent Limitations Required by the Proposed Inland Surface Waters Plan", (City and County of Sacramento, California) December 1990.

G. Water Quality Act of 1987

Wednesday August 10, 1994

SESSION VI: WORK SESSION ON BMP MONITORING FOR DATA TRANSFERABILITY

1. **"Parameters to Report with BMP Data"**
   Ben Urbonas
   Urban Drainage and Flood Control District, Denver, Co.

2. **"Constituents and Methods for Assessing BMPs"**
   Eric Strecker
   Woodward-Clyde Consultants

PARAMETERS TO REPORT WITH BMP MONITORING DATA

By Ben R. Urbonas, M. ASCE*

ABSTRACT

This paper presents an argument for standardization of the physical, chemical, climatic, geological, biological, and meteorological parameters being reported along with the data acquired by various investigators on the performance of structural stormwater Best Management Practices (BMPs) used to enhance stormwater quality. Also, a standard minimum list of such parameters is suggested. Such a list is needed if we want to have a meaningful exchange of data among the various studies being conducted throughout the world. Transferability of performance results and consistency, or lack of it, in the performance of various BMPs has been an ongoing problem. A mutually agreed upon minimum list of reporting parameters that can be used to relate the performance of BMPs to some, or all, of these parameters could begin to address this problem. Over time such standardization will conserve the resources being expended by various field investigations and may eventually lead to improvements in the selection of and in the design of various BMPs.

INTRODUCTION

Much data have been collected over the past 10 to 20 years on the performance or "efficiency" of many structural stormwater quality BMPs. Most existing data relate to the performance of detention basins (i.e., detention basins that drain out completely after a storm runoff end, sometimes called "dry pond"), retention ponds (i.e., ponds that have a permanent pool of water and retain at least part of one storm's runoff after its runoff period ends, sometimes called "wet pond") and wetlands. Less data are available on field effeciveness of other types of BMPs. Howeve, this data and/or its reporing has lacks consistency. In addition, musch of the reported results do not show clear mathematical relationships between the performance of similar BMPs among various sites in which they were investigated. One of the reasons may be that sufficient parametric information about each site has typically not been reported along with the performance data to permit systematic analysis of data collected under a variety of field studies, or to relate these data to a set of physical, climatic, geologic, or hydrologic conditions.

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What we have now is a variety of independent interpretations with very little attempt to relate to other investigations that may have occured in the past or may beoccuring concurrently. Some of these interpretations may make a lot of sense while others leave us wondering and questioning what was studied and found and why? At the same time, and more importantly, we cannot answer with any degree of confidence what role various site parameters play in the performance of any particular BMP.

As an example for a retention pond, is it more important to know the *pond size vs. inflow event volume* ratio when designing for the removal of Total Suspended Solids (TSS) or Total Phosphorous (TP), or is it more important to know the *surface area of the pond vs. tributary watershed area* ratio, or is another set of parameters more important? Such questions can only be answered by a systematic and consistent BMP monitoring activities, wherever they may take place. Without these we will never be able to develop reliable, field tested, selection and design guidance for structural BMPs, guidance that we can need to use these BMPs with confidence.

When we examine what occurs at a retention pond, there are two distinctly separate phases of sedimentation. The first takes place during storm runoff when settling occurs under turbulent conditions, the other takes place during the quiescent conditions between storm runoff periods. In addition, in-between runoff events biological and chemical processes can remove or remobilize suspended and dissolved constituents in the water column.

In the TSS removal example discussed above, the settling of solids under quiescent conditions is a function of particle density, particle size and the fluid's viscosity, which in turn is a function of temperature. According to Dobbin (1944) and Camp (1946), particle settling under dynamic inflow conditions is dependent on the unit surface hydraulic loading (i.e., Q/A), the measured distribution of TSS particle settling velocities and critical shear stress, which in turn is a function of flow velocity and depth. There is also evidence (Grizzard et al; 1986) that TSS and other constituent removal efficiencies can be significantly affected by the initial concentration of the constituent. Laboratory and field data using stormwater show that it is easy to remove 80 to 90 percent of TSS from urban runoff when its initial concentration is high (e.g., > 400 mg/l) and difficult to remove even 20% when the initial concentrations are low (e.g., < 20 mg/l).

There are a number of key parameters that need to be obtained and reported whenever BMP performance is monitored. Identifying all such parameters at this time is not posible. We can add to the list as we learn more about the passive treatment mechanisms and the performance of structural BMPs. However, an initial list is suggested for a variety of BMPs that are currently or may be field tested in the future for effectiveness. They need to be reported in all study reports, data transfer reports, and other literature, along with performance data such as the inflow and outflow event mean concentrations (EMCs), the percentages of removal of each constituent, the flow rates and the volumes entering and leaving each structural BMP facility being investigated.

As municipalities and industries in United States of America begin to operate under the federally mandated National Pollutant Elimination Program's separate stormwater discharge permit system, we can expect a profound increase in the amount of stormwater monitoring data being collected and reported. Much of it will be associated with the performance of various BMPs. This data will be collected in a variety of ways, using different monitoring and reporting techniques, manual sampling, automatic sampling, different constituent detection levels, etc. The selection of the techniques used at each site will be determined by local conditions, budgets, expertise of the investigators, and other factors impossible to predict in advance. Some level of consistency in how this data and the type BMP parameters being reported will be needed if we ever hope to make any sense of this data or hope to draw repeatable quantitative conclusions. This will be of particular challenge when trying to draw conclusion in how this data relates to various BMP's and tributary watershed's design parameters.

It is hoped that the consistent use in the professional literature of a minimum set of standard parameters will result in more reliable tools for the selection of structural BMPs and in better design tools than we have today. In developing this list, various potential physical, biologic and chemical processes were considered for several types o BMPs . Although this list is extensive, every attempt was made to kept it as brief as possible. This does not mean, however, that other site specific parameters should not be measured or reported.

It is also recommend at this time that additional parameters be carefully evaluated before adding them to this list. It is not the intent to limit this initial list or to keep out other potential parameters of merit. I is suggested that before adding on to this list consider tha the complexity of finding meaningful empirical relationships expands exponentially with each newly added parameter. Also, we need to be sure that any new parameter is not already within this list, either as part of another parameter or within a grouping of the parameters on the present list. For example, it is not necessary to report the tributary impervious watershed area if the total watershed area and its percent of total imperviousness are reported.

REPORTING CONSTITUENTS AND THEIR REMOVALS

The way that we report data on the constituents in the water column and their removal rates is dictated is we have a detail study report or a summary paper. The

former merits much more detail. Also, should data be reported as event mean concentrations for a storm or should it be reported as a set of discrete sample data obtained at different times during a storm? There is a need to have some level of consistency in how we handle this issue.

Data and Study Reports

Typically, literature reports the constituents being monitored, their removal efficiencies and associated flows. Sometimes the constituents are reported as EMCs entering and leaving the BMP facility, while at other times data are reported for individual discrete samples taken throughout the runoff event even though discrete samples are often composited into a single EMC. To provide consistency, it is recommended that stormwater BMP data be reported in literature as paired inflow and outflow EMCs for all the events sampled, along with the event's volume of runoff (inflow and outflow if different) and percent constituent removal rates during each event.

The collection and the reporting of discrete sample data taken at various times during runoff events is not discouraged by the above recommendation. It is, however, very expensive to test each discrete sample for a number of constituents and many stormwater data collection efforts elect to test only the flow weighted composite sample to find the storm's EMC. If budgets permit, however, much understanding can be gained through the collection and analysis of discrete water quality samples throughout the runoff hydrograph. The reporting of storm composite EMCs in published literature is suggested for the sake of reporting constancy, while any available discrete sample data can be made available to investigators upon request as ASCII or data base files, along with the organization and format of these files.

Inconsistencies also occur in literature in reporting removal efficiencies. To cope with this, it is recommended that the percent removal (PR) for any constituent be calculated and reported for each monitored event using the inflow and outflow loads. If the facility records less surface outflow than inflow, as can be the case when infiltration/percolation occurs, the outflow loads should be reported for the surface outflow component based on the measured outflows and for the subsurface component based on the estimates of the water infiltrated/percolated, into the ground. This should prevent the impression that infiltration/percolation actually eliminates constituents, instead of, as sometimes happens, transferring them to the groundwater flow regime. Equation 1 is suggested as the basic equation for calculating the percent removal rate of any sampled constituent.

$$PR = \frac{V_{in} \cdot EMC_{in} - V_{out} \cdot EMC_{out}}{V_{in} \cdot EMC_{in}} \cdot 100 \qquad (1)$$

in which, PR = percent constituent load removed,
V_{in} = storm runoff volume inflow into the BMP facility,

EMC_{in}	=	event mean concentration of inflow volume,
V_{out}	=	storm runoff volume outflow from a into the BMP,
EMC_{out}	=	event mean concentration of outflow volume,

Reporting of constituent concentrations in dry weather inflows and outflows, if any, can reveal much about the true performance of a BMP. Many on-site BMPs do not experience dry weather flows and the reporting of the percent constituent removal efficiencies for storm events is sufficient. However, if dry weather flows are present, they sometimes can have a very significant effect on the actual constituent removal rates that take place over an extended period of time (Urbonas et al, 1994). To help us understand how any BMP being studied is affected by dry weather flows, it is recommended that constituent concentrations in dry weather flows be obtained and reported in sufficient numbers to provide averages and their coefficient of variation.

Report Summaries and Published Summary Papers

Summaries of monitoring studies and published papers often cannot include all the data that were collected. As a result, the information has to be reduced to fit the available space. Again there is no consistency in how this is done and it is suggested that, as a minimum, summary reports and published summary papers report the constituent EMC data as monitoring period (or season) averages for both the inflow and outflow, along with the inflow (and outflow if different) volume averages and numbers of EMC data points (i.e., storm events sampled) for each parameter, along with each average's coefficient of variation (CV). These data need to be accompanied by the lon-term average percent removal rates for each constituent reported as the arithmetic mean of individual removal rates. Calculated these using Equation 2.

$$PR_{av} = \frac{\sum_{1}^{n} PR_{i}}{n} \tag{2}$$

in which,			
	PR_{av}	=	Average % removed, all monitored events, single constituent,
	n	=	number of events for which percent removals were calculated,
	PR_i	=	% removed for the i_{th} event sampled.

BASIC SEDIMENTATION EQUATIONS

Much of the performance effectiveness attributed to BMPs currently focusws on the removal of TSS from runoff. This is definitely not always the case. Local concerns, such as those in watersheds tributary to Chesapeake Bay and the watersheds in State of Florida suffering from groundwater depletio, may dictate that the removal of nutrients is of greatest concern. or, as is the case for the watershed draining to San Francisco Bay, the removal of copper, soluble and total, may be of most interest. Never the less, the selection of the parameters being suggested are based on the principles for the removal of TSS and on the removal of other constituents. The

reduction in the toxicity of some of the constituents was also considered in developing the recommended list.

The TSS removal process is much more complex than can be explained using simple sedimentation equations. Nevertheless, these equations provide some of the mathematical basis for identifying many of the physical parameters that should be looked at, especially when considering the design of facilities to remove particulates and the constituents that adhere to them.

Newton's Sedimentation Law For Spherical Particles:

Newton proposed the following equation to describe the settling velocity of a particle in a fluid:

$$V_s = \sqrt{\frac{4}{3} \cdot \frac{d_p \cdot g \cdot (r_p - r_v)}{C_D \cdot r_v}} \tag{3}$$

in which,			
	V_s	=	settling velocity of a given particle size in m/s
	d_p	=	diameter of the particle in m
	r_p	=	specific gravity of the particle,
	r_v	=	specific gravity of the fluid,
	g	=	gravitational acceleration in m/s^2
	C_D	=	drag coefficient, a function of Reynolds Number R_n, which in turn is a function of the fluid's temperature.

Basic Suspended Solid Settling in Turbulent Flow:

Geyer (1954) suggested a relationship to describe the sediment fraction that can be removed in a pool of water under the dynamic conditions that can occur as water enters the pool at one end and overflows an outlet at the other end. This relationship, Equation 4, relies on the pool's hydraulic surface loading rate, namely the flow-through rate divided by the pool's surface area.

$$R_d = 1.0 - \left[1.0 + \frac{1}{n} \cdot \frac{V_s}{Q/A}\right]^{-n} \tag{4}$$

in which,			
	R_d	=	fraction of the inflow solids removed under dynamic conditions,
	V_s	=	settling velocity of a given particle size in m/s (ft/sec),
	Q	=	flow through rate in cubic m/s (ft/sec),
	A	=	surface area of the permanent water pool in m^2 (ft^2),
	n	=	turbulence, or short-circuiting, constant.
		=	1.0 for poor performance, high sort-circuiting potential,

= 5.0 for very good performance, low short-circuiting potential,
= ∝ for ideal performance.

As n approaches infinity, Equation 4 reduces to:

$$R_d = 1.0 - e^{-kt} \qquad (5)$$

in which, k = V_s/h, sedimentation rate coefficient in /s units,
h = average depth of the pond in m (ft),
t = V/Q, resident time in the pool in seconds
V = volume of the pool in m^3

GENERAL PARAMETERS TO CONSIDER FOR ALL BMPS

There are a number of general parameters that should be recorded and reported, regardless of the type of BMP being tested. Some of these can be used to assess the aquatic environment and the toxicology of the constituents being monitored. Others, such as temperature, give the investigator an idea of the fluid's density and viscosity, both of which influence the settleability of solids. Table 1 lists a number of such general parameters. All of them can be measured in the field and, except for V_{SD}, are relatively inexpensive to obtain.

RUNOFF PARAMETERS

Since storm runoff is a function of the tributary watershed area and its imperviousness, always report the *Tributary Watershed* (A_T), its *Total Percent Imperviousness* (I_{TT}) and the *Percent of the Total Imperviousness that is Hydraulically Connected* (I_{IC}) to the storm conveyance system. Often not reported in published literature is information about storm runoff peaks, runoff volumes or storms and of base flows associated with BMP facilities. Figure 1 illustrates storm runoff events as a time series of hydrographs, which information can be summarized using a probability distribution graph shown in Figure 2. To help us find relationships between runoff distribution data at a variety of sites being monitored and the performance of these BMPs, it is recommended that, as a minimum, runoff data (and outflow data if different) be summarized as suggested below for *Runoff Volume, Storm Runoff Duration* and *Storm Runoff Inter-Event Time* parameters as follows:

TABLE 1. GENERAL PARAMETERS TO REPORT FOR ALL BMPs

Inlet and Outlet	Plan, profile and details, including dimensions and elevations of the inlet and outlet works. Include inflow baffles and outlet trash racks, if any.
Temp •	Water temperature of influent, effluent and possibly the pond itself. Summarize this data as monitoring seasonal average, along with its coefficient of variation.
V_{SD}	Settling velocity distribution of the sediments in stormwater determined from a number of settling column tests.
Alkalinity & Hardness	Affect the solubility and the toxicity of metals and of other constituents. To be measured and reported as the Event Mean Concentration (EMC) of the influent and the effluent of the facility.
Conductivity •	Provides a surrogate indicator of ionic activity in the water column, which may indicate the availability of metals to aquatic life in toxic state. Reporting *dissolved* metals along with *total* metals data provides an indicator of potentially available toxic forms.
pH •	Affects the solubility and toxicity of metals and other constituents.
•	Indicates that these parameters are to be measured in the field and reported as the mean of the measured values.
Solar Radiation	Measured daily, only at retention ponds, wetlands and other biologically active treatment water quality facilities. Summarize this data as the mean of daily averages for the monitoring season and their Coefficient of Variation.
Maintenance	Provide type and frequency of maintenance such as dredging of sediments, harvesting, mowing, removing and replacing filter media, etc.
Facility Description	Full description of the BMP, including layout, typical cross-section and profile, inlet and outlet details, vegetative cover, etc.

Runoff Volume Parameters During Monitoring Season:

V_R = Volume of the average runoff event in watershed mm (in),

V_{R50} = Volume of the 50th percentile runoff event in watershed mm (in),

CV_{VR} = Coefficient of Variation in the volumes of runoff events ($_{SD-R}/V_R$),

in which V_{SD-R} = Standard deviation of Runoff volumes,

V_B = Volume of the seasonal dry weather base flow in watershed mm (in),

Q_P = Average runoff peak rate in m^3/s (ft^3/sec),

CV_{QP} = Coefficient of Variation of flow peaks.

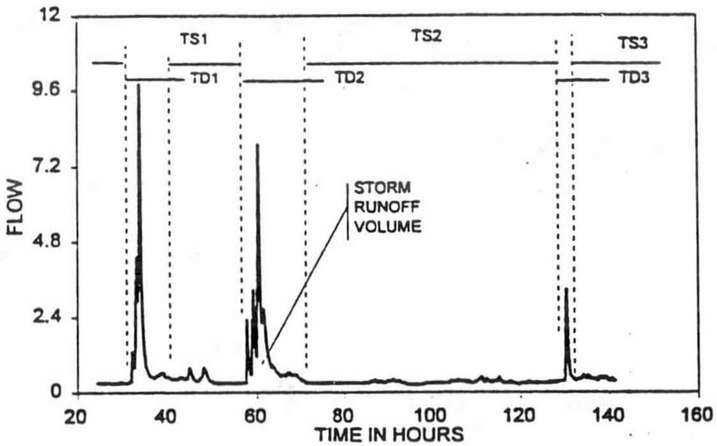

Figure 1. Time series of storm hydrographs, their duration and inter-event times.

Time Variable Parameters of Storms During Monitoring Season:

Storm Runoff Inter-Event (Separation) Time:

T_S = Average separation period between the end of a storm runoff hydrograph and the beginning of the next one in hours,

T_{S50} = The 50th percentile of storm runoff event separation periods in hours,

CV_{TS} = Coefficient of Variation in storm runoff event separation periods (T_{SD-S}/T_S), in which T_{SD-S} = Standard deviation of storm runoff event separation periods.

Storm Runoff Duration:

T_D = Average duration of storm runoff in hours,

T_{D50} = The 50th percentile value of storm runoff duration in hours.

CV_{TD} = Coefficient of Variation in storm runoff duration (T_{SD-D}/T_D), in which T_{SD-D} = Standard deviation of storm runoff duration.

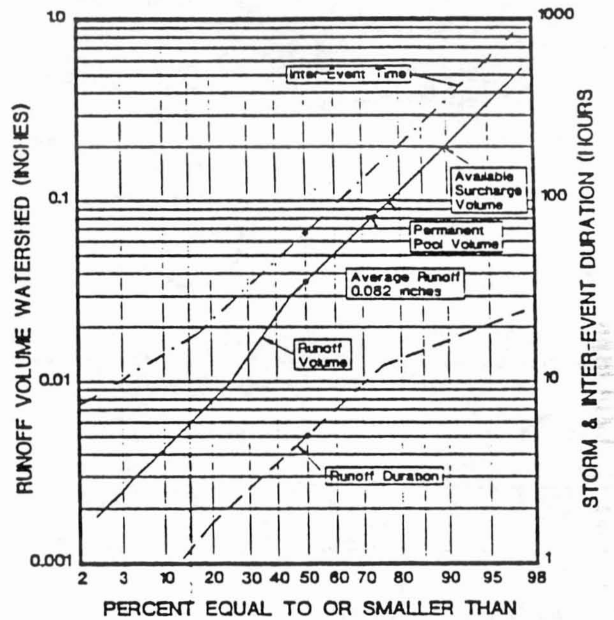

Figure 2. Example of cumulative probability distribution of Surface Runoff, Storm Separation and Inter-Event Time for one BMP site (After Urbonas et al. 1994).

PARAMETERS FOR RETENTION PONDS

Figure 3 illustrates a plan view of an idealized stormwater retention pond used as a structural BMP. Retention ponds such as this always have some surcharge detention storage above the permanent pool water surface.

There are several pollutant removal mechanisms at work within a retention pond. These include sedimentation during runoff events and in between runoff events, other physical processes, chemical processes and biological processes. As a result, more information needs to be reported for these types of facilities than for facilities that remove pollutants primarily though physical processes. Also, keeping these points and Equations 3 through 5 in mind, the following set of parameters emerge as needing to be reported with removal efficiency data of retention ponds.

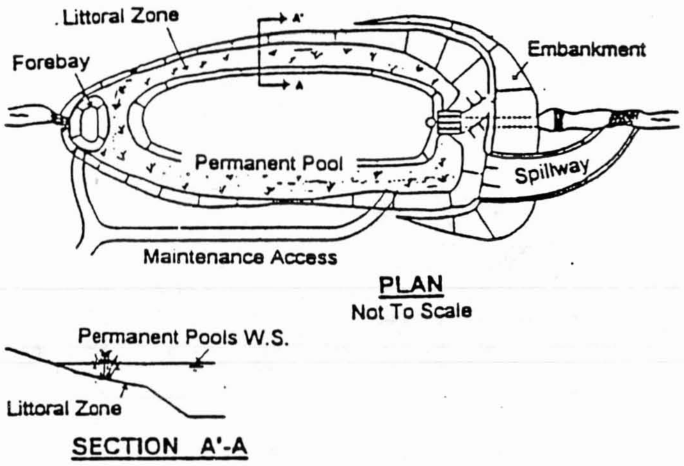

Figure 3. Plan of an Idealized Retention Pond. (After UDFCD, 1992)

Surface Area and Pond Layout Parameters:

A_P = Surface area of the permanent pool in m^2 (ft^2),

A_L = Surface area of the littoral zone (zone ≤ 0.5 m (1.5 ft) deep) in m^2 (ft^2),

A_D = Surface area of the top of the surcharge detention basin in m^2 (ft^2),

L_P = Length of the permanent pool or flow path in m (ft),

L_D = Length of the surcharge detention basin in m (ft),

A_F = Surface area of the forebay in m^2 (ft^2),

L_F = Length of the forebay in m (ft).

Basin Volume Parameters:

V_P = Volume of the permanent pool in m^3 (ft^3),

V_D = Design volume of the surcharge detention basin above the permanent pool's water surface in m^3 (ft^3),

V_F = Volume of the forebay in m^3 (ft^3).

Emptying Time Parameters:

T_E = Time needed to empty 99% of V_D assuming no inflow takes place while the surcharge pool is emptying, in hours, and

$T_{0.5E}$ = Time needed to empty the upper one-half of V_D assuming no inflow takes place while the surcharge pool is emptying, in hours.

PARAMETERS FOR EXTENDED DETENTION BASINS

Fugue 4 shows the plan vies of an idealized extended detention basin. Such basins employ sedimentation as their primary pollutant removal mechanism. As a result, Equations 3, 4 and 5 also apply to extended detention basins, but have to be viewed somewhat differently than for a retention pond. In a retention pond, sediments that settle below the overflow outlet level are essentially trapped within the permanent pool and are less likely to be discharged through the outlet. The trapped sediment continues to settle to the bottom of the pond even after the surcharge volume is drained off. In an extended detention basin stormwater empties thorough an outlet located on the bottom. As the sediments settle to the bottom they concentrate within the lower levels of the ever shrinking pool and discharge through the outlet. Unless they are scoured out, only the sediments that deposit on the bottom can be trapped within the basin.

The design for extended detention basins thus requires much longer drain times to permit the sediments to settle onto the bottom of the basin. Current state-of-practice suggests that the emptying time be set at 24 to 48 hours for a volume equal to the average runoff event expected to occur at the design site. Current practice also suggests that extended detention basins be designed to have two levels. The lower level basin is filled frequently by the predominant numbers of small runoff events, while the upper basin is inundated only few times a year. This two layer design significantly improves the upper basin's usability for other community uses.

The list that follows reflects most of the parameters of importance for an extended detention basin. Many of the same parameters that were recommended for retention ponds are repeated for an extended detention basin.

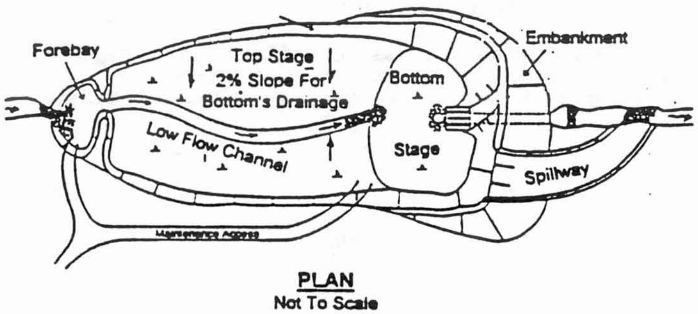

Figure 4. Plan of an Idealized Extended Detention Basin. (After UDFCD, 1992)

Surface Area and Plan Layout Parameters:

A_D = Surface area of the extended detention basin in m^2 (ft^2),

L_D = Length of the extended detention basin in m (ft),

A_B = Surface area of the bottom stage (i.e., lower basin) in m^2 (ft^2),

L_F = Length of the forebay in m (ft).

Basin Volume Parameters:

V_D = Total Volume of the extended detention basin in m^3 (ft^3)

V_B = Volume of the Bottom stage only of the basin in m^3 (ft^3)

V_F = Volume of the Forebay in m^3 (ft^3)

Time Variables:

Use the same *Emptying Time* parameters as defined for the retention pond.

PARAMETERS FOR WETLAND BASINS

Figure 5 depicts an idealized wetland basin. Some wetland basins are similar in their operation to retention ponds while others resemble extended detention basins, the distinction between the two being whether or not the wetland basin has standing water or a wetland meadow as its bottom. The pollutant removal mechanisms are probably similar to those found in retention ponds and in detention basins, except that stormwater comes in contact with wetland flora and fauna. This contact and the physical structure of the wetland provide pollutant removals through adsorption and biochemical processes and possibly through reoxygenation of the sediments and detoxification of the water column, processes that may or may not be available in retention ponds and are not available in detention basins.

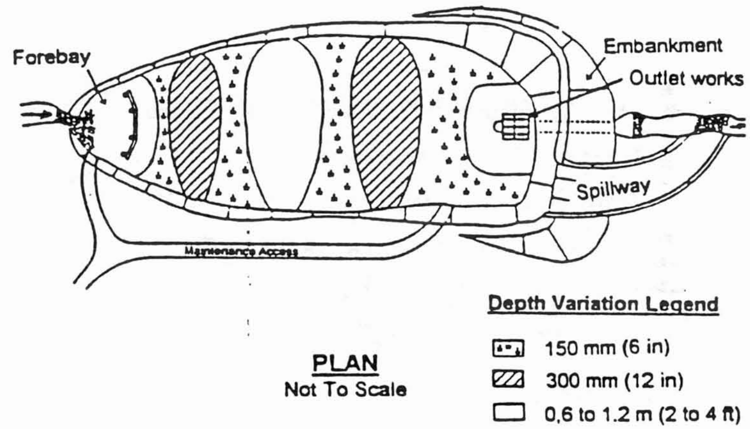

Figure 5. Plan of an Idealized Wetland Basin. (After UDFCD, 1992)

In addition to the parameters of Equations 3, 4 and 5, each performance monitoring program should report parameters that are peculiar to the wetland being studied. Most currently available wetland monitoring data rarely contain such information, often not even reporting many of the parameters commonly being reported for other BMPs. Because the quantification of wetland performance as a BMP is relatively new, very little information can be found in current literature and it is difficult to suggest parameters to report when reporting the performance data of wetland basins. Table 2 and the list that follows it suggest the parameters that appear to be most important, many of which are identical to those recommenced for retention ponds.

TABLE 2. ADDITIONAL GENERAL PARAMETERS TO REPORT FOR WETLANDS

Type of Wetland	Cattail marsh, northern peat land, meadow, palustrine, southern marshland, hardwood swampland, brackish marsh, high altitude riverine, freshwater riverine, mixed (include types), constructed or natural, etc.
Rock Filter?	Is there a rock filter media present in the wetland bottom?
Dominant Plant Species	Lists the dominant plant species in the wetland and the age of these plants, namely, time since their original planting or replanting.

Surface Area and Layout Plan Parameters:

A_P = Surface area of permanent wetland pool, if any, in m^2 (ft^2),

A_M = Surface area of the meadow wetland, if any, in m^2 (ft^2),

$P_{0.30}$ = Percent of permanent pool less than 0.30 m (<12 in) in depth,

$P_{0.60}$ = Percent of the permanent pool more than 0.60 m (>24 in) in depth,

A_S = Surface area of the surcharge detention basin's top in m^2 (ft^2),

L_S = Length of the wetland surcharge/detention pool or flow path in m (ft),

A_F = Surface area of the forebay in m^2 (ft^2),

L_F = Length of the forebay in m (ft).

Basin Volume Parameters:

V_P = Volume of the permanent pool, if any, in m^3 (ft^3),

V_D = Design volume of the surcharge/detention basin in m^3 (ft^3),

V_F = Volume of the forebay in m^3 (ft^3).

Time Variables:

Use the same *Emptying Time* parameters as defined for the retention pond.

PARAMETERS FOR WETLAND CHANNELS

Channels can be designed to have a wetland bottom which are designed to flow very slowly. Figure 6 show a profile for such a channel. When properly designed, the channel's bottom is covered by wetlands, with only the sideslopes having terrestrial vegetation. The flow velocity is controlled by transverse berms, by check dams or by an outlet at the downstream end of a given channel's reach. In the last case, the channel is essentially a long and narrow wetland basin.

The pollutant removal mechanisms in wetland bottom channels are similar to those found in wetland basins, except that contact time of stormwater with the wetland vegetation is likely to be less. Because of the flowing channel nature of this BMP, the following parameters, in addition to those in Tables 1 and 2, should provide the information needed to compare the performance of different installations:

$V_{2\text{-}yr}$ = Average channel velocity during a 2-year runoff event in m/s (ft/sec),

A_D = Surface area of the wetland bottom in square m^2 (ft^2),

L_D = Length of the wetland channel in m (ft).

Prt = Describe any pretreatment provided ahead of the channel (e.g. detention).

Time Variables.

There are no *Emptying Time* parameters to report for wetland channels.

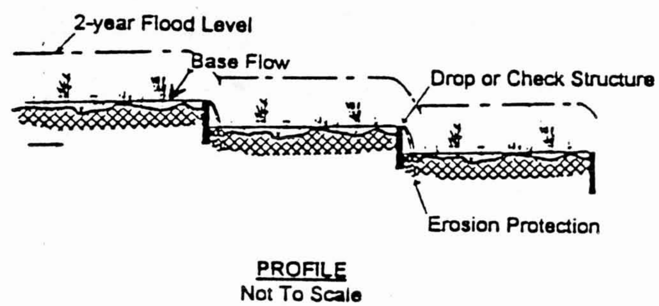

Figure 6. Profile of an Idealized Wetland Bottom Channel. (After UDFCD, 1992)

PARAMETERS FOR SAND FILTERS

Sand filters can be installed as basins or as sand filter inlets. Figure 7 illustrates an idealized filter basin and Figure 8 does the same for a filter inlet. Typically, these installations will have a detention basin or a retention pond (or tank) upstream of the filter to remove the heavier sediment and, if properly designed, some of the oil and grease found in stormwater. However, such a pretreatment basin is not always present. All of the parameters called for a *Retention Pond* or for an *Extended Detention Basin* should also be reported along with the information about the sand filter whenever the filter is preceded by a pre-treatment basin. For example, a filter inlet is often equipped with an underground tank which helps to remove some of the sediment, oil and grease before stormwater is applied onto the filter. Such a tank is similar to a retention pond and all of the parameters associated with a retention pond, such as volume, surface area, length, surcharge volume, etc. should be reported.

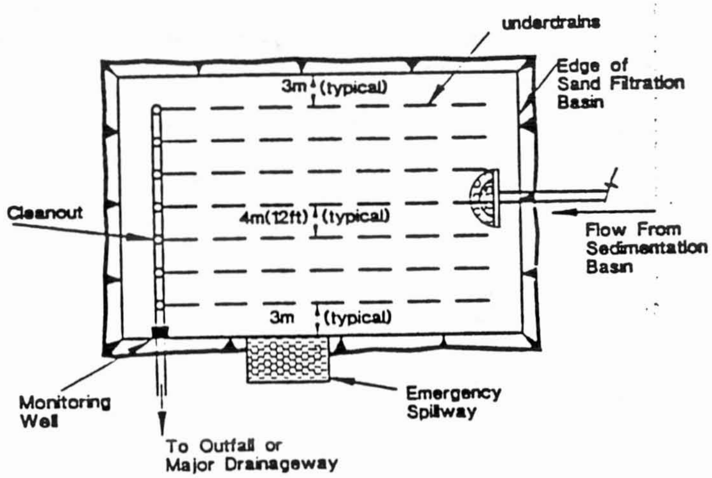

Figure 7. Plan of an Idealized Sand Filter Basin. (After UDFCD, 1986)

In addition to the parameters of the pond or basin associated with the filter, provide the following:

- Dimensions of the installation.
- Depth of various filter material layers.
- Type of filter media, its median particle size (i.e., D_{50}) and its Coefficient of Uniformity.
- Maintenance frequency.
- All associated drainage and flooding problems attributed to the installation because of its configuration size, maintenance practices, etc.

Time Variables:

Use same parameters for *Emptying Time* as defined for the retention pond.

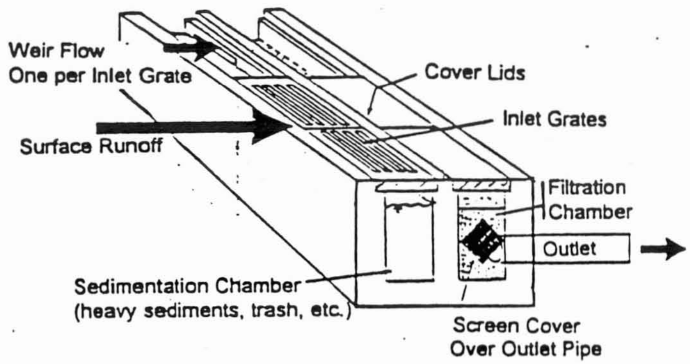

Figure 8. An Idealized Sand Filter Inlet. (After Shaver, 1993)

PARAMETERS FOR OIL, GREASE AND SAND TRAPS

An oil, grease and sand trap is an underground tank, similar to the one illustrated in Figure 9. It is nothing more then a special configuration of a retention pond. As a result, report all of parameters listed for a *Retention Pond* should also be reported for these installations. Typically these installations have a forebay and an outlet basin. In addition to reporting the parameters for a pond, provide the *dimensions of the installation, details of its design (including skimmers, sorbent pillows, lamella plates, baffles, etc.) and the maintenance provided during the testing period.* Because these type of traps are much smaller than a surface pond, the flow-through velocity is of concern because it can cause trapped oil, grease and sediment to be remobilized and flushed out of the trap. As a result, provide the ***average flow velocity that can be expected to occur in this device during a 2-year storm***, which velocity can be used as an index for comparing the performance a variety of installations.

Time Variables:

Use the same *Emptying Time* parameters as defined for a retention pond.

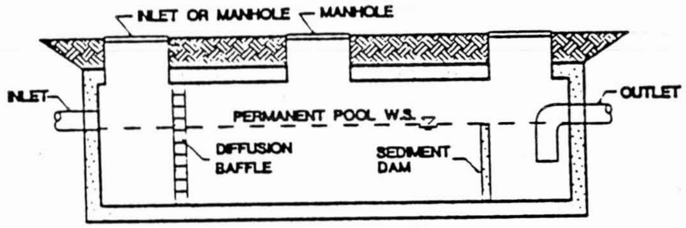

Figure 9. An Idealized Oil, Grease and Sand Trap (After Neufeld, 1994).

PARAMETERS FOR INFILTRATION AND PERCOLATION FACILITIES

An idealized percolation trench is illustrated in Figure 10. For percolation trenches and for infiltration basins report all of the parameters suggested for the *Extended Detention Basin*. In addition, report the following:

- Depth to high groundwater and to impermeable layers below the infiltrating surface of the basin, or below the bottom of the percolation trench.

- The hydraulic conductivity of soils adjacent to percolation trenches and the saturated surface infiltration rates of soils underlying infiltration basins.
- Dimensions of the installation.
- Maintenance needs and associated drainage and flooding problems attributed to the installation.
- Failures to empty out the captured water completely within the design emptying time.

Time Variables:

Use the same *Emptying Time* parameters as defined for a retention pond.

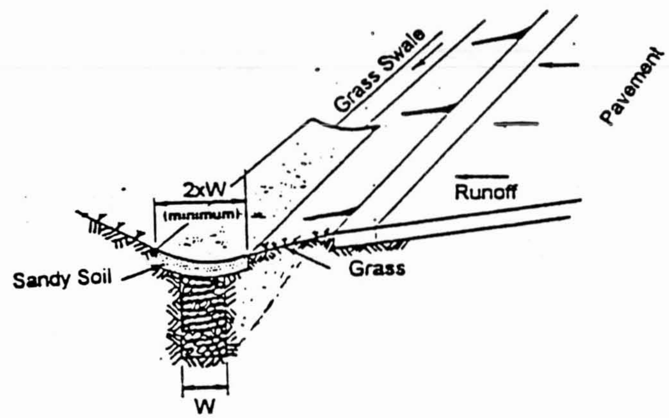

Figure 10. An Idealized Percolation Trench. (After Urbonas & Stahre, 1993)

SUMMARY AND RECOMMENDATIONS

In summary, there is a great need for consistent reporting of various BMP parameters along with field testing data on their performance. Table 3 these parameters. It is recommended that all agencies and organizations that undertake field studies of BMP performance be encouraged to include in their reports and report summaries the information suggested in this paper. Only through a concerted effort by stormwater professionals to report the suggested minimum list of parameters about each installation, or some other list that the research community deems more appropriate, will all of the field research activities yield parametric relationships that refine and optimize structural BMP designs.

FURTHER REVIEW COMMENTS TO ASCE

A paper that presented the concepts and recommendations made in this paper is also being published by the American Society of Civil Engineer, Water Resource Planning and Management Division's Journal. Anyone wishing to comment on this topic and these recommendations is invited to write to the ASCE Journal's services. All comments are welcome as this topic deserves wide debate and discussion.

ACKNOWLEDGMENTS

The author acknowledges the many professionals that contributed to the development of this paper. The initial and pre-final drafts were distributed to approximately 40 individuals, many of who have contributed significantly to the field of stormwater management over the last 25 to 30 years. A special thanks goes to all those that responded with their comments and suggestions. As a result, the recommendations being made in this paper reflect the suggestions, opinions and the experience of many individuals and not only those of the author. Special acknowledgment goes to the following for their specific and extensive review comments and suggestions offered on this topic to the author: Eric Strecker, John Warwick, Betty Rushton and Jim Wulliman.

TABLE 3. SUMMARY OF REPORTABLE BMP SITE PARAMETERS.

Parameter	Ret. Pnd	Ext. Det. Bsin	Wet-land Bsin	Wet-land Chn'l	Sand Filetr	Oil/ Sand Trap	Infilt. & Perc.
Tributary Watersned Area - A_T	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total % Trib. Watershed is Impervious - I_{IT}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
% of Impervious Area Hyd. Connected - I_{IC}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gutter/Sewer/Swale/Ditches in Watershed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Avarage Storm Runoff Volume - V_R	Yes	Yes	Yes	Yes	Yes	Yes	Yes
50th Percentile Runoff Volume - V_{R50}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coeff. Var. of Runoff Volumes- CV_{VR}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Av. Daily Base Flow Volume - V_B	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Average Runoff Inter-Event Time - T_S	Yes	Yes	Yes	Yes	Yes	Yes	Yes
50th Percentile Inter-Event Time - T_{S50}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coeff. Var. of Inter-Event Times - CV_{TS}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Average Storm Duration - T_D	Yes	Yes	Yes	Yes	Yes	Yes	Yes
50th Percentile Storm Duration - T_{D50}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coeff. Var. of Storm Durations- CV_{TD}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Water Temperature - *Temp*	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Alkalinity, Hardness & pH	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sediment Settling Velocity Dist. - V_{SD}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type & frequency of maintenance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inlet & Outlet dimensions & details	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Solar Radiation	Yes	NO	Yes	Yes	NO	NO	NO
Volume of Permanent Pool - V_P	Yes	NO	Yes	NO	Yes	Yes	NO
Perm. Pool Surface Area - A_P	Yes	NO	Yes	NO	Yes	Yes	NO
Littoral Zone Surface Area - A_L	Yes	NO	NO	NO	NO	NO	NO
Length of Permanent Pool - L_P	Yes	NO	Yes	NO	Yes	Yes	NO
Detention (or Surcharge) Vol. - V_D	Yes	Yes	Yes	NO	Yes	Yes	Yes
Detention Basin's Surface Area - A_D	Yes	Yes	Yes	NO	Yes	Yes	Yes
Length of Detention Basin - L_D	Yes	Yes	Yes	NO	Yes	Yes	Yes
Brim-full Emptying. Time - T_E	Yes	Yes	Yes	NO	Yes	Yes	Yes
½ Brim-full Emptying Time - $T_{0.5E}$	Yes	Yes	Yes	NO	Yes	Yes	Yes
Bottom Stage Volume - V_B	NO	Yes	NO	NO	NO	NO	NO
Bottom Stage Surface Area - A_B	NO	Yes	NO	NO	NO	NO	NO
Forebay Volume - V_F	Yes	Yes	Yes	NO	Yes	Yes	Yes
Forebay Length - L_F	Yes	Yes	Yes	NO	Yes	Yes	Yes
Wetland Type, Rock Filter Present?	NO	NO	Yes	Yes	NO	NO	NO
% of Wetland Surface at $P_{0.3}$ & $P_{0.6}$ Depths	NO	NO	Yes	Yes	NO	NO	NO
Meadow Wetland Surface Area - A_M	NO	NO	Yes	Yes	NO	NO	NO
Plant Species and Age of Facility	Yes	Yes	Yes	Yes	NO	NO	NO
2-year Flood Peak Velocity	NO	NO	NO	Yes	NO	Yes	NO
Depth to groundwater or impermeable layer	NO	Yes	Yes	NO	NO	NO	Yes

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KEY WORDS

Best Management Practices

Field Testing

Monitoring

Paramers

Performance

Standardization

Stormwater

Water Quality

Thursday, August 11, 1994

SESSION VII: MONITORING RECEIVING WATER TRENDS

1. **"Time-Scale Toxic Effects in Aquatic Ecosystems"**
   Edwin Herricks
   University of Illinois at Champaign;
   Ian Milne and Ian Johnson
   Water Research Centre - Medmenham, United Kingdom;

2. **"Use of Sediment and Biological Monitoring"**
   Eric H. Livingston, Ellen McCarron, Thomas Seal and Gail Sloane
   Florida Department of Environmental Protection

3. **"Water Quality Trends from Stormwater Controls"**
   Robert Pitt
   University of Alabama at Birmingham

4. **"Watershed Protection Using an Integrated Approach"**
   Earl Shaver, John Maxted and David Carter
   State of Delaware DNREC;
   Gray Curtis
   Madrigal Software Corporation

Use of Sediment and Biological Monitoring to Evaluate Stormwater Discharges

Eric H. Livingston[1], Ellen McCarron, Thomas Seal and Gail Sloane

ABSTRACT

Assessing the environmental effects of stormwater discharges presents many new and complex challenges. Unlike traditional point sources of pollution, these discharges are intermittent, creating temporally and spatially variable shock loadings to receiving waters. Consequently, traditional assessment techniques which rely solely upon sampling and characterization of the water column are ineffective in determining the environmental effects of stormwater discharges. This paper will discuss the need and rationale for alternative sampling and assessment procedures that provide a more ecologically-based manner of determining the environmental effects of stormwater discharges. Activities undertaken by the Florida Department of Environmental Protection in the past few years to develop biological community assessment and coastal sediment monitoring tools to evaluate stormwater discharges will be summarized. The development and use of a coastal and estuarine sediment assessment tool, based on the relationship between sediment aluminum and metal concentrations, will be reviewed. Similarly, the steps taken to develop and implement a riverine biological community assessment tool, based on comparisons between impacted sites and ecoregion reference sites, are reviewed.

INTRODUCTION

During the late 1970s, stormwater and other nonpoint sources (NPS) of pollution were identified as major contributors to the degradation of Florida's surface and ground water resources. To minimize stormwater pollutant loadings discharged from new land use activities, the Florida Environmental Regulation Commission adopted a statewide stormwater treatment regulation in February 1982. This rule, implemented cooperatively by the state's Department of Environmental Protection and five regional water management districts, establishes permitting procedures and, for various types of stormwater management practices, design criteria presumed to achieve a specified treatment level. This rule is one of numerous statutes and

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regulations that have been implemented during the past 20 years to minimize the detrimental environmental effects associated with the state's extremely rapid growth. Collectively, the individual laws and programs enacted during this period can be considered "Florida's Watershed Management Program" (Livingston, 1993).

An essential component of this watershed management program is monitoring, to evaluate environmental conditions and the program's environmental benefits. In the past, water quality management actions focused on traditional point sources of pollution, such as domestic or industrial wastewater discharges, making monitoring and evaluation relatively easy. These point sources typically discharge effluents of uniform, known quality at continuous design flows, making them relatively easy to assess, model and control. Point source assessments generally have relied almost solely upon water column chemistry monitoring. On the other hand, stormwater and other nonpoint sources of pollution, because of their intermittent, diffuse, land use specific nature, are highly variable in effluent quality and environmental effects. Of particular environmental concern is the cumulative impact on a water body from the numerous stormwater/nonpoint sources within a watershed. Traditional water quality monitoring and management efforts generally suffer from several deficiencies in understanding and managing stormwater/NPS pollution. These deficiencies include difficulty in:

1. Assessing intermittent, shock loadings of pollutants.
2. Assessing cumulative impacts of multiple sources.
3. Comparing water bodies and establishing priorities for management actions.
4. Distinguishing actual or potential problems from perceived problems.
5. Discriminating anthropogenic loadings from natural watershed loadings of metals and nutrients.
6. Establishing cost-effective ways to assess pollution trends and understand overall watershed pollution.

Most stormwater pollutants accumulate over time in sediments, not the water column. Therefore, assessment methods to determine the cumulative effects of watershed stormwater/NPS pollution sources on aquatic systems or to evaluate the effectiveness of management programs should include evaluation of sediments and the organisms that reside there and in other aquatic habitats. This paper will review the development and implementation of sediment and biological monitoring protocols in Florida which are being used to improve evaluation and management of stormwater and other intermittent pollution sources, along with traditional point sources.

ASSESSING SEDIMENT CONTAMINATION

Sediment quality is a sensitive indicator of overall environmental quality. Sediments influence the environmental fate of many toxic and bioaccumulative substances in aquatic ecosystems. Sediments tend to integrate contaminant concentrations over time and may represent long-term sources of contamination. Specifically, sediment quality is important because many toxic contaminants found in only trace amounts in water can accumulate to elevated levels in sediments. Sediment-associated contaminants can also directly affect benthic and other sediment-associated organisms. In addition to the physical and chemical relationships between sediments and contaminants, sediments provide benthic and pelagic communities suitable habitats for essential biological processes (e.g. spawning, incubation, rearing, etc.).

Sediments provide an essential link between chemical and biological processes. By understanding this link, environmental scientists can develop assessment tools and conduct monitoring programs to more rapidly and accurately evaluate the health of aquatic systems. Therefore, sediment quality data provide essential information for evaluating ambient environmental quality conditions in water bodies. Additionally, information about the amount and quality of sediments within stormwater systems, stormsewers and other stormwater conveyances can help trace pollution sources, prioritize areas for implementing control measures, and help to assure proper disposal of accumulated sediments.

Assessing sediments to determine whether stormwater pollutants are causing or contributing to ecological problems within a water body has not been done very often. Consequently, only recently have standard sediment assessment procedures been developed. Before sediments can be reliably used to assess the effects of pollutants on aquatic systems, three fundamental sediment monitoring issues must be addressed:

- accurate, reliable sediment sampling and laboratory analysis techniques.
- interpretive techniques to determine whether materials ("pollutants", especially metals) found in sediments are natural or anthropogenic (from human activities).
- sediment quality assessment guidelines correlating sediment "pollutant" concentrations with biological effects. These are needed to assess whether sediment materials are potentially available to return to the water column or through food chains in amounts likely to adversely affect water quality and living resources.

FLORIDA'S SEDIMENT ASSESSMENT PROJECTS

Florida has an extensive coastline (approximately 11,000 miles) and an unusual diversity of estuarine types. Conditions in its many estuaries range from nearly pristine to localized severe degradation. Metals are of particular concern in terms of protecting and rehabilitating estuaries because of their potential toxic effects and because high metal concentrations can signal the presence of other types of pollution. Natural metal concentrations can vary widely among Florida estuaries presenting special difficulties in comparing estuarine systems statewide and in making consistent, scientifically defensible management decisions.

In the past, determining whether estuarine and coastal sediments were anthropogenically enriched with metals was a difficult process requiring comprehensive site-specific assessments. In 1983, staff from the Department's Office of Coastal Zone Management, in association with Dr. Herb Windom of the Skidaway Institute of Oceanography, began a nearly decade long effort to develop a practical

approach for assessing metals contamination in coastal sediments. Projects undertaken include:

1. The Deep Water Ports Project, a survey of sediment quality in eleven major ports around the state, performed in 1983-84.
2. The Statewide Survey of Clean Reference Sites, a survey of sediment quality in many relatively isolated, unimpacted locations around the state, done between 1986 and 1991.
3. Ongoing surveys, some in conjunction with the National Atmospheric and Oceanic Administration, initiated in 1985 to survey sediment quality in estuaries throughout Florida.

From these projects an assessment procedure was developed which relies on normalization of metal concentrations to a reference element. In Florida, normalization of metal concentrations to aluminum concentrations in estuarine sediments provided the most promising method of comparing metal levels regionally. Other elements such as iron or lithium can also be used as normalizing elements for assessing estuarine and marine sediments. Development of this sediment assessment procedure required three components of monitoring to be addressed:

1. Refinement of sediment sampling protocols and laboratory analytical techniques to assure that sediment data is accurate and comparable.
2. Development of an interpretive technique to determine whether sediment materials are naturally occurring or from anthropogenic sources within a watershed.
3. Development of sediment quality assessment guidelines to help determine whether sediment bound pollutants are harmful to the environment.

Part 1. Collection of Sediment Samples

To ensure that the information used to develop the interpretive tool represented the diverse Florida sediments, uncontaminated sediments from around the state were examined for their metal content and the natural variability of metal/aluminum relationships was statistically assessed (FDER, 1988). Sediment samples from 103 stations in uncontaminated estuarine/coastal areas were collected and analyzed for aluminum and other environmentally and geochemically important metals. The areas sampled encompassed various sediment types ranging from terrigenous, aluminosilicate-rich sediments in northern Florida to biogenic, carbonate-rich sediments in southern Florida. These "clean" sites were selected subjectively, based upon their remoteness from known or suspected anthropogenic metal sources.

The following sampling procedures were developed and refined into a standard protocol:

1. Prior to field sampling, station locations were determined after studying local watershed information (land use, drainage patterns and systems, water depths, potential sediment deposition areas), navigation charts, and meeting with local government staff.
2. Stations were located using LORAN-C by latitude and longitude, compass bearings, and cross referenced to navigational charts. In 1991, the standard field

protocol was changed and Global Positioning System (GPS) is now used to locate stations.

3. Upon arrival at the station, the boat was anchored and engines shut off. The location, time, date, weather conditions, and compass bearings (and GPS location) were recorded in a station log notebook along with water column physical parameters taken at the surface, mid-depth, and bottom.
4. Sediments were collected in replicate from the boat using a stainless 9X9" PONAR grab sampler. The grab was suspended from a hoist, acid washed and rinsed with deionized water before use, and rinsed with ambient water between grabs. A 10% HCl solution was used to acid rinse all utensils, the sampling grab, and spatulas used to process samples. Once the sampler was retrieved, it was carefully emptied into a clean, acid washed and rinsed tub. The top two cm of sediment were scooped from the top of the grab. Repeated grabs were made at the same site until enough material was collected for all analyses.
5. Sediments were collected by using sediment coring tubes at stations where the water was too shallow for the boat, or where sensitive habitats (sea grass beds, corals) precluded use of the grab sampler. Acid washed and rinsed clear cellulose-acetate-butyrate core tubes with caps were used for each sample, with three replicate samples collected at each station. Core tubes were plunged into the sediment and the top capped. A diver retrieved the core tube by displacing the sediment around the core, putting on the bottom cap, and lifting the core tube. Cores were taken to the boat where they were transferred into containers using an acid washed extruding tool. The top 3-5 cm of the cores were packed in the collecting jar. Each replicate sample was a composite of the three cores.
6. Samples were transferred to glass jars or whirlpaks which have been precleaned to meet EPA specifications for organic and inorganic materials. Sample containers were labeled, then placed on ice.
7. Since 1991, several changes have been made to the FDEP standard field protocol including:
   a. A 12"X12" Kynar coated stainless steel "Young" grab is used to collect sediment. It is deployed in a similar fashion as the PONAR.
   b. In addition to acid washing, full strength acetone is used to rinse all gear prior to sampling and between all stations. This volatilizes any organic contaminants that might be on the sampler.
   c. The top two centimeters of sediment are scooped from the top of the sampler with an acetone rinsed sterile scoop. The sediment is then transferred to a stainless container, and homogenized using an acid washed, acetone rinsed, long handled stainless scoop.

<u>Part 2. Laboratory Analysis of Sediment Samples</u>

From 1982 to 1990, all FDEP sediment samples were analyzed by Savannah Laboratories and Environmental Services, Inc. (SLES) in Savannah, Georgia. From 1990 to the present, the Skidaway Institute of Oceanography (SIO) in Savannah analyzed sediments. Physical characteristics, such as grain size and percent organic matter, were determined for sediment samples which were then analyzed for nine

metals (aluminum, arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc). Except for mercury, SLES analyzed metals using graphite furnace or flame atomic absorption spectrometer and analyzed organic compounds using gas chromatographic techniques. SIO analyzed metals by ICP (inductively-coupled plasma) mass spectrometry or by atomic absorption spectrometry.

Before analysis for metals, particular care was taken to totally digest the sediment samples using hydrofluoric, nitric, and perchloric acids as required by the project quality assurance plan. Total digestion of the sediment sample is essential when using the sediment assessment tool because of its normalization method to estimate metal contamination. Total digestion is strongly encouraged to produce comparable date for general environmental and trend monitoring of pollutants. FDEP conducted a laboratory intercalibration exercise, in which four laboratories participated, to assess the accuracy and precision of reported metals data from coastal sediments and from sediment reference materials (Schropp, 1992). Results of this exercise and an international intercalibration exercise (Loring and Rantala, 1988) both showed that sediment trace metal data from different laboratories may not be comparable if different sample digestion techniques are used.

<u>Part 3. Distinguishing Natural vs. Anthropogenically Enriched Sediments</u>

Once methods to reliably and accurately collect and analyze sediment samples were refined, the next step was to develop an interpretive tool to determine whether metals in sediments were natural or from human activities. To understand this assessment tool, one must generally understand the geochemical processes that govern the behavior and fate of metals in estuarine and marine waters. Natural estuarine sediments are predominantly composed of river-transported debris resulting from continental weathering. The solid debris is composed chiefly of chemically resistant minerals, such as quartz and clay minerals, which are the alteration products of other aluminosilicate minerals. The weathering solution also contains dissolved metals leached from the parent rock. Because of their low solubilities, however, the transporting solution (e.g., rivers) carries low amounts of metals. Most metals transported by rivers are tightly bound in the aluminosilicate solid phases. As a consequence, weathering causes little fractionation between the naturally occurring metals and aluminum.

In general, when dissolved metals from natural or anthropogenic sources come in contact with saline water, they quickly adsorb to particulate matter and are removed from the water column to bottom sediments. Thus, metals from both natural and anthropogenic sources are ultimately concentrated in estuarine sediments, not the water column. Since much of the natural component of metals in estuarine sediments is chemically bound in the aluminosilicate structure, the metals are generally immobile. However, the adsorbed anthropogenic or "pollutant" component is more loosely bound and may be more available to estuarine biota and may be released to the water column when sediments are disturbed (e.g., by dredging or storms).

The tool for interpreting metal concentrations in estuarine sediments is based on demonstrated, naturally occurring relationships between metals and aluminum. Specifically, natural metal/aluminum relationships were used to develop guidelines to distinguish natural from contaminated sediments for several metals commonly released to the environment from anthropogenic activities. Aluminum was chosen as a reference element to normalize sediment metals concentrations for several reasons:

1. After silicon, it is the most abundant naturally occurring metal;
2. It is highly refractory;
3. The relative proportions of metals and aluminum in crustal materials are fairly constant;
4. Its concentration is rarely influenced by anthropogenic sources.

Using the data from sediments collected and analyzed as part of the Statewide Survey of Clean Reference Sites, a metal to aluminum normalization method was developed (FDEP, 1988) At these sites, sediment metal concentrations are generally expected to express natural relationships with aluminum. Eight metals (As, Cd, Cr, Cu, Hg, Pb, Ni, and Zn) were tested to determine their relationship to aluminum with a set of graphical tools developed to assess trace metal contamination in a sediment sample. For example, Figure 1 shows that as aluminum concentrations in "clean" sediments increase, metals concentrations, in this case lead, also increase. Least squares regression analysis, using aluminum concentration as the independent variable and the concentration of the other metal as the dependent variable, were performed on log-transformed data and 95% prediction limits were calculated. Significant correlations were obtained for arsenic, cadmium, copper, lead, nickel, and zinc. The plotted regression lines and prediction limits provide the basis for interpreting metal concentrations in sediments.

To determine whether estuarine sediments are enriched with metals, a mean value of each metal (derived from replicate or triplicate samples) is calculated and points representing corresponding metal and aluminum values are plotted (Figure 2). The sediment is judged to be natural or metal enriched depending on where the points lie relative to the regression lines and prediction limits. If a point falls within the prediction limits, then the metal concentration is within the natural range. If a point falls above the upper prediction limit, then the sediment is considered to be metal-enriched. Before concluding sediment "enrichment", the accuracy of the analytical results should be confirmed, since an unusual point can be indicative of procedural errors. Since the results are interpreted with respect to the 95% prediction limit, some points from "clean" stations may plot outside the prediction limit. The greater the distance above the prediction limit, the greater degree of enrichment. An enrichment factor, which is the ratio of the measured metal concentration to its maximum expected concentration in natural sediments, can be calculated using the following equation (FDEP, 1994):

$$\text{MetalEnrichmentFactor} = \frac{\text{ObservedMetalConcentration}(\mu g/g)}{\text{MaxExpectedNaturalMetalConc}(\mu g/g)}$$

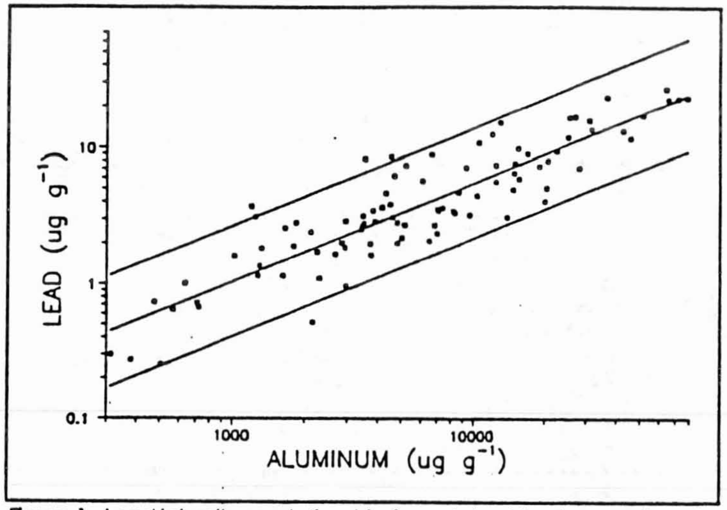


Figure 1. Lead/aluminum relationship from statewide clean sediments.

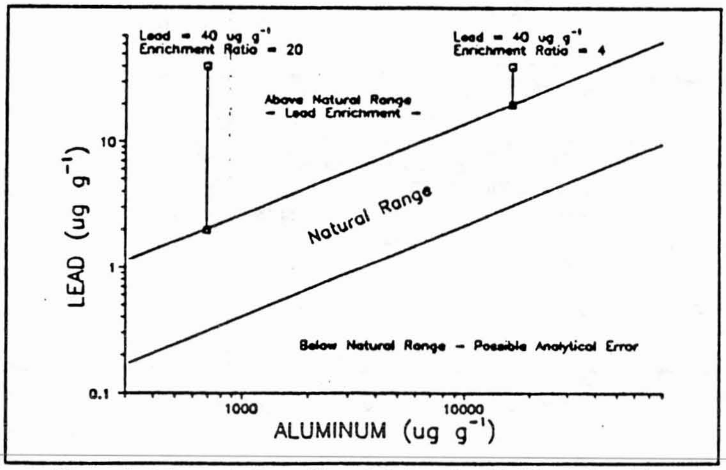


Figure 2. Interpretation of Lead data using Pb/Al relationship.

Applications of the Interpretive Tool

The effectiveness and utility of this sediment assessment tool has been tested in a variety of regional studies (Tampa Bay, Schropp et al., 1989; SE Atlantic and Gulf coasts, Hanson and Evans, 1991; Louisiana, Pardue et al., 1992). The results of these studies indicate that aluminosilicate minerals have a major influence on metal concentrations in natural sediments. The interpretive tool using metal and aluminum relationships allows results of sediment chemical analyses to be used for a variety of environmental information needs:

1. Distinguishing natural versus enriched metals concentrations in coastal sediments.
2. Normalizing metals to a reference element allows comparisons of metal concentrations among sites within a watershed.
3. Comparing investigative results from different watersheds. By normalizing metal concentrations to aluminum, an assessment of relative metal enrichment levels can be made, allowing watersheds to be ranked according to specific metal enrichment problems.
4. Tracking the influence of a pollution source.
5. Monitoring trends in sediment metal concentrations over time.
6. Determining sediment sampling or analysis procedural or laboratory errors.
7. Screening sediment data to promote cost-effective use of elutriate or other sediment quality tests.

Limitations of the Interpretive Tool (FDER, 1988)

Funding limitations in Florida have prevented the collection and analysis of sediment samples from freshwater systems to evaluate if the tool can be used in those aquatic systems. However, such sampling is underway in Washington and previously was completed in Illinois. Use of this tool requires knowledge of local conditions and applying professional judgement. Consider the following points when using this interpretive tool:

1. The interpretive tool is useless without reliable data. Results from single, non-replicated samples should not be used. Ideally, sediment samples should be collected in triplicate. If budget constraints dictate analysis of only duplicate samples, the third sample should be archived. In the event of a disparity in the results of replicate analyses, the archived sample should be retrieved and analyzed to resolve the problem.
2. Sediment metals must be analyzed using techniques appropriate for saline conditions and capable of providing adequate detection limits. Because naturally-occurring aluminum and other metals are tightly bound within the crystalline structure of sedimentary minerals, the metal analysis method must include total digestion using HF, HNO_3, and $HClO_4$ acids. If aluminum is not completely released by a thorough digestion, metal to aluminum ratios may appear to be unusually high.
3. Natural concentrations of cadmium and mercury are very low and are near normal analytical detection limits. Because of this, analytical precision and accuracy are reduced and special care must be taken to obtain accurate laboratory results.
4. The data set is, to the extent possible, representative of various types of natural "clean" sediments found in Florida estuaries. Only in a few instances should aluminum concentrations exceed 100,000 ppm (10% aluminum). Any samples containing greater than 100,000 ppm aluminum should be examined carefully for evidence of contamination or analytical error.
5. Interpretation of metal concentrations, using these metal to aluminum relationships, must also consider sediment grain size, mineralogy, coastal hydrography, and proximity to sources of metals.

Part 4. Determining the Ecological Significance of Enriched Sediments

Sediment chemistry data alone do not provide an adequate basis to identify or manage potential sediment quality problems. After determining that sediments are anthropogenically enriched with pollutants, the next assessment step is to determine whether these sediment-bound pollutants are harmful to the environment. Biologically-based numerical sediment quality assessment guidelines (SQAGs) also are required to interpret the ecological significance of sediment chemistry data by providing a basis for assessing the potential effects of sediment-associated contaminants.

MacDonald (1993) reviews the variety of approaches which have been devised to formulate sediment quality guidelines (SQGs). A suitable strategy for deriving SQAGs for Florida must recognize the limitations of the existing database to evaluate the potential biological effects of sediment-associated contaminants. Therefore, the strategy must address both the immediate requirement for defensible SQAGs and the long-term requirement for increased reliability and applicability of these guidelines (i.e., guidelines that account for the environmental characteristics that influence the bioavailability of sediment-associated contaminants).

To develop a tool to assess the potential ecological effects of sediment based contaminants, the FDEP, in association with MacDonald Environmental Sciences, reviewed eight approaches to derive sediment quality assessment guidelines that would be applicable to Florida coastal conditions and appropriate for the state's specific needs. Several criteria were established to objectively evaluate the approaches and select a relevant strategy to derive these guidelines. The primary considerations in selecting the recommended strategy were practicality, cost-effectiveness, scientific defensibility, and broad applicability to sediment quality assessment. This review indicated that each of the approaches has deficiencies that limit its direct application in Florida. For this reason, an integrated strategy for deriving numerical SQAGs was recommended for the state of Florida (MacDonald, 1993). This strategy provides relevant near term assessment tools and a basis to refine these guidelines as the necessary data become available.

Using the recommended approach, numerical SQAGs have been developed for 25 priority contaminants in Florida coastal waters (MacDonald, 1993) using a modification of the NOAA's National Status and Trends Program Approach (Long and Morgan, 1990). These guidelines, derived from numerous investigations of sediment quality conducted throughout North America, are based on a weight-of-evidence linking contaminant concentrations and adverse biological effects. In this respect, the guidelines represent a cost-effective response to a practical need for assessment tools. However, these guidelines are preliminary and will likely be refined with results from field validation and other related studies now underway in Florida and elsewhere in North America. The guidelines should be used with other interpretive tools to conduct comprehensive and reliable assessments.

Effects-based SQAGs provide a basis to assess the potential for biological effects associated with various contaminant concentrations. MacDonald (1993) derived no observed effects levels (NOELs) and probable effects levels (PELs) to define three ranges of contaminant concentrations: the probable effects range, the possible effects range, and the no effects range.

The probable effects range is the concentration range of specific sediment contaminants within which biological effects are usually or always observed (probable effects range ≥ PEL). Sediments with contaminant concentrations within the probable effects range *represent significant and immediate hazards to exposed organisms*. Sites with concentrations of one or more contaminants that fall within the probable effects range should be given the highest priority in implementing sediment quality management options. However, direct biological assessment is required at these sites to determine the nature and extent of effects that could be manifested.

The possible effects range is the concentration range of a specific sediment contaminant with uncertain adverse biological effects (NOEL < possible effects range < PEL). This range is likely to be dependent on factors, such as bioavailability, that may influence the toxicity of the substance. Sediment-associated contaminants *represent potential hazards to exposed organisms* when concentrations fall within this range. Sediments with contaminant concentrations within this range require further assessment to determine the biological significance of the contamination. In general, further assessment would be supported by biological tests designed to evaluate the biological significance of sediment-associated contaminants to key species of aquatic biota.

The no effects range of sediment contaminant concentrations where biological effects are rarely or never observed (no effects range ≤ NOEL). Sediments with concentrations of contaminants within the no effects range are *considered to be of acceptable quality* for those contaminants. In general, further investigations of sediment quality conditions within this range are relatively lower priority. However, biological testing may be required to validate the results of the initial assessment of the potential for adverse biological effects, particularly in sediments with low levels of total organic carbon, acid volatile sulfide, and/or other variables that could influence the bioavailability of sediment-associated contaminants.

<u>A Framework For Assessing Site-specific Sediment Quality Conditions in Florida</u>

MacDonald (1993) developed a framework for the Florida Department of Environmental Protection for future use of sediment quality assessment guidelines and related tools. This framework, which identifies essential considerations to address in conducting site-specific sediment quality assessment programs, consists of:

1. Collect Historical Land and Water Use Information
   - Land uses - current and historical; industrial, commercial
   - Infrastructure including stormwater systems
   - Pollution sources - point and nonpoint
   - Hydrology, physiography, ecology
2. Collect and Evaluate Existing Sediment Chemistry Data
   - Sediment deposition location, patterns, transport,
   - Sediment physical and chemical characteristics
   - Temporal and spatial variability, vertically and horizontally
   - Determine data reliability, acceptability, applicability
3. Collect Supplemental Sediment Chemistry Data
   - Determine contaminants, sampling locations
   - Delineate temporal and spatial variability in sediment contamination
   - Prepare and follow QA Plan for sampling, handling, and analysis protocols
4. Conduct Preliminary Assessment of the Potential for Biological Effects of Sediment-Associated Contaminants
   - Compare sediment contaminant concentrations to SQAGs
5. Evaluate Natural versus Anthropogenic Sources of Sediment-Associated Contaminants
   - Determine sources using the previously described sediment assessment procedure
6. Conduct Biological Assessment of Sediment Quality
   - Determine whole sediment toxicity
   - Conduct short-term bioassays, long-term microcosm studies, etc.
   - Develop site-specific SQAGs
   - Conduct biological community assessments
7. Implement Management of Sediment Quality
   - Evaluation factors include nature and severity of sediment contamination, potential for exposure of aquatic life, site or regional management goals, availability of remediation technology, costs, and public expectations.
   - Actions may range from none to continued monitoring to remedial actions such as removal and treatment of sediment contaminants or source control implementation.

This framework is designed to provide a consistent approach to assessing sediment quality in marine and estuarine areas. However, the framework is not intended to replace accepted sediment testing protocols such as developed for the ocean disposal of dredged material. Instead, it is intended to provide general guidance to support the sediment quality assessment process.

Applications and Limitations of the Recommended Sediment Assessment Approach

The sediment quality assessment strategy provides a consistent basis to evaluate sediment quality in Florida. While the SQAGs represent an integral element of this strategy, they should be used with other assessment tools to efficiently and cost-effectively evaluate ambient sediment quality conditions. In this context, these SQAGs may be used to:

- Interpret the results of sediment quality monitoring data to assess the potential adverse biological effects associated with concentrations of sediment-associated contaminants.
- Support the design of sediment quality monitoring programs by evaluating existing sediment chemistry data to rank areas and chemicals of concern allowing monitoring priorities to be more clearly and effectively identified.
- Identify the need for site-specific investigations to support regulatory or watershed management decisions, including source controls and the siting of regional stormwater management systems.
- Evaluate the hazards associated with increased levels of contaminants at specific sites.
- Facilitate multijurisdictional agreements on sediment quality issues and concerns by establishing site-specific sediment quality objectives that help define the responsibilities of various levels of government in preventing and remediating sediment contamination.

These guidelines were established to provide a consistent basis for evaluating estuarine sediment quality in Florida. However, these guidelines are preliminary and, as such, have certain limitations on their application. Therefore, SQAGs:

- Are applicable to marine and estuarine waters only, not to freshwater systems.
- Should not be used in lieu of water quality criteria. However, they may be used to evaluate the effectiveness of regulatory programs and identify the need for more stringent regulations.
- Should not be used to define uniform values for sediment quality on a statewide basis (i.e., they should not be used as sediment quality criteria). Ambient environmental conditions may influence the applicability of these guidelines at specific locations;
- Should not be used as criteria for the disposal of dredged material and should not replace formal assessment protocols established for disposal of dredged material.
- Should not be used directly as numerical clean-up levels at severely contaminated sites (e.g., Superfund sites).
- Are designed to determine the potential for sediment-associated contaminants to induce biological effects. Direct cause and effect relationships should not be inferred when comparing chemical data to the recommended guidelines.
- Have been derived primarily from acute toxicity study results. Few data are available on the chronic responses of aquatic organisms to contaminants associated with sediments.
- Should be used with other assessment tools and protocols, such as the FDEP metals interpretive tool and the Green Book (EPA and ACE, 1991), to provide

comprehensive evaluations of sediment quality.

- Were developed using information from various North American locations. These data may not be representative of the wide range of Florida sediment types. For this reason, caution should be exercised in using these guidelines, particularly in carbonate-dominated sediments in southern Florida.

Part 5. Using the Sediment Assessment Tools

MacDonald (1993) stresses the importance of combining the effects-based guidelines and the metals interpretive tool. MacDonald examines data on levels of sediment-associated lead from two geochemically distinct systems, Biscayne Bay and Apalachicola Bay, to illustrate the integrated sediment quality assessment framework. Figure 3 shows a summary of the available data (FDEP, 1994) on the levels of sediment-associated lead in the Miami area. The data, sorted by increasing concentration, were assigned sample numbers of 1 to 108. Evaluation using the SQAGs suggests that approximately 15% of the samples fall within the probable effects concentration range (exceed the PEL of 160 mg/kg). Another 20% of the samples fall within the possible effects range (between the NOEL and the PEL). Therefore, comparing sediment chemistry data with the numerical SQAGs suggests a relatively high probability of observing adverse biological effects. Further examination of these data using the metals interpretive tool (Figure 4) demonstrates that sediments from this area are clearly anthropogenically-enriched with lead. Roughly 90% of the samples exceed the 95% prediction limits established for clean sites. Concordance between the effects-based tool and the geochemically-based tool suggests that the Miami area should be a priority area for further investigations to evaluate sediment toxicity.

In Apalachicola Bay, roughly 20% of the samples had lead levels that exceeded the NOEL of 21 mg/kg (Figure 5). Comparison of the ambient lead levels in Apalachicola Bay with SQAGs suggests possible adverse biological effects at a significant number of sites. However, further evaluation using the metals interpretive tool indicates that aluminum-normalized lead level in Apalachicola Bay sediments is indicative of those measured in clean sediments in Florida (Figure 6). While the effects-based tool predicts the possibility of adverse effects at some sites, the geochemical tool demonstrates that lead concentration in Apalachicola Bay are naturally-occurring and, as such, should not be considered hazardous to aquatic organisms. This system does not require further investigations to evaluate the extent of sediment toxicity.

In 1994, the Sediment Research Group of FDEP released the *Florida Coastal Sediment Contaminants Atlas*, which describes the spatial extent of sediment contamination in Florida's coastal waterbodies. The *Atlas* presents the results of the previously mentioned FDEP coastal sediment surveys. In addition, the *Atlas* has been strengthened by inclusion of sediment data from the NOAA National Status and Trends Program, as well as sediment data produced by the Mote Marine Laboratory, an independent marine research facility located in Sarasota, Florida. The *Atlas*

Figure 3. Conc. of Pb in sediments of Biscayne Bay.

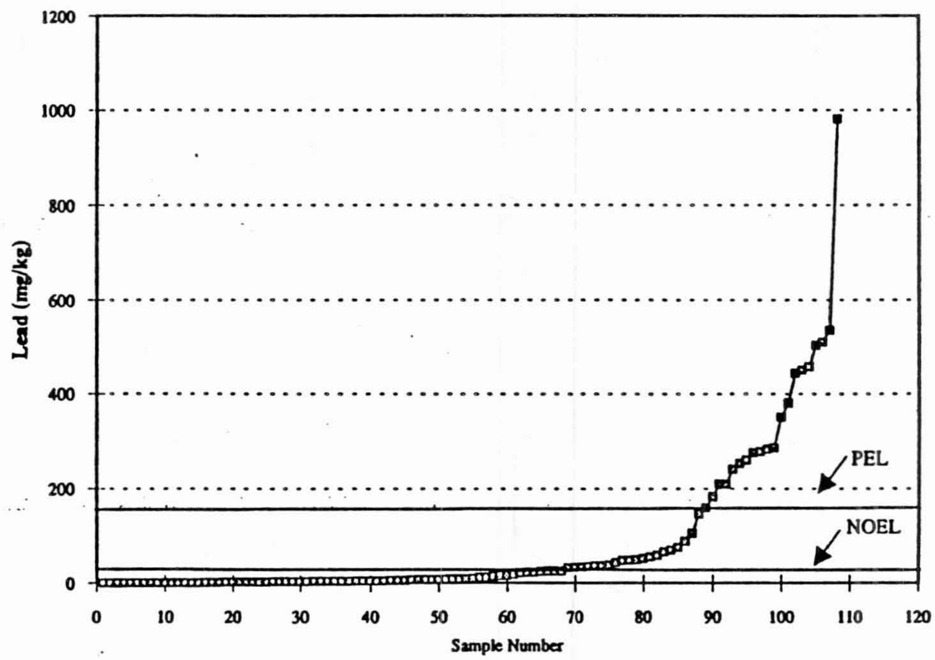


Figure 4. Alum. normalized conc of Pb in Biscayne Bay sediments.

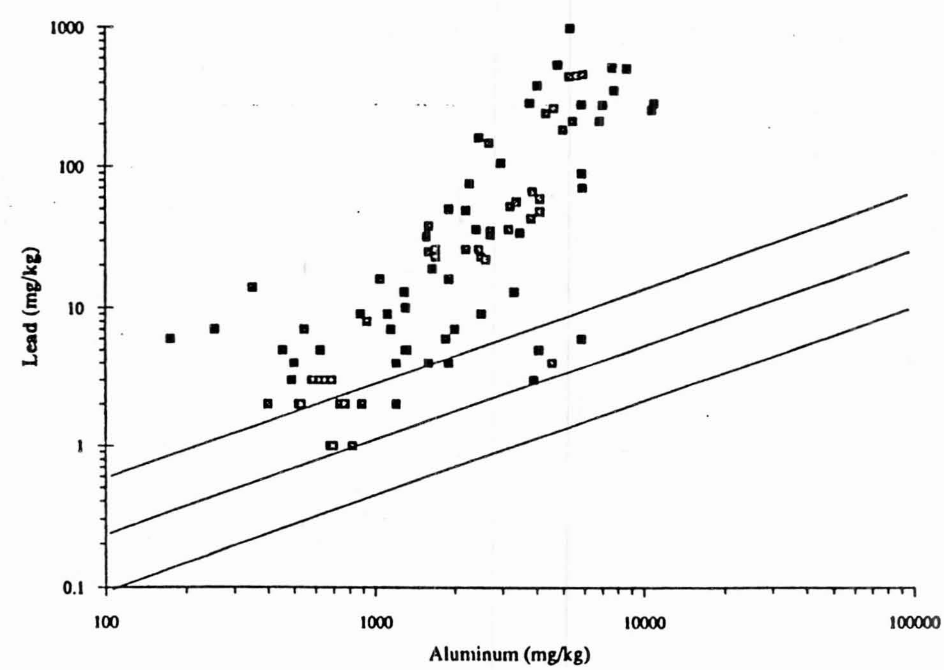


Figure 5. Conc. of Pb. in sediments of Apalachicola Bay.

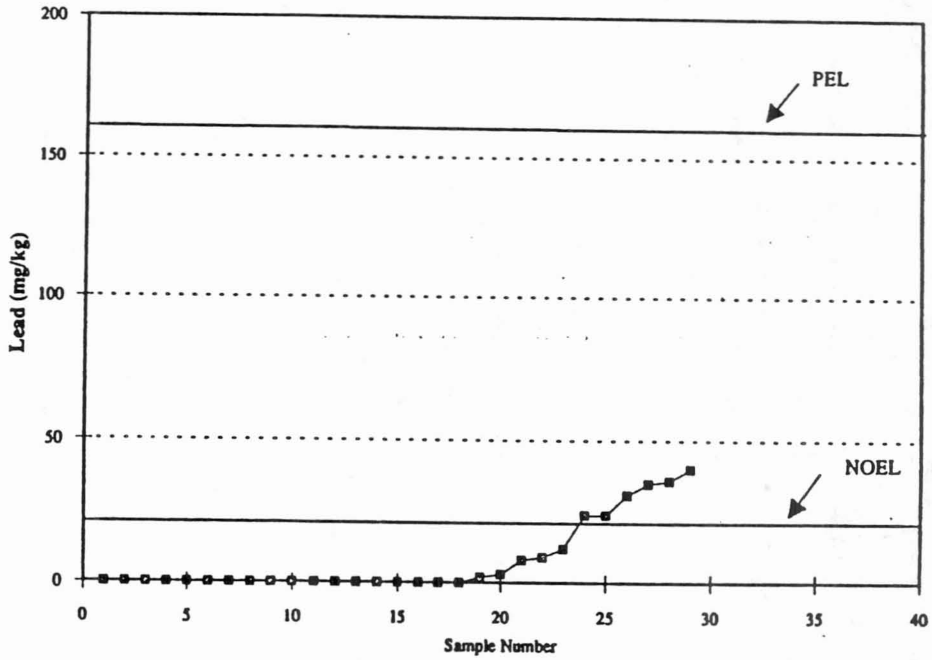
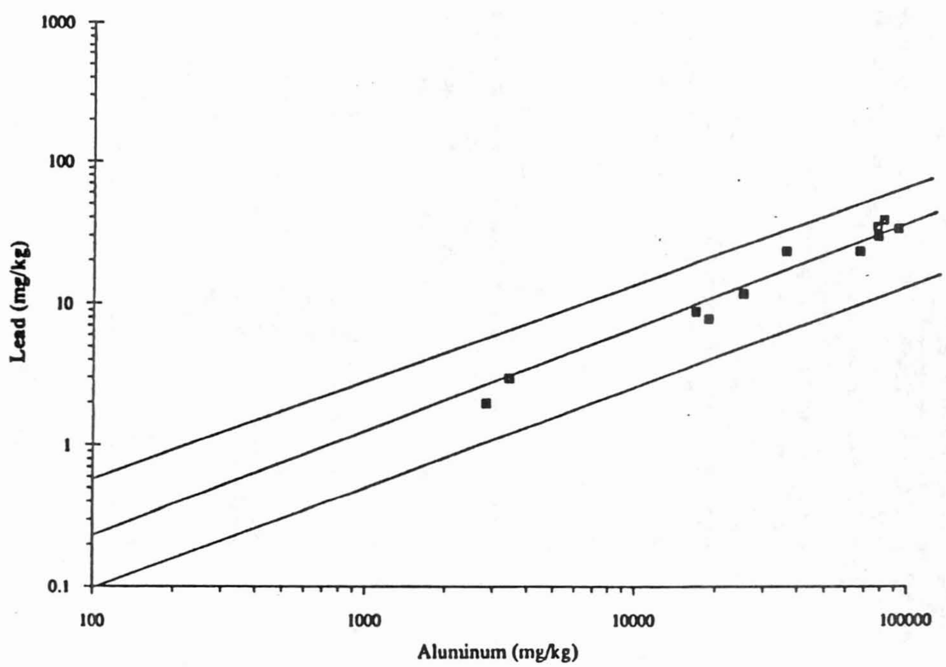


Figure 6. Alum-normalized conc of Pb in Apalach Bay sediments.



includes information on the eight metals and five classes of organic compounds - chlorinated hydrocarbons, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), phenolic hydrocarbons, and aliphatic hydrocarbons. A Technical Volume accompanies this *Atlas* and provides ancillary information for users of this document.

Although the Department was not able to fully assess sediment contamination along Florida's extensive coastline, it appears that the highest concentrations of contaminants in sediments are generally near urban centers. However, low to moderate levels of contaminants are common adjacent to many less developed coastal areas. Stormwater runoff appears to be the major cause of contamination of sites identified in the *Atlas*. Regional monitoring of contaminants in living resources and sediments, followed by sediment toxicity studies, is strongly recommended to keep a finger on the pulse of Florida's freshwater and marine ecosystems.

BIOLOGICAL COMMUNITY MONITORING

Since enactment of the Federal Clean Water Act, most efforts to preserve, maintain and restore water quality have relied upon and been directed by chemical and physical measurements of the water column. While this approach may be useful in assessing the effects of continuous point discharges, such as domestic or industrial wastewaters, it cannot accurately determine environmental impairments from intermittent sources such as stormwater or other nonpoint source discharges.

Intermittent discharges create shock loadings to a water body with the ecological effects depending on complex interactions of many variables. Moreover, most stormwater pollutants become attached to sediment particles or settle quickly, exerting detrimental effects over a long period. Furthermore, stormwater discharges degrade habitat (eg, channel and bank erosion) and cause tremendous siltation, neither of which are detected by water chemistry sampling. Karr et. al. (1986) group environmental factors affecting most aquatic ecosystems into five major classes: chemical variables, biotic interactions, flow regime, habitat structure, and energy source. These factors interact to determine the integrity of water resources reflected by the resident aquatic life. Alterations to the physical, chemical, or biological process can adversely affect the aquatic biota and, therefore, the biological integrity of the water body. Monitoring methods integrating all five classes are necessary to accurately assess and manage surface water quality and aquatic life resources.

Inclusion of biological community monitoring allows a more holistic, systems approach that greatly enhances surface water quality assessment and management. While chemical data reflect short-term conditions that exist when a particular sample is collected, biological communities accurately indicate overall environmental health because they continuously inhabit receiving waters where they integrate a variety of environmental influences - chemical, physical and biological.

Biological assessment involves an integrated analysis of functional and structural

components of aquatic communities. Bioassessments are best used to detect aquatic life impairments and assess their relative severity. Once an impairment is detected, additional chemical and biological toxicity testing can identify the causative agent and its source. Both biological and chemical methods play critical roles in successful pollution control and environmental management programs. They are complementary, not mutually exclusive, approaches that enhance overall program effectiveness.

Some advantages of bioassessments are:

1. Biological communities reflect overall ecological integrity (chemical, physical and biological).
2. Over time, biological communities integrate the effects of different stressors, providing a measure of fluctuating environmental conditions.
3. By integrating responses to highly variable pollutant inputs, biological communities provide a practical approach for monitoring stormwater/nonpoint source impacts and the effectiveness of best management practices.
4. Routine monitoring of biological communities can be relatively inexpensive, particularly when compared to the cost of assessing toxic substances.
5. The public is very interested in the status of biological communities as a measure of environmental health.
6. Biological communities offer a practical way to evaluate the habitat degradation typically associated with stormwater discharges.

Determining Biological Integrity - Rapid Bioassessment Concept

Although the principal goal of the Federal Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the nation's water resources, difficulties in defining an ecological approach to assessing biotic integrity has led regulatory agencies to rely primarily on chemical measurements. However, Karr and Dudley (1981) define biotic integrity as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitats within a region". This practical definition is based on measurable characteristics of aquatic communities and comparisons to a regional reference site thus providing a framework for bioassessments.

Recent advances in computer technology and, more importantly, in biological community assessment techniques makes bioassessments more practical. These advances include geographic information systems (GIS) and available digitized data bases, refined laboratory and field methods, development of standard assessment techniques, a practical and useful definition of biological integrity, and the regional reference site concept. These advances provide a framework to incorporate biological community assessments and "biocriteria" into surface water management programs.

In 1985, EPA conducted a survey to identify states that routinely performed biological assessments and to evaluate the field methods being used. A workgroup of state and EPA biologists was formed to review the existing methods and to refine protocols for monitoring benthic macroinvertebrates and fish. In May 1989, EPA published "Rapid Bioassessment Protocols for Use in Streams and Rivers" to which the reader is referred for a more comprehensive discussion of this topic.

The rapid bioassessment protocols (also known as community bioassessment protocols) advocate an integrated assessment, comparing habitat (physical structure and flow regime) and biological measures with empirically defined reference conditions. Reference conditions are established through systematic monitoring of actual sites (ecoregion reference sites) that represent the natural range of variation in "least disturbed" water chemistry, habitat, and biological condition. The concept of ecoregions and ecoregional reference sites is discussed in a July 1989 EPA publication "Regionalization as a Tool for Managing Environmental Resources".

With the publication of these two landmark publications, states began intensive work to refine the ecoregions and protocols to suit local conditions and needs. The state-of-the-art in this rapidly developing field continues to evolve into many more variations. The original authors of the documents strongly advocate customizing both ecoregions and the bioassessment protocols. The most important common element required in these efforts is the use of a scientific approach which can be defended.

Consequently, before this protocol can be used and biological community assessment programs implemented, state specific analyses must be undertaken. This presents many unique challenges, requiring special expertise, adequate funding and several years. For example, state specific subecoregions must be delineated, appropriate ecoregion reference sites selected and sampled, community bioassessment sampling and evaluation methods modified, appropriate biological community metrics selected, and each of these must be verified.

These techniques offer the best means of accurately assessing the impacts of stormwater and other nonpoint sources of pollution. The Florida Bioassessment Project was designed to address many of the above issues to develop a refined bioassessment protocol for use in Florida streams to document impairment from nonpoint sources of pollution and to determine the effectiveness of management programs.

THE FLORIDA STORMWATER/NPS BIOASSESSMENT PROJECTS

In 1990, the Stormwater/Nonpoint Source Management Section of the Florida Department of Environmental Protection began a multi-year effort to refine and enhance current biological community assessment methods. This work consists of four primary components: I. Delineating subecoregions and selecting reference sites; II. Developing standardized biological sampling and habitat assessment methods; III. Evaluating biological data to develop and verify biological metrics and an index of biotic integrity; and, IV. Developing or revising biocriteria. The rest

of this paper will discuss program components I through III.

Four contracts, funded by EPA Section 104 (b)(3), 205(j)(1), and 319 grants, are the central focus of this effort:

1. Florida Regionalization Project, contracted to the EPA Environmental Research Lab and to ManTech Environmental Technology, Inc. of Corvallis, Oregon, and led by James Omernik and Glenn Griffith. The two primary tasks included subdividing Florida's three ecoregions into subregions, and selecting and verifying ecoregion reference sites (Component I).
2. Bioassessment for the Nonpoint Source Program, contracted to EA Engineering, Science, and Technology, whose project manager is Mike Bastian, and Tetra Tech, Inc., whose project manager is Mike Barbour. This project's objectives include reviewing and refining DEP's existing biological sampling and analysis procedures; development of standardized stream macroinvertebrate sampling and habitat assessment protocols; testing the protocols by collecting data at candidate reference sites; and, developing candidate biological metrics to quantify the biotic integrity of benthic macroinvertebrates (Components II and III).
3. Development of a Florida Index of Biotic Integrity, contracted to Tetra Tech and Mike Barbour. This project continues the statistical analysis of biomonitoring data being collected from the candidate reference sites and other sites. In particular, the metrics will be refined by further testing and verification of the recommended biological metrics (Component III).
4. Development of a Biological Data Base, contracted to Lori Wolfe Enterprises, a local computer programming firm (Corollary project).

Component I. Delineating Ecoregions and Selecting Reference Sites

Spatial frameworks can profoundly influence the effectiveness of research, assessment, and management of many water resource problems, especially those caused by stormwater and nonpoint sources. Traditionally, we have relied on spatial frameworks based on political boundaries, watersheds, hydrologic units, or physiographic regions. However, these units do not correspond to patterns in vegetation, soils, land surface form, land use, climate, rainfall or other characteristics that control or reflect spatial variations in surface water quality or aquatic organisms.

Effective water quality management programs must recognize the significance of land/water interactions, nonpoint sources, and regional variations in attainable water quality. Water quality assessments need a regional framework to:
1. compare regional land and water patterns;
2. compare ecological and habitat similarities and differences;
3. establish realistic, achievable chemical and biological standards;
4. assess the effects of all pollution sources within a watershed, especially intermittent discharges;
5. predict the effectiveness of management practices;
6. prioritize assessment and management efforts;

7. locate monitoring and special study sites; and
8. extrapolate site-specific information to larger areas.

Omernik (1987) proposed using spatial frameworks based on ecological regions (ecoregions) to assess the health of aquatic systems. Ecoregions are areas of relative homogeneity in ecological systems and relationships between organisms and their environments. Ecoregions usually are defined by patterns of homogeneity in a combination of factors such as climate, physiography, geology, soils, vegetation and dominant land uses. These regions also define areas within which there are different patterns in human stresses on the environment and different patterns in the existing and attainable quality of environmental resources. Ecoregions reflect similarities in the type, quality and quantity of water resources and the factors affecting them. Therefore, regional patterns of environmental factors reflect regional patterns in surface water quality.

Omernik (1987) originally identified 76 ecoregions in the conterminous United States including three in Florida. These ecoregions were useful for stratifying streams in Arkansas, Nebraska, Ohio, Oregon, Washington, and Wisconsin. They were used to set water quality standards in Arkansas, lake management goals in Minnesota, and to develop biocriteria in Ohio. However, in many states, the resolution of the ecoregions was of insufficient detail leading to collaborative projects involving states, EPA regions and the EPA Environmental Research Lab-Corvallis to refine ecoregions and delineate subregions.

Delineating regions or subregions typically involves compiling and reviewing relevant materials, maps and data; outlining the regional characteristics; drafting the regional and subregional boundaries; digitizing the boundary lines, creating digital coverages, and producing maps; and revising after review by state managers and scientists. To delineate subregions in Florida, aerial and satellite images, maps, and other documents were obtained describing environmental characteristics including physiography, geology, soils, climate, land use, vegetation, wetlands, and various biological communities. Analysis of this information led to the definition of the following ecoregions and subregions in Florida (Griffin et. al., 1994):

1. The Southeastern Plains Ecoregion, with three subregions - Southern Pine Plains and Hills, Dougherty/Marianna Plains, and Tifton Upland/Tallahassee Hills
2. The Southern Coastal Plain Ecoregion, with six subregions - Gulf Coast Flatwoods, Southwestern Florida Flatwoods, Central Florida Ridges and Uplands, Eastern Florida Flatwoods, Okefenokee Swamps and Plains, and Sea Island Flatwoods.
3. The Southern Florida Coastal Plain Ecoregion, with four subregions - Everglades, Big Cypress, Miami Ridge and Atlantic Coastal Strip, and Southern Coast and Islands.

Once ecoregions and subregions are delineated and field verified, **ecoregion reference sites** must be selected. An essential component of the management framework, these sites allow us to evaluate the environmental health of a locale by

comparing it to a known reference site - a key concept in Karr and Dudley's definition of biotic integrity, which compares site evaluations to the aquatic community of "natural habitats within a region". Ecoregion reference sites used in water resources management must have two essential components: they must represent the ecoregion, and have ecological conditions that can be reasonably attained given current background conditions.

Reference sites must be carefully selected because they will be used for two purposes: (1) Benchmark for establishing regional biocriteria; and, (2) Control sites to which test sites will be compared. The two main criteria for selecting reference sites are that they be minimally impaired and that they represent the region's natural biological community. The ideal reference site will have extensive, natural, riparian vegetation; a diversity of substrate materials; natural physical structures; a natural hydrograph; a representative and diverse abundance of naturally-occurring biological communities; and a minimum of known, human induced disturbances or discharges. General guidelines for selecting reference sites are given in EPA (1989a).

To select stream subecoregion reference sites in Florida, the following steps were taken:

1. Using GIS techniques, information about the general characteristics of each ecoregion and subregion was analyzed to better understand representative conditions. Information reviewed included topographic maps, land use and soil maps, county highway maps, vegetational coverage maps, Landsat imagery, and the 1988 and 1990 Florida Water Quality Assessment 305(b) reports.

2. A set of stream sites with surface watersheds that appear relatively undisturbed and entirely within a subecoregion was chosen in which candidate reference sites were located. The actual number of sites per watershed is a function of the apparent homogeneity or heterogeneity of the region, the size of the region, hydrologic characteristics, and the number of candidate sites available. Access is a major factor in selection of the final reference sites. The number of candidate sites per subregion varied, ranging from only eight in subregion 75C, the Central Florida Ridges and Uplands where relatively few streams are found, to twenty sites in subregion 75D, the Eastern Florida Flatwoods. A list of the candidate sites was developed that included the subregion, site number, stream name and location, major basin, county, GIS map name, watershed area, and other information.
3. Department and water management district biologists reviewed the information for each candidate site and then conducted site visits. This ground reconnaissance allowed staff to get a sense of the usefulness of the subecoregions, the characteristics that comprise reference sites in each region, the range of characteristics and types of disturbances in each region, and how site characteristics and stream types vary between regions. Using this process, sites were dropped that were found unsuitable because of disturbances not apparent on aerials or maps or because of anomalous situations while additional sites were identified.

4. Aerial reconnaissance was conducted to identify disturbances not observable from the ground, to get a better sense for spatial patterns of disturbances and geographic characteristics in each region, and to photograph typical characteristics, site locations, or disturbances.
5. Over 100 subecoregional candidate reference sites originally were selected by EPA and FDEP biologists. A thorough review process for each site to determine its representativeness and an analysis of available staff hours to conduct bioassessments was performed, reducing the number of sites to 83.

The distribution of reference sites varies among DEP districts as well as among subecoregions. The number of sites in the districts range from three to 30 while the number of subecoregion sites varies from six to 13. This information is summarized below:

Subecoregion		Reference Sites
65F	Southern Pine Plains and Hills	8
65G	Dougherty/Marianna Plains	6
65H	Tifton Upland/Tallahassee Hills	8
75A	Gulf Coast Flatwoods	3
75B	Southwestern Florida Flatwoods	12
75C	Central Fla Ridges & Uplands	8
75D	Eastern Fla Flatwoods	10
75E	Okefenokee Swamp & Plains	8
75F	Sea Island Flatwoods	9

It is important to remember that reference sites represent the least or minimally disturbed ecosystem conditions. All of them have some level of disturbance which is a moving target because of ongoing human activity and natural processes. Since levels of impact are relative on a regional basis, the characteristics of appropriate reference sites will be different in different ecoregions and subregions and for different waterbody and habitat types. It is desirable, therefore, to have a large number of reference sites for each region to help define the different types of streams, to characterize the natural variability within similar stream types, and to clarify the factors that characterize the best sites from factors present in the lower quality sites.

Component II. Developing Standard Biological Assessment Methods

The technical objectives of this component included:
1. Review existing bioassessment protocols used by FDEP's "Point Source Fifth Year Inspection Program" as a template for proposed refinement of protocols for the NPS program.
2. Develop a standardized and cost-effective methodology to (a) collect and process benthic macroinvertebrates collected from Florida streams, and (b) to perform an assessment of habitat conditions.
3. Develop a Standard Operating Procedures Manual (SOP) as a quality assurance/quality control document to provide consistent, standardized methods for sampling freshwater benthic macroinvertebrates and evaluating habitat in rivers and streams.

4. In conjunction with the Ecoregionalization project, design a statewide standardized biological sampling and habitat assessment program to collect data for use in classifying reference streams and in developing the candidate measurements of biotic integrity.
5. Conduct a training program in which FDEP and water management district field biologists discuss and learn the new protocols.

One of the most important aspects of the community bioassessment procedure is the evaluation of stream habitat, which includes physical characteristics and water quality. Since conditions in the watershed determine conditions in the stream, habitat quality is dependent on land use, channel and riparian features as well as instream factors such as substrate types and velocity.

In 1991, the FDEP developed its first habitat evaluation methods (Frydenborg, 1991) based on EPA's Rapid Bioassessment Protocols document (EPA, 1989b). The components of habitat evaluation are: (1) physical/chemical characterization, and, (2) habitat assessment. Physical/chemical characterization includes determining predominant surrounding land uses; identifying local watershed erosion, nonpoint, and point source pollution sources; estimating stream depth, width, high water mark, temperature, and velocity; noting stream alterations such as impoundment or channelization; estimating canopy cover; and evaluating sediment/substrate. Water quality parameters measured include pH, dissolved oxygen, conductivity, and secchi disk depth; and, noting water clarity, color, odors and surface oils.the measurement and observation of land use, riparian zone conditions, channel and substrate features and water quality. Habitat assessment includes evaluating water velocity, substrate and cover, channel conditions, bank stability and riparian zone vegetation based on their capacity to support a stable, well balanced benthic community.

Most of the technical objectives of Component II have been achieved (FDEP, 1994b). However, all SOPs continue to be reviewed. Using DEP training funds, DEP's biologists attend quarterly "Biocriteria Committee Meetings" where they participate in workshops, discussions, and field exercises to learn about the bioassessment protocols. Beginning in the summer of 1992, DEP biologists from the Tallahassee and district offices conducted bioassessments, following the procedures set forth in the SOP, at all of the candidate reference sites. Sampling at these sites, and at additional reference sites, has continued on a summer-winter sampling schedule.

Component III. Data Analysis, Development of Metrics and Index of Biotic Integrity

Framework for Habitat Assessments: An analysis of the reference site habitat data was undertaken to (1) characterize the expected or typical condition for habitat parameters in least-disturbed streams and (2) refine the existing habitat evaluation methods. Sites were classified by (1) the aggregate subecoregions (6575a, 75bcd, 75ef) identified with the biometrics; (2) their designation as part of a subset of subecoregional sites versus all sites; and, (3) by flow conditions at the time of sampling. It was determined by analysis of the biological data that the aggregate subecoregions were the most appropriate classification scheme to explain variability in the data. Statistical analysis of the data was used to identify the habitat features that have a limited amount of variability and could be used to define the typical condition. The typical conditions, based on one sampling event and only four sampling sites in tow subecoregions (75ef), will be modified when the results of additional sampling events are evaluated.

Framework for Biometrics: The purpose of using multiple metrics in assessing biological condition is to maximize the information available regarding the elements and processes of aquatic communities. Metrics allow the ecologist to use meaningful indicator attributes in assessing the status of communities in response to perturbation. The definition of a metric is a characteristic of the biota that changes in some predictable way with increased human influence (Barbour et al., in review). The validity of an integrated assessment using multiple metrics is supported by the use of measurements of biological attributes firmly rooted in sound ecological principles (Karr et al. 1986; Fausch et al. 1990; Lyons 1992).

The development of appropriate metrics follows a determination of (1) taxa to be sampled, (2) the biological characteristics of reference conditions, and to a certain extent, (3) the anthropogenic influences being assessed. In many situations, multiple stressors impact ecological resources, and specific "cause-and-effect" assessments may be difficult. However, changes in individual metrics or suites of metrics in response to perturbation by certain stressors (or sets thereof) are important diagnostic assessment indicators. For this reason, use of a multimetric approach for evaluating nonpoint source effects upon the biota is a more powerful tool than traditional approaches to bioassessment.

The basic approach to developing metrics is modeled after EPA's technical guidance for biocriteria (Barbour et al., in review). Candidate metrics are selected based on knowledge of aquatic systems, flora and fauna, literature reviews, and historical data. Candidate metrics are evaluated for efficacy and validity for implementation into the bioassessment program. Less robust metrics, or those not well-founded in ecological principles, are excluded as a result of this research process. Metrics with little or no relationship to stressors are rejected. Core metrics are those remaining that provide useful information in discriminating between good or poor quality ecological conditions. It is important to understand the effects of various stressors on the behavior of specific metrics. Metrics that use the relative sensitivity of the monitored populations to specific pollutants, where these relationships are well-characterized, can be useful as a diagnostic tool. Core metrics should be selected to represent diverse aspects of structure, composition, individual health, or processes of the aquatic biota. Together they form the foundation for a sound, integrated analysis of the biotic condition to judge the attainment of biological criteria. For a metric to be useful, it must have the following attributes: (1) relevant to the biological community

under study and to the specified program objectives; (2) sensitive to stressors and provides a response that can be discriminated from natural variation; (3) environmentally-benign to measure in the aquatic environment; and (4) cost-effective to sample and to implement into water resource programs.

To select metrics for Florida streams, a two phase process was used which included an optimization phase, whereby the metrics are evaluated for their relevance and natural variability, and a calibration phase, which is necessary to determine the discriminatory power and sensitivity to perturbation. In the first phase, all potential metrics having relevance to Florida stream macroinvertebrate communities were identified. These metrics were classified into categories roughly corresponding to various elements and processes of the macroinvertebrate assemblage (Table 1). Categories used for this metric classification corresponded to the following:

A. Richness measures, which signify the relative variety or diversity of the aquatic assemblage.
B. Composition measures, which provide information on the make-up of the assemblage and the relative abundance of particular taxa to the total community.
C. Tolerance measures, which relate to the relative sensitivity or tolerance of the assemblage and component populations to various types of perturbation.
D. Trophic measures, which are surrogates of more complicated processes, such as biotic trophic interaction, production and food source availability. Trophic metrics primarily are related to functional feed group designation and density, both difficult to evaluate. Therefore, these metrics are in an evolutionary status around the country and will continue undergoing refinement.

Selecting Candidate Metrics: From the biological data collected at the candidate reference sites in Summer 1992, a total of 47 metrics were calculated and entered into the data base. These parameters were analyzed using a number of statistical methods including covariate and autocorrelation analysis, analysis of variance, and cluster analysis. Two key graphical displays, scatter plots of physicochemical variables versus biological metrics and box-and-whisker plots, were relied on for evaluating site classifications and discriminatory power. All of the 47 metrics fit the condition of biological relevance since they represent elements and processes of the macroinvertebrate assemblage and are thought to change in a predictable fashion in response to perturbation. However, by evaluating the inherent variability within the reference site database, 35 candidate metrics were identified. A highly variable metric would not be useful because the discriminatory power would be diminished. Conversely, a metric that has a narrow variance within a maximum or optimal range for reference conditions would be a useful metric. Box-and-whisker plots of the sites classified by subecoregions were used to depict the natural variability of each metric.

Fourteen of the 35 metrics appear to be appropriate as candidate metrics from this initial evaluation (Table 1). These are the metrics that illustrate a relatively tight range of values among the various subecoregions and are at the high end of their range of values for the reference sites. Four of the metrics are from the richness measures and consist of the Number of Total Taxa, EPT Index, the Number of

Metric Category	Rejected Candidate Metrics	Final Core Metrics	Definition Summary	Response to Increasing Biological Condition
Richness Measures	% Ephemeroptera Taxa # Coleoptera Taxa # Orthocladiinae Taxa # Tanytarsini Taxa	% Total Taxa	Measures overall variety of macroinvertebrate assemblage	↑
		EPT Index	Sum of no. taxa in 3 insect orders: Ephemeroptera, Plecoptera, Trichoptera	↑
		# Chironomidae Taxa	Sum of no. larval midge taxa	↑
		# Crustacean/Mollusc Taxa	Sum of no. calcium-dependent tax	↑
Composition Measures	% Oligochaeta, % Odonata, % Ephemeroptera, % Isopoda, % Trichoptera, % Plecoptera, % Coleoptera, % Gastropoda, % Pelecypoda, % Amphipoda, % Orthoclads to Chironomids % Tanytarsini to Chironomids	Shannon-Wiener Index	Measures general diversity using richness and evenness measures	↑
		% Dominant Taxon	Measures dominance of single most abundant taxon	↓
		% Diptera	Relative abundance of dipterans	↓
		% Crustacean/Mollusc	Relative abundance of crustacean/mollusc	↓
Tolerance Measures	# Class 1 and Class 2 Taxa	Florida Index	Uses abundance and pollution tolerance values for some invertebrates, heavily weighted to arthropods	↑
		% Class 1 and Class 2	Total no. Class 1 and Class 2 individuals/total no. individuals	↑
		Hilsenhoff Biotic Index	Uses abundance and pollution tolerance values for all invertebrates	↓
Trophic Measures	# Scraper/Piercer Taxa % Scrapers, % Predators, Density	% Collector-Gatherers	Relative abundance of this functional feeding group	↓
		% Collector-Filterers	Relative abundance of this functional feeding group	↑
		% Shredders	Relative abundance of this functional feeding group	↑

Table 1 Candidate and Selected Core Metrics

Chironomidae Taxa, and the Number of Crustacean plus Mollusc Taxa. The Shannon-Wiener Index, Percent Diptera, and Percent Crustaceans and Molluscs are from the composition measures. Candidate metrics from the sensitivity measures are the Florida Index, Percent Class 1 and Class 2 Individuals, the HBI, and Percent Dominant Taxon. Percent Collector-Gatherers, Percent Collector-Filterers, and Percent Shredders are representative trophic measures.

These 14 metrics were evaluated by using them as the basic candidate metrics with which to classify the sites, compare the efficiencies of the collecting gear, and test the discriminatory ability of the metrics. Through these additional analyses, some metrics may be eliminated. The resulting core metrics will then be used to develop an aggregation technique to evaluate the biological condition of the sites.

Metric Classification: Once candidate metrics were identified, analyses was performed to develop a classification system for Florida streams that would aggregate the streams into a small number of classes that could be managed and monitored with similar expectations. The classes should account for significant variation in the biological metric data with classes that do not contribute to the variation explained separated from those that do. Classification analysis was done with the dip net data.

Two classification schemes were tested: ecoregional (geographic) and stream type. Nine subecoregions in two ecoregions were in the area sampled in this program, and several stream types were identified that classify the influence of limestone, silica, and organic matter in the streamwater. Four stream types included in this investigation were sand-bottom streams, calcareous-influenced sand streams (with limestone springs or substrates), swamp-influenced streams (draining swamps and bogs), and alluvial streams (large, broad streams with multiple influences). Only the 14 candidate biological metrics (those that showed promise for discriminating reference from impaired conditions) were used to test the alternative classifications.

The distributions of values of the 14 candidate metrics were plotted as box-and-whisker plots for each of the nine subecoregions investigated. The consistent pattern that emerged from this analysis was that biological metrics of Florida streams tend to aggregate in three groups: the subecoregions of the Florida panhandle (65f, g, h, and 75a), the subecoregions of peninsular Florida (75b, c, and d), and the two subecoregions in the northeast of Florida (75e and f). Metric values of panhandle streams seem to indicate higher stream quality than in the peninsula. The Florida Index, the EPT index and their components were highest in panhandle streams. The Hilsenhoff Biotic Index, an index of tolerant species, was lowest in panhandle streams. Diversity and taxa richness were slightly higher in panhandle streams. Metric values of peninsular streams indicated lower quality than in the panhandle, but slightly higher than the northeast ecoregions. These last two subecoregions, the Okefenokee Swamps and Plains, and the Sea Islands Flatwoods, seemed to have the lowest stream quality of any of the reference sites. However, only four streams were analyzed from this area, and a larger sample would allow comparisons to be made with more confidence.

There were, however, some differences in metric values among the subecoregions within the aggregated groups. In particular, subecoregion 75a, the Gulf Coast Flatwoods, appears intermediate or transitional between region 65, the Southeastern Plains and the other Southern Coastal Plain subecoregions, 75b, c, and d, with several metrics having intermediate values in subecoregion 75a. The Gulf Coast Flatwoods, subecoregion 75a, receives runoff from subecoregions 65f, g, and h, and has lower topographic relief than ecoregion 65.

A similar graphical analysis of metric values plotted by stream type revealed a much weaker influence of stream type, with only four of thirteen metrics having different values in calcareous and alluvial streams than in sand-bottom streams. Two of the metrics are indicators of the variety and abundance of crustaceans and molluscs, which are expected to be more abundant in calcium-rich waters.

Based on the above analysis, the following classification of Florida streams was recommended:

- Streams of the Florida Panhandle, comprising the Southeastern Plains ecoregion (65f, g, h) and the Gulf Coast Flatwoods (75a).
- Streams of peninsular Florida, comprising the Southwestern Florida Flatwoods (75b), the Central Florida Ridges and Uplands (75c), and the Eastern Florida Flatwoods (75d).
- Streams of northeastern Florida, comprising the Okefenokee Swamps and Plains (75e) and the Sea Island Flatwoods (75f).
- Alluvial streams and rivers that receive inflow from several subecoregions. The alluvial rivers are characterized by a predominance of surface run-off, seasonal fluctuations in water quality and flow and a relatively high sediment load.

The above classification must be considered preliminary because of small sample size in several subecoregions and classes. Therefore, the following caveats apply:

- Subecoregion 75a, the Gulf Coast Flatwoods, may be different from the other panhandle subecoregions, but a larger sample (more sites) is needed to verify or refute its affinity to the other panhandle subecoregions.
- Subecoregions 65g, 75c, 75e, and 75f, and the alluvial class, are all under-represented in the data set (N = 2 to 4), and any conclusions regarding these are tentative.

Each of the three major groups is also a contiguous geographic region (panhandle, peninsula, and northeast), with observable physical and chemical differences between the three regions. The observed regional biological differences are partly related to acid-base chemistry of the regions. Peninsula Florida is dominated by limestone bedrock, and surface and ground waters are typically well-buffered. Water in the panhandle and northeastern Florida are more often poorly-buffered or acidic.

Relationships between ambient pH and several metric values are seen and can be explained by strong correlations between certain faunal groups and water with a certain pH.

Metric Calibration: The candidate metrics were then calibrated through an evaluation of both reference and impaired sites. The ability of a metric to discriminate between a reference and a known impaired site is necessary for the calibration of the metric for monitoring and assessment purposes. Data obtained from Florida DEP's point source program were used to evaluate the performance of the metrics at sites already determined as being impaired.

Data from Florida DEP's Point Source Program were used as a framework to evaluate the ability to discriminate between "good" and "bad" biological condition. Sites in this point source program were either upstream or downstream of known point source dischargers. Many of the upstream control sites in the point source program were not necessarily good reference sites, because of habitat degradation or some other reason. Two considerations in using the point source data are that although the season of collection was the same as that of the reference sites, some point source data were collected the previous year; and the methods used in the point source program were similar, but not identical in all respects to those employed in the nonpoint source program. However, these considerations did not prevent integration of the data from the two programs to evaluate discriminatory ability.

The evaluation and judgement of the core metrics concluded that five of the metrics, the EPT Index, Number of Total Taxa, Shannon-Wiener Index, Florida Index, and Percent Filterers, were relatively strong in discriminating impairment. Two metrics—the Number of Chironomidae Taxa and Percent Gatherers—were not useful at all in discriminating between reference and impaired sites. It was recommended that these two metrics be removed from the suite of core metrics, pending analysis of additional data.

A corollary study was performed to compare biological sampling methods to determine whether (1) Hester-Dendy artificial substrate samplers provide data representative of stream biological status, and (2) whether dip nets or Hester-Dendy substrates are more powerful for detecting biological impairment. Results from statistical analysis of metrics suggest that dip net data are as good or somewhat better than Hester-Dendy data in distinguishing biological impairment in Florida streams. These results, together with the fact that use of a Hester-Dendy is more labor intensive and costly, support the use of dip net collections as the primary macroinvertebrate collecting gear for the NPS monitoring program in Florida.

Florida Index Development: The stream invertebrate index for Florida was developed by aggregating the metrics that proved responsive to independent measures of impacts. Aggregation simplifies management and decision-making so that a single index value is used to determine whether action is needed. The exact nature of the action needed (e.g., restoration, mitigation, enforcement) is not determined by the index value, but by analysis of the component metrics. The approach used to define a Florida index was to develop expectations for the values of each of the metrics from the reference data set, and to score metrics according to whether they are within the range of reference expectations. Metrics within the range receive a high score, those outside receive a low score. The index value is then the sum of the metric scores. The index is further normalized to reference condition, such that the distribution of index values in the reference sites forms the expectations for the region.

In an assessment, streams can be judged for impairment based on the summed index value. If the index value is below a criterion, then the stream is judged impaired. The index value criterion is based on the index value distribution in reference streams; for example, the 25th percentile (lower quartile) of reference expectations is commonly used. Reference sites had been carefully selected to be representative of least impacted conditions in each ecoregion, and investigators involved in site selection and sampling were confident that the reference sites represented best available conditions in Florida streams. Therefore, the lower quartile of each metric distribution in reference sites was selected as the criterion for the minimum value of the metric representative of reference conditions. Thus, any metric value above the lower quartile of the reference distribution received the highest possible score. Using this rationale scoring criteria were developed which is a modification of the methodology of Karr et al.(1986; Karr 1991). Using the scoring criteria, a stream invertebrate index for Florida was calculated in three different ways as alternatives for optimizing the index.

- All metrics summed.
- As above, but with the Shannon-Wiener Index removed since it is strongly correlated with the Percent of Dominant Taxon as well as with Total Number of Taxa and, therefore, may be redundant with these.
- As above, but with all weak metrics removed. Weak metrics are those with limited ability to discriminate between reference and impaired conditions.

All three versions of the index were able to discriminate between reference and impaired conditions better than the individual metrics. Removing the Shannon-Wiener Index does not affect discrimination ability, nor does removing the weaker metrics.

The recommended stream invertebrate index for Florida is: (1) to remove the Shannon-Wiener Index because of its redundancy with the Number of Taxa and the Percent of the Dominant Taxon, and its inclusion does not improve the resolution; but (2) to retain the weaker metrics because their correlations with other metrics are not strong (thus they are independent measures), and because they may respond to stressors not represented in the point-source data set. The list of core metrics that compose the stream invertebrate index are: Number of Total Taxa, EPT Index,

% Dominant Taxon, % Diptera, Florida Index, % Filterers, and, % Shredders in the Panhandle (Ecoregions 65, 75a) and in the Peninsula (Ecoregions 75b, c, d), with # Crustacean/Mollusc Taxa and % Crustacean/Mollusc added in the Peninsula.

All of these metrics will be re-evaluated with a more complete data set of impaired streams and in different seasons.

DISCUSSION AND CONCLUSIONS

Adding sediment and biological community assessments to traditional water quality monitoring and evaluation approaches greatly enhance the ability of these tools to ascertain the environmental effects of stormwater discharges. The importance of this biological assessment framework in accurately assessing the environmental health of surface waters is seen by comparing Ohio's use attainment conclusions. The Ohio Environmental Protection Agency incorporated biocriteria into its water quality standards regulations in recent years (Yoder, 1989). These biocriteria are based on a system of tiered aquatic life uses representing five classes. These include coldwater habitat, warmwater habitat, exceptional warmwater habitat, modified warmwater habitat and limited resource waters. These designations have been qualitatively defined in ecological terms, and chemical criteria, either quantitative or narrative, have been established for each. Using both the water chemistry and bioassessment data, conclusions about the attainment of beneficial uses in Ohio water bodies include (EPA, 1989a):

- Based on chemical data, 52% of the segments fully attained aquatic life uses;
- Based on biosurvey data, only 23% achieved full attainment;
- The two types of assessment agreed on full attainment in 17% of the cases with overall agreement on 46% of the cases;
- In 35% of the cases, chemical data indicated full attainment but biosurvey data indicated partial or non-attainment. In nearly half of these cases, impairments were due to habitat or flow modifications, or siltation.

Unfortunately, as can be seen from the activities described in this paper, conducting the preliminary technical analyses that are essential to establish the scientific rationale for these assessment tools is not easy, quick, nor inexpensive. Ultimately, the goal of these efforts is to develop quantitative biocriteria which can be used to more effectively assess, manage and evaluate stormwater/NPS pollution sources and management efforts. Metrics reflecting community characteristics may be considered appropriate in biocriteria programs if their relevance can be demonstrated, response range is verified and documented, and the potential for application in water resource programs exists. However, before the FDEP can adopt biocriteria, lots more work must be done to further refine, calibrate and evaluate the biometrics. Frequent evaluation of metrics and indices is an essential feature of the use of biocriteria. However, once established, the multimetric approach for assessing biological condition offers the following attributes: (1) relies on information about several populations or species assemblages, rather than just target species; (2) relates to a community-level potential or expectation based on a reference condition; (3) uses multiple metrics to function as surrogate measures of more complicated elements and processes; and (4) incorporates ecological principles that enable an interpretation of exposure/response relations.

Sediment assessment, together with watershed characterization and mapping of pollution sources, can be used to screen watersheds and sub-basins to determine potential "hot spots". Bioassessment and water chemistry sampling can then be done to assess the actual health of the aquatic system in these locations. The initial focus of a bioassessment should be on habitat quality. Based on a regional reference, the habitat at an impacted site may be equal to or less than the desired quality for that particular system. If the habitat at the impact site and reference are equal, then a direct comparison of biological condition can be made. If the habitat at the impact site is lower in quality than the reference, the habitat potential should be evaluated as a first step. A site-specific control may be more appropriate than a regional reference for an assessment of an impact site. If so, then care must be taken in selecting an appropriate site-specific reference site to assure that its habitat and sediment characteristics are representative for the area. Once a determination of the appropriate reference site type is made, possible outcomes of the bioassessment are: (1) no biological effects; (2) effects due to habitat degradation; (3) effects due to sediment or water quality; or (4) effects due to a combination of sediment, water quality and habitat degradation.

The projects described in this paper greatly contributed to the development, refinement, calibration, and testing of several essential sediment and biological community assessment tools in Florida. The Department is anxious to begin using these tools to better assess the effects of intermittent pollutant sources, evaluate the effectiveness of BMPs and management programs, prioritize watersheds and subbasins for management activities, and, in conjunction with the water management districts, to develop and implement the stormwater pollutant load reduction goals (PLRGs) required by State Water Policy and being established through the state's Surface Water Improvement and Management Program. The sediment and biological community assessment methods, in conjunction with the recently started effort by the Department to receive delegation of EPA's NPDES permitting program and a future initiative for basin wide monitoring, permitting, and compliance, provide the technical and institutional tools needed to cost-effectively reduce stormwater/NPS pollutant loadings on a watershed basis.

However, before these initiatives can be fully implemented, even more analysis and evaluation needs to be done to refine the assessment methods. For the NPS bioassessment program, issues still to be resolved include (FDEP, 1994b):

1. Test the level of subsampling to improve the integrity of the data. The level of subsampling is presently set at 100 organisms. However, only a small portion of the entire sample is processed to obtain 100 organisms. The subsampling levels of 100-, 200-, and 300-organisms need to be tested for appropriateness

with a cost/analysis benefit performed following the power-cost efficiency (PCE) procedure of Ferraro et al. (1989). The PCE should provide the best compromise between the least costly subsampling effort (100-organism) and the most rigorous (300-organism).
2. Evaluate the winter index period to validate both the site classification and suite of metrics for assessment and monitoring during that season. The present analyses are relevant only to the first collection of the summer index period. It is probable that the present site classification and core metrics would not be altered significantly for the winter data set, but this supposition needs to be tested. In addition, subsequent summer and winter datasets collected in 1993 and 1994 should be incorporated into the analysis. The FDEP recently obtained a Section 104(b)(3) grant from EPA that will allow these analyses to be performed by Tetra Tech.
3. Validate the classification of 65g, 75a, 75e, and 75f. These subecoregions are under-represented by reference sites. An evaluation of their classification could be improved with the sampling of additional sites. A collaboration with the neighboring states of Georgia and Alabama may be instrumental in increasing the sample size of the sites. A greater portion of the subecoregions of 65g, 75e, and 75f are in those neighboring states.
4. Evaluate the Hilsenhoff Biotic Index (HBI) as a sensitivity measure. The HBI was evaluated as part of the present data analyses. However, too many assumptions had to be made regarding the tolerance assignment to the various taxa. Logically, the HBI should be more meaningful than similar measures in assessing biological condition, because the index incorporates information from the whole assemblage. The proper assignment of tolerance scores should be addressed and the efficacy of the HBI metric re-evaluated. Similarly, tolerance assignments should address a broader range of pollutants.
5. Conduct habitat evaluations at reference and habitat-limited sites to determine the resolving power of the habitat parameters along a gradient of impact. This kind of analysis has been done for the biometrics using macroinvertebrate data from point source impact studies. Sites with nonpoint source habitat limitations e.g., erosion, deforestation, etc. should be included and the evaluation will require site-specific chemical analyses to separate chemical and physical limitations to the biota.
6. Develop a software program to handle the storage, sorting, and analysis of the biological and habitat data. For the department to successfully implement the bioassessment program, a "user-friendly" program should be developed. A contractor has been hired to review the current Florida DEP computer programs for handling specific biological data sets and to modify them to include the present suite of metrics and assessment approach.

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Detecting Water Quality Trends from
Stormwater Discharge Reductions

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Abstract

The detection of changes in pollution levels over time is an important objective of many environmental monitoring programs. This is especially true in stormwater pollution control. In some areas, a great deal of money has been spent to reduce stormwater discharges of pollutants (both urban and rural) and there is much pressure to demonstrate improvements in water quality. Trend analyses can be an important and powerful tool in demonstrating benefits of stormwater pollution control. Unfortunately, lack of data, or poorly designed data gathering efforts, greatly hinder the use of this technique. This paper will describe several trend analyses tools and the types of data needed for their implementation. It will also present a case study showing water quality benefits in a lake associated with the implementation of an innovative stormwater control program.

A full-scale plant, using the Karl Dunkers' system for treatment of separate stormwater and lake water, has been operating since 1981. The treatment facility is located in the northern part of Lake Rönningesjön, near Stockholm, Sweden. Excess flows are temporarily stored before treatment. Stormwater is pumped to the treatment facility during rains, with excess flows stored inside in-lake flow balancing tanks (the Flow Balancing Method, or FBM). The treatment system consists of a chemical treatment system designed for the removal of phosphorus and uses ferric chloride precipitation and crossflow lamella clarifiers. The stormwater is pumped from the flow balancing storage tanks to the treatment facility. Lake water is also pumped to the treatment facility during dry periods, after any excess stormwater is treated.

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The FBM and the associated treatment system significantly improved lake water quality through direct treatment of stormwater and by pumping lake water through the treatment system during dry weather. The annual average removals of phosphorus from stormwater and lake water by the ferric chloride precipitation and clarification treatment system were 66 percent, while the annual average total lake phosphorus concentration reductions averaged about 36 percent.

Statistically Based Trend Analyses

Several publications have excellent descriptions of statistical trend analyses for water quality data. In addition to containing detailed descriptions and examples of experimental design methods to determine required sampling effort, Gilbert (1987) devotes a large portion of his book to detecting trends in water quality data and includes the code for a comprehensive computer program for trend analysis.

Reckhow and Stow (1990) present a comprehensive assessment of the effectiveness of different water quality monitoring programs in detecting water quality trends using EPA STORET data for several rivers and lakes in North Carolina. They found that most of the data (monthly phosphorus, nitrogen, and specific conductance values were examined) exhibited seasonal trends and inverse relations with flow. Some of the data also exhibited autocorrelation. The remaining random variation (considering the correlations) was then used to determine the number of monthly samples needed for a given power (β) and significance (α). In many cases, large numbers of samples would be needed to detect changes of 25 percent or less (typical for stormwater retro-fitting activities).

Uri (1991) used the Box and Jenkins model to examine trends in sediment loadings to a portion of the Iowa River. The sediment loadings more than doubled in the years from 1948 to 1985. They also presented a method to examine factors causing this trend. They found a strong cause-and-effect relationship between acreage planted in soy beans and corn. For each 1 percent increase in planted area for either of these two crops, a sediment load increase of about 0.4 percent was likely.

Reckhow, *et al.* (1992) prepared a detailed manual presenting nonparametric analysis methods for examining water quality trends in lake waters. The manual presents a brief summary of basic concepts and approaches in applied statistics, followed by discussions of hypothesis testing and common assumptions for statistical tests. The manual contains detailed examples of lake and watershed wide water quality trend analyses. SAS macros are included to efficiently evaluate water quality trends.

Spooner and Line (1993) present recommendations for monitoring requirements in order to detect trends in receiving water quality associated with nonpoint source pollution control programs, based on many years experience with the Rural Clean Water Program. These recommendations, even though derived from rural experience, should also be very applicable for urban receiving water trend analyses. The following is a general list (modified) of their recommended data needs for associating water quality trends with land use/treatment trends:

• Appropriate and sufficient control practices need to be implemented. A high level of participation/control implementation is needed in the watershed to result in a substantial and more easily observed water quality improvement. Controls need to be used in areas of greatest benefit (critical source areas, or in drainages below major sources) and most of the area must be treated.

• Control practice and land use monitoring is needed to separate and quantify the effects of changes in water quality due to the implemented controls by reducing the statistical confusion from other major factors. Monitor changes in land use and other activity on a frequent basis to observe temporal changes in the watershed. Seasonal variations in runoff quality can be great, along with seasonal variations in pollutant sources (monitor during all flow phases, such as during dry weather, wet weather, cold weather, warm weather, for example). Collect monitoring data and implement controls on a watershed basis.

• Monitor the pollutants affecting the beneficial uses of the receiving waters. Conduct the trend analyses for pollutants of concern, not just for easy, or convenient, parameters.

• Monitor for multiple years (at least 2 to 3 years for both pre- and post-control implementation) to account for year-to-year variability. Utilize a good experimental design, with preferable use of parallel watersheds (one must be a control and the other undergoing treatment).

Other water quality trend analysis references contained in Uri (1991) include Box and Jenkins (1970), Hipel and McLeod (1989), Hipel, *et al.* (1988), Hirsch (1988), Hirsch and Slack (1984), and Taylor and Loftis (1989). Reckhow, *et al.* (1992) also listed the following applicable references: Berryman, *et al.* (1988), Hirsch, et al. (1982), Lettenmaier (1976), and Montgomery and Loftis (1987).

Preliminary evaluations before trend analyses are used

Gilbert (1987) illustrates several sequences of water quality data that can confuse trend analyses. It is obviously easiest to detect a trend when the trend is large and the random variation is very small. Cyclic data (such as seasonal changes) often are confused as trends when no trends exist (type 1 error) or mask trends that do exist (type 2 error) (Reckhow and Stow 1990; Reckhow 1992). Three data characteristics need to be addressed before the data can be analyzed for trends because of confusing factors. These include:

• Measure data correlations, as most statistical tests require uncorrelated data. If data are taken close together (in time or in location), they are likely partially correlated. As an example, it is likely that a high value is closely surrounded by other relatively high values. Close data can therefore be influenced by each other and do not provide unique information. This is especially important when determining confidence limits of predicted values or when determining the number of data needed for a trend analyses (Reckhow and Stow 1990). Test statistics developed by Sen can use dependent data, but they may require several hundred data observations to be valid (Gilbert 1987).

• Remove any seasonal (or daily) effects, or select a data analysis procedure that is unaffected by data cycles. The nonparametric Sen test can be used when no cycles are present, or if cyclic effects are removed, while the seasonal Kendall test is not affected by cyclic data (Gilbert 1987).

• Identify any other likely predictable effects on concentrations and remove their influence. Normally occurring large variations in water quality data easily mask commonly occurring subtle trends. Typical relations between water quality and flow rate (for flowing water) can be detected by fitting a regression equation to a concentration vs. flow plot. The residuals from subtracting the regression from the data are then tested for trends using the seasonal Kendall test (Gilbert 1987).

Reckhow (1992) presents a chart listing specific steps that need to be taken to address the above problems. These steps are as follows:

(1) Check the data for deterministic patterns of variability (such as concentration versus flow by using graphical and statistical methods). If deterministic patterns exist, subtract the modeled pattern from the original data, leaving the residuals for subsequent seasonality analyses.

(2) Examine the remaining residuals (or data, if no deterministic patterns exist) for seasonal (can be short period, such as daily) variations. Again use graphical and statistical methods. If "seasonality" exists, subtract the modeled seasonality from the data (residuals from #1 above), leaving the remaining residuals for subsequent trend analyses.

(3) Conduct the trend analysis on the residuals from #2 above, using the standard seasonal Kendall test . If a trend exists, subtract the trend, leaving the remaining residuals for subsequent autocorrelation analyses.

(4) Test the remaining residuals from #3 above (or the raw data, if no deterministic or cyclic patterns or trends were found) for autocorrelation. If the autocorrelation is significant, re-evaluate the trends using an autocorrelated-corrected version of the seasonal Kendall (or regular Kendall) test. If no autocorrelation was found, use the standard seasonal Kendall test if seasonality was identified, or the

standard Kendall test if no seasonality was identified. The final residual variation is then used (after correcting for autocorrelation) in calculating the required number of samples needed to detect trends for similar situations.

Statistical methods available for detecting trends

Graphical methods. Several sophisticated graphical methods are available for trend analyses that use special smoothing routines to reduce short-term variations so the long-term trends can be seen (Gilbert 1987). In all cases, simple plots of concentrations versus time of data collection should be made. This will enable obvious data gaps, potential short-term variations, and distinct long-term trends to be possibly seen.

Regression methods. A time-honored approach in trend analysis is to perform a least-squares linear regression on the quality versus time plot and to conduct a *t* test to determine if the true slope is not different from zero (Gilbert 1987). However, Gilbert (1987) points out that the *t* test can be misleading due to cyclic data, correlated data, and data that are not normally distributed.

Mann-Kendall test. This test is useful when missing data occur (due to gaps in monitoring, such as if frozen waters occur during the winters, equipment failures, or when data are reported as below the limit of detection). Besides missing data, this test can also consider multiple data observations per time period. This test also examines trends at multiple stations (such as surface waters and deep waters, etc.) and enables comparisons of any trends between the stations. This method also is not sensitive to the data distribution type. This test can be considered a nonparametric test for zero slope of water quality versus time of sample collection (Gilbert 1987). Short-term (such as seasonal changes) cycles and other data relationships (such as flow versus concentration) affect this test and must be corrected. If data are highly correlated, then this test can be applied to median values in each discrete time groupings.

Sen's nonparametric estimator of slope. Being a nonparametric test based on ranks, this method is not sensitive to extreme values (or gross data errors) when calculating slope (Gilbert 1987). This test can also be used when missing data occur in the set of observations. It is closely related to the Mann-Kendall test.

Seasonal Kendall test. This method is preferred to most regression methods if the data are skewed, serially correlated, or cyclic (Gilbert 1987). This test can be used for data sets having missing values, tied values, censored values (less than detection limits) or single or multiple data observations in each time period. The testing of homogeneity of trend direction enables one to determine if the slopes at different locations are the same, when seasonality is present. Data correlations (such as flow versus concentration) and dependence also affect this test and must be considered in the analysis.

The code for the computer program contained in Gilbert (1987) computes Sen's estimator of slope for each station-season combination, along with the seasonal Kendall test, Sen's aligned test for trends, the seasonal Kendall slope estimator for each station, the equivalent slope estimator for each season, and confidence limits on the slope.

Watershed Characteristics and Treatment System

Lake Rönningesjön is located in Täby, Sweden, near Stockholm. Figure 1 shows the lake location, the watershed, and the surrounding urban areas. The watershed area is 650 ha, including Lake Rönningesjön itself (about 60 ha), and the urban area that has its stormwater drainage bypassing the lake (about 175 ha). The effective total drainage area (including the lake surface) is therefore about 475 ha. Table 1 summarizes the land use of the lake watershed area. About one-half of the drainage area (including the lake itself) is treated by the treatment and storage operation.

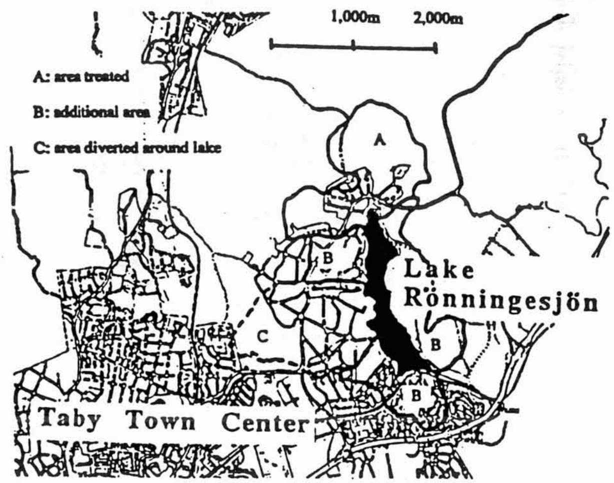

Figure 1. Lake Rönningesjön watershed in Taby, Sweden.

Table 1. Lake Rönningesjön Watershed Characteristics

	Area Treated	Additional Area	Total Area
urban	50 ha	100 ha	150 ha (32%)
forest	75 ha	80 ha	155 ha (32%)
agriculture	65 ha	45 ha	110 ha (23%)
lake surface	60 ha		60 ha (13%)
total drainage	250 ha	225 ha	475 ha (100%)

The lake volume is about 2,000,000 m^3 and has an annual outflow of about 950,000 m^3. The estimated mean lake resident time is therefore slightly more than two years. The average lake depth is 3.3 m. It is estimated that the rain falling directly on the lake surface itself contributes about one-half of the total lake outflow.

The treatment process consists of an in-lake flow balancing storage tank system (the Flow Balancing Method, or FBM) to contain excess stormwater flows which are pumped to a treatment facility during dry weather. The treatment facility uses ferric chloride and polymer precipitation and crossflow lamella clarifiers. Figure 2 illustrates the layout of the FBM, the treatment facility, and the lake discharge in the northern end of Lake Rönningesjön. Figure 3 shows the cross-section of the FBM in the lake. It is make of plastic curtains forming the cell walls, supported by floating pontoons and anchored to the lake bottom with weights.

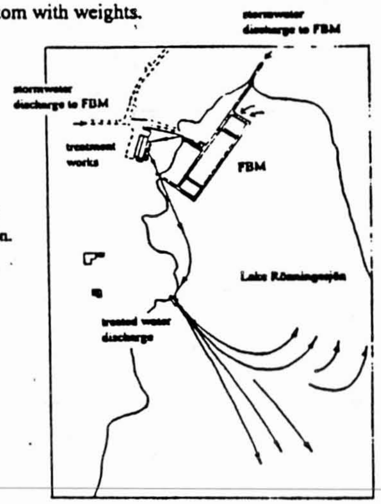

Figure 2. Treatment system layout in Lake Rönningesjön.

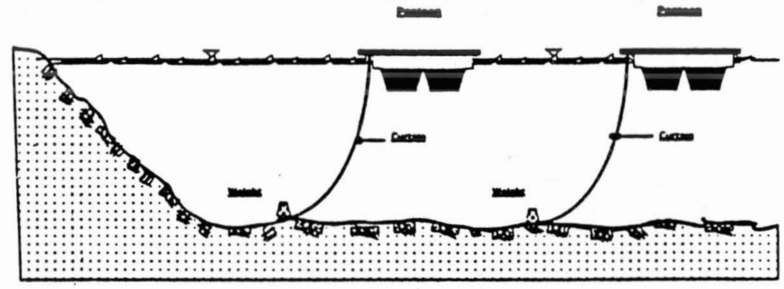

Figure 3. Cross-section of FBM in-lake tanks.

Figure 4 shows that the FBM provides storage of contaminated water by displacing clean lake water that enters the storage facility during dry weather as the FBM water is pumped to the treatment system. All stormwater enters the FBM directly (into cell A). The pump continuously pumps water from cell A to the chemical treatment area. If the stormwater enters cell A faster than the pump can remove it, the stormwater flows through curtain openings (as a slug flow) into cells B, C, D, and finally E, displacing lake water (hence the term flow balancing). As the pump continues to operate, stormwater is drawn back into cell A and then to the treatment facility. The FBM is designed to capture the entire runoff volume of most storms. The Lake Rönningesjön treatment system is designed to treat water at a higher rate than normal to enable lake water to be pumped through the treatment system after all the runoff is treated.

The FBM is mainly intended to be a storage device, but it also operates as a wet detention pond, resulting in sedimentation of particulate pollutants within the storage device. The first two cells of the FBM facility at Lake Rönningesjön were dredged in 1991, after 10 years of operation, to remove about one meter of polluted sediment.

The treatment flow rate is 60 m^3/hr (about 0.4 MGD). The ferric chloride feed rate is about 20 to 35 grams per cubic meter of water. About 30 m^3 of thickened sludge is produced per day for co-disposal with sludge produced at the regional sanitary wastewater treatment facility. The annual operating costs are about $28,000 per year (or about $0.03 per 100 gallons of water treated), divided as shown in Table 2.

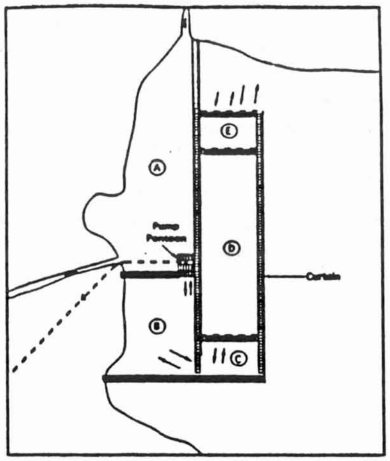

Figure 4. Flow pattern in FBM.

Table 2. Stormwater Treatment System Operating Cost Breakdown

chemicals	26%
electricity	8
sludge transport	3
labor	41
sampling and analyses	22

From 1981 through 1987, the FBM operated an average of about 5500 hours per year (about 7.6 months per year), treating an average of about 0.33 million m^3 per year. The treatment period ranged from 28 to 36 weeks (generally from April through November). The FBM treatment system treated stormwater about 40% of its operating time and lake water about 60% of its operating time. The FBM treatment system directly treated about one-half of the in-flowing waters to the lake (at a level of about 70% phosphorus removal).

Lake Rönningesjön and Treatment System Phosphorus Budgets

Two tributaries flow directly to the treatment facility. Excess flows (exceeding the treatment plant flow capacity) are directed to the FBM in the lake. As the flows in the tributaries fall below the treatment plant capacity, pumps in the FBM deliver stored stormwater runoff for treatment. When all of the stormwater is pumped from the FBM, the pumps deliver lake water for treatment. Tables 3 and 4

summarize the runoff and lake volumes treated and phosphorus removals during the period of treatment.

Table 3. Water Balance for Treatment System (m^3)

	From Trib. A	From Trib. B	Total Stormwater	From Lake	Total treated and discharged	Stormwater, % of total treated
1981	185,100	101,100	286,200	121,600	407,700	70
1982	112,700	41,000	153,700	238,700	391,900	39
1983	14,400	6,400	20,800	250,000	271,000	8
1984	122,000	53,000	175,000	95,000	270,000	65
1985	96,600	46,500	143,100	149,000	292,400	49
1986	216,000	86,000	302,000	48,000	350,000	86
1987	243,000	97,000	340,000	13,000	353,000	96
1988	26,200	19,300	45,500	186,300	231,800	20
1989	24,900	19,900	44,800	267,700	312,500	14
1990	12,160	8,330	20,490	201,270	221,760	9
1991	11,610	7,780	19,390	121,730	141,120	14

Table 4. Phosphorus Treatment Mass Balance (kg)

	From Trib. A	From Trib. B	From Lake	Total to treatment	P discharged to Lake	P removal	% removal
1981	20.3	16.8	10.2	47.3	13.6	33.7	71.2
1982	8.0	8.0	18.0	34.0	12.8	21.2	62.4
1983	1.5	2.5	20.0	24.0	11.0	13.0	54.2
1984	10.0	9.5	3.0	22.5	10.0	12.5	55.6
1985	7.1	5.9	2.1	15.1	4.3	10.8	71.5
1986	15.2	21.4	3.7	40.3	5.1	35.2	87.3
1987	18.6	7.5	1.7	27.8	4.3	23.5	84.5
1988	1.7	2.3	9.2	13.2	6.1	7.1	53.8
1989	1.7	1.4	14.1	17.2	7.6	9.6	55.8
1990	1.3	0.3	10.5	12.1	3.7	8.4	69.4
1991	7.7	9.8	5.6	23.1	8.9	14.2	61.5

There have been highly variable levels of phosphorus treatment from stormwater during the period of operation. 1988 through 1990 had low phosphorus removals. These years had relatively mild winters with substantial stormwater runoff occurring during the winter months when the treatment system was not operating. Normally, substantial phosphorus removal occurred with spring snowmelt during the early weeks of the treatment plant operation each year. The greatest phosphorus improvements in the lake occurred during the years when the largest amounts of stormwater were treated.

The overall phosphorus removal rate for the 11 years from 1981 through 1991 was about 17 kg/year. About 40% of the phosphorus removal occurred in the FBM from sedimentation processes, while the remaining occurred in the chemical treatment facility. This phosphorus removal would theoretically cause a reduction in phosphorus concentrations of about 10 µg/L per year in the lake, or a total phosphorus reduction of about 100 µg/L during the data period since the treatment system began operation. About 70% of this phosphorus removal was associated with the treatment of stormwater, while about 30% was associated with the treatment of lake water.

<u>Observed Long-Term Lake Rönningesjön Water Quality Trends</u>

Lake Rönningesjön water quality has been monitored since 1967 by the Institute for Water and Air Pollution Research (IVL); the University of Technology, Stockholm; the Limnological Institute at the University of Uppsala; and by Hydroconsult Corp. Surface and subsurface samples were obtained at one or two lake locations about five times per year. In addition, the tributaries being treated, incoming lake water, and discharged water, were all monitored on all weekdays of treatment plant operation. The creek tributary flow rates were also monitored using overflow weirs.

The FBM started operation in 1981. Based on the hydraulic detention time of the lake, several years would be required before a new water quality equilibrium condition would be established. A new water quality equilibrium will eventually be reached after existing pollutants are reduced from the lake water and sediments. The new water quality conditions would be dependent on the lake flushing rate (or detention time, estimated to be about 2.1 years), and the new (reduced) pollutant discharge levels to the lake. Without lake water treatment, the equilibrium water quality would be worse and would take longer to obtain.

Figure 5 is a plot of all chlorophyll *a* data collected at both the south and north sampling stations. Very little trend is obvious, but the wide swings in chlorophyll *a* values appeared to have been reduced after the start of stormwater treatment. Figure 6 is a three-dimensional plot of smoothed chlorophyll *a* data, indicating significant trends by season. The values started out relatively low each early spring and dramatically increased as the summer progressed. This was expected and was a function of algal growth. Homogeneity, seasonal Kendall and Mann-Kendall statistical tests (Gilbert 1987) were conducted using the chlorophyll *a* data. The homogeneity test was used to determine if any trends found at the north and south sampling stations were different. The probabilities that the trends at these two stations were the same were calculated as follows:

	χ^2	Probability
season	14.19	0.223
station	0.00001	1.000
station-season	0.458	1.000
Trend	21.64	0.000

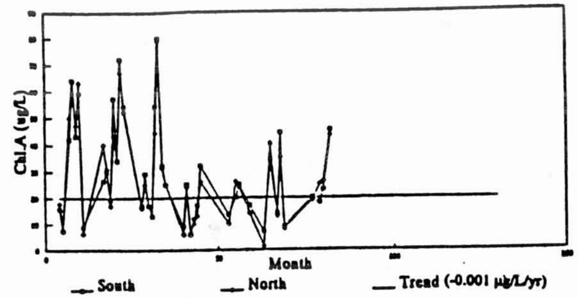

Figure 5. Chlorophyll *a* observations with time (µg/L)

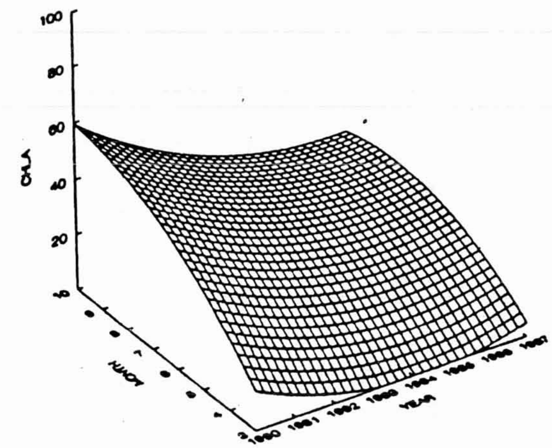

Figure 6. Chlorophyll *a* trends by season and year (µg/L).

This test shows that the trend was very significant (P<0.001) and was the same at both sampling stations (P=1.000). The seasonal trend tests only compared data obtained for each season, such as comparing trends for June observations alone. The station-season interaction term shows that the chlorophyll *a* concentration trends at the two stations were also very similar for all months (P=1.000). Therefore, the sampling data from both stations were combined for further analyses.

The seasonal Kendall test calculated the chlorophyll *a* concentration trends and determined the probabilities that they were not zero, for all months separately. This test and the Mann-Kendall tests found that both the north and south sampling locations had slight decreasing (but very significant) overall trends in concentrations with increasing years ($P \leq 0.001$). However, individual monthly trends were not very significant ($P \geq 0.05$). The trends do show an important decrease in the peak concentrations of chlorophyll *a* that occurred during the fall months during the years of the FBM operation. The 1980 peak values were about 60 µg/L, while the 1987 peak values were lower, at about 40 µg/L.

Swedish engineers (Söderlund 1981; and Lundkvist and Söderlund 1988) summarized major changes in the algal species present and in the algal biomass in Lake Rönningesjön, corroborating the chlorophyll *a* and phosphorus limiting nutrient observations. From 1977 through 1983, the lake was dominated by a stable population of thread-shaped blue-green algaes (especially *Oscillatoria sp. and Aphanizomenon flos aquae f. gracile*). Since 1985, the algae population was unstable, with only a small amount of varying blue green (*Gomphosphaeria*), silicon (*Melosira, Asterionella* and *Synedra*) and gold (*Chrysochromulina*) algae species. They also found a substantial decrease in the algal biomass in the lake. From 1978 through 1981, the biomass concentration was commonly greater than 10 mg/L. The observed maximum was about 20 mg/L, with common annual maximums of 15 mg/L in July and August of each year. From 1982 through 1986, the algal biomass was usually less than 10 mg/L. The observed maximum was 14 mg/L and the typical annual maximum was about 6 mg/L each late summer. The lake showed an improvement in its eutrophication level since the start of the stormwater treatment, going from hypotrophic to eutrophic.

Figure 7 is a plot of all Secchi disk transparency data obtained during the project period. A very large improvement in transparency is apparent from this plot, but large variations were observed in most years. Figure 8 shows these annual variations in grouped box plots. A large improvement may have occurred in the first five years of stormwater treatment and then the trend may have decreased. The smoothed plot in Figure 9 shows significant improvement in Secchi disk transparency since 1980. This three-dimensional plot shows that the early years started off with clearer water (as high as 1 m transparency) in the spring and then degraded as the seasons progressed, with transparency levels falling to less than 0.5 m in the fall months. The later years indicated a significant improvement, especially in the later months of the year.

Homogeneity, seasonal Kendall and Mann-Kendall statistical tests (Gilbert 1987) were conducted using the Secchi disk transparency data. The homogeneity test was used to determine if any trends found at the north and south sampling stations were different. The probabilities that the trends at these two stations were the same were calculated as follows:

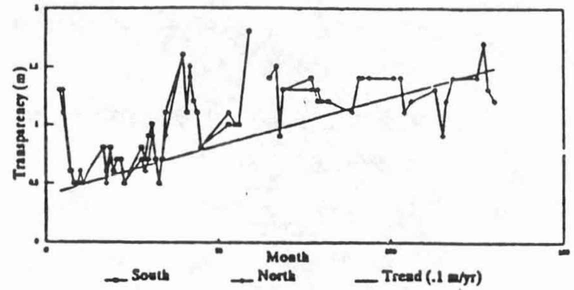

Figure 7. Secchi disk transparency observations with time (m).

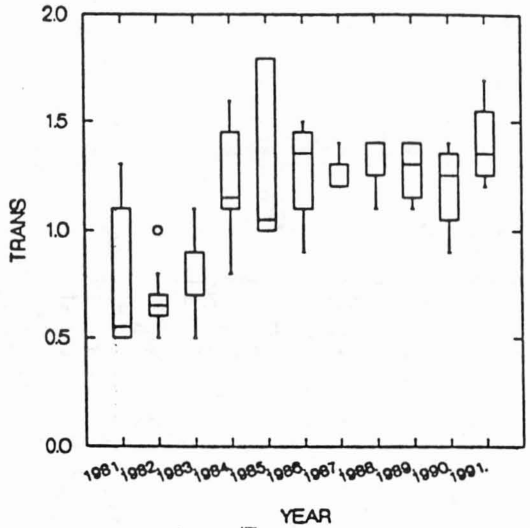

Figure 8. Secchi disk transparencies grouped by year (m).

	χ^2	Probability
season	17.15	0.103
station	0.012	0.913
station-season	3.03	0.990
Trend	29.44	0.000

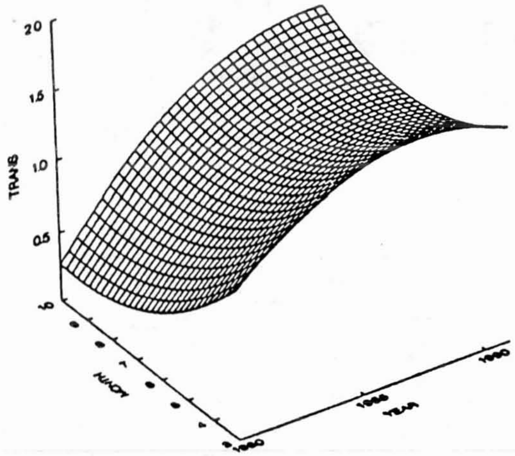

Figure 9. Secchi disk trends by season and year (m).

These statistics show that the observed trend was very significant ($P<0.001$) and was the same at both stations. The Seasonal Kendall and Mann-Kendall tests found that both the north and south sampling locations had increasing transparency values (the average trend was about 0.11 meter per year) with increasing years ($P<0.001$). The trend in later years was found to be less than in the early years. The transparency has remained relatively stable since about 1987 (ranging from about 1 to 1.5 m), with less seasonal variations.

Figure 10 plots observed phosphorus concentrations with time, while Figure 11 is a smoothed plot showing seasonal and annual variations together. The initial steep phosphorus concentration decreases in the early years of the FBM operation were followed by a sharp increase during later years. The increase was likely associated with the decreased levels of stormwater treatment during the mild winters of 1988 through 1990 when the treatment system was not operating; large amounts of untreated stormwater were discharged into the lake instead of being tied up as snow to be treated in the spring as snowmelt runoff.

Individual year phosphorus concentrations leveled off in the summer (about July). These seasonal phosphorus trends were found to be very significant ($P\leq0.002$), but were very small, using the seasonal Kendall test (Gilbert 1987). Homogeneity

tests found no significant differences between lake sample phosphorus concentrations obtained at the different sampling locations, or depths, irrespective of season:

	χ^2	Probability
season	15.38	0.166
station	0.0033	0.954
station-season	1.64	0.999
Trend	12.43	0.000

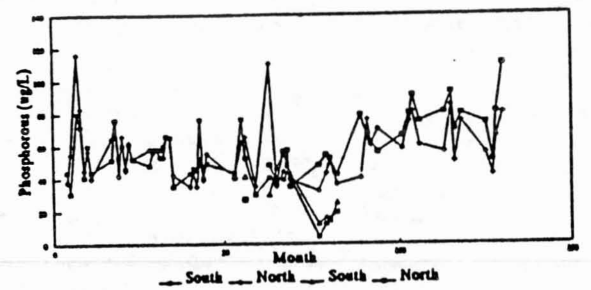

Figure 10. Total phosphorus observations with time (µg/L).

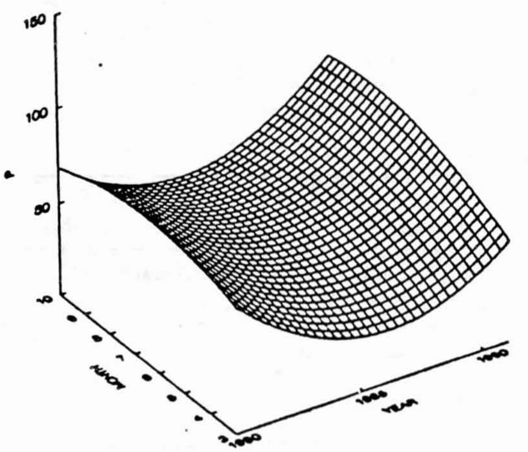

Figure 11. Total phosphorus trends by season and year (µg/L).

The overall lake phosphorus concentrations ranged from about 15 to 130 μg/L, with an average of about 65 μg/L. The monitored stormwater, before treatment, had phosphorus concentrations ranging from 40 to >1,000 μg/L, with an average of about 200 μg/L.

Figure 12 shows all Kjeldahl nitrogen values plotted with time and Figure 13 is a smoothed plot showing seasonal versus annual trends. An increase in nitrogen concentrations is also seen to have occurred from the beginning of each year to the fall months. However, the overall annual trend decreased during the first few years of the FBM operation, but it then subsequently increased. These total nitrogen concentration variations were similar to the total phosphorus concentration variations. However, homogeneity, seasonal Kendall and Mann-Kendall statistical tests (Gilbert 1987) conducted using the nitrogen data found that neither the north or south sampling locations had significant concentration trends with increasing years (P>0.2). However, lake Kjeldahl nitrogen concentration reductions were found to occur during years when the FBM system was treating the largest amounts of stormwater.

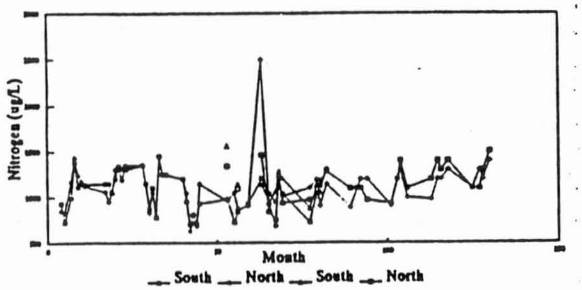

Figure 12. Total Kjeldahl nitrogen observations with time (μg/L).

Lake Water Quality Model

A simple water quality model was used with the Lake Rönningesjön data to determine the total annual net phosphorus discharges into the lake and to estimate the relative magnitude of various in-lake phosphorus controlling processes (associated with algal growth and sediment interactions, for example). These estimated total phosphorus discharges were compared to the phosphorus removed by the treatment system. The benefits of the treatment system on the lake water quality were then estimated by comparing the expected lake phosphorus concentrations as if the treatment system was not operating, to the observed lake phosphorus concentrations.

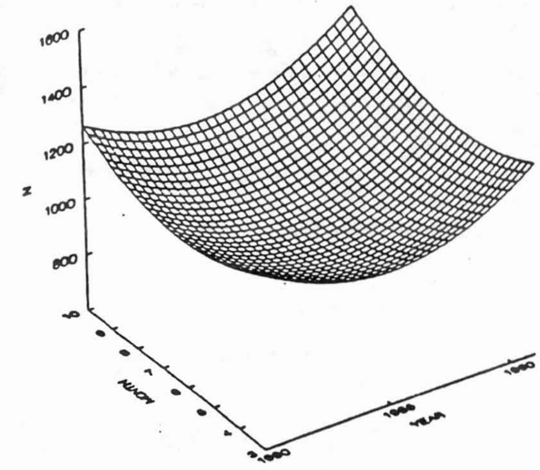

Figure 13. Total Kjeldahl nitrogen trends by season and year (μg/L).

Thomann and Mueller (1987) presented the following equation to estimate the resulting water pollutant concentrations associated with varying input loadings for a well-mixed lake:

$$S_t = (M/V) \exp(-T/Td) \qquad \text{eq. 1}$$

where S_t = concentration associated with a step input at time t,
M = mass discharge per time-step interval (kg),
V = volume of lake (2,000,000 m^3),
T = time since input (years), and
Td = hydraulic residence time, or lake volume/lake outflow (2.1 years).

This equation was used to calculate the yearly total mass discharges of phosphorus to Lake Rönningesjön, based on observed lake concentrations and lake hydraulic flushing rates. It was assumed that the varying concentrations observed were mostly caused by varying mass discharges and much less by variations in the hydraulic flushing rate. The flushing rate was likely to vary, but by relatively small amounts. The lake volume was quite constant and the outflow rate was expected to vary by less than 20 percent because of the relatively constant rainfall that occurred during the years of observation (average rainfall of about 600 mm, with a coefficient of variation of about 0.15).

The total mass of phosphorus discharged into the lake each year from 1972 to 1991 was calculated using the following equation (an expansion of equation 1), solving for the M_{n-x} terms:

$$S_n = M_n [\exp(-T_n/Td)/V] + M_{n-1} [\exp(-T_{n-1}/Td)/V] + M_{n-2} [\exp(-T_{n-2}/Td)/V] + M_{n-3} [\exp(-T_{n-3}/Td)/V] + ... \quad \text{eq. 2}$$

where S_n is the annual average phosphorus concentration during the current year, M_n is the net phosphorus mass discharged into the lake during the current year, M_{n-1} is the phosphorus mass discharged during the previous year, M_{n-2} is the phosphorus mass that was discharged two years previous, etc.

The effects of discharges into the lake many years previous to a concentration observation have little effect on that year's observations. Similarly, more recent discharges have greater effects on the lake's concentrations. The magnitude of effect that each year's step discharge has on a more recent concentration observation is dependent on the exp($-T_n$/Td) factors shown in equation 2. A current year's discharge affects that year's concentration observations by about 40 percent of the steady-state theoretical value (M/V), and a discharge from five years previous would only affect the current year's concentration observations by less than ten percent of the theoretical value for Lake Rönningesjön. Similarly, a new steady-state discharge would require about 4 years before 90 percent of its equilibrium concentration would be obtained. It would therefore require several years before the effects of a decrease in pollutant discharges would have a major effect on the lake pollutant concentrations.

The annual control of phosphorus ranged from about 10 to 50 percent, with an average lake-wide level of control of about 36 percent, during the years of treatment plant operation. It is estimated that there would have been about a 1.6 times increase in phosphorus discharges into Lake Rönningesjön if the treatment system was not operating. There was a substantial variation in the year to year phosphorus discharges, but several trends were evident. If there was no treatment, the phosphorus discharges would have increased over the 20 year period from about 50 to 75 kg per year. With treatment, the discharges were held relatively constant at about 50 kg per year (as evidenced by the lack of any observed phosphorus concentration trend in the lake). During 1984 through 1987, the phosphorus discharges were quite low compared to other years, but increased substantially in 1988 and 1989 because of the lack of stormwater treatment during the unusually mild winters.

Figure 14 is a plot of the annual average lake phosphorus concentrations with time. If there had been no treatment, the phosphorus concentrations in the lake would

have shown a relatively steady increase from about 50 to about 100 µg/L over the 20 year period. With treatment, the lake phosphorus concentrations were held within a relatively narrower range (from about 50 to 75 µg/L). The lake phosphorus concentration improvements averaged about 50 µg/L over this period of time, compared to an expected theoretical improvement of about 100 µg/L. Therefore, only about one-half of the theoretical improvement occurred, probably because of sediment-water interchange of phosphorus, or other unmeasured phosphorus sources.

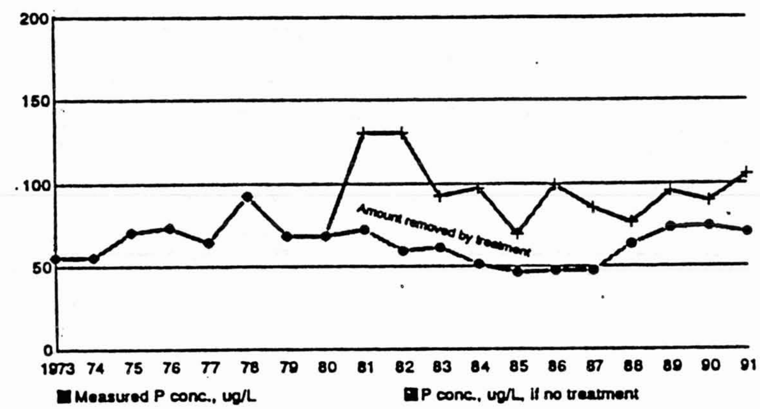

Figure 14. Effects of treatment on Lake Rönningesjön total phosphorus concentrations (µg/L).

Conclusions

The in-lake flow balancing method (FBM) for storage of excess stormwater during periods of high flows allowed for lower treatment flow rates, while still enabling a large fraction of the stormwater to be treated for phosphorus removal. The treatment system also enabled lake water to be treated during periods of low (or no) stormwater flow. The treatment of the stormwater before lake discharge accounted for about 70 percent of the total observed phosphorus discharge reductions, while the lake water treatment was responsible for the remaining 30 percent of the discharge reductions. The lake water was treated during 60 percent of the operating time, but resulted in less phosphorus removal, compared to stormwater treatment. The increased efficiency of phosphorus removal from stormwater compared to lake water was likely due to the more abundant particulate forms of phosphorus that were removed in the FBM by sedimentation and by the stormwater's higher dissolved phosphorus concentrations that were more efficiently removed during the chemical treatment process.

Lake transparency improved with treatment. Secchi disk transparencies were about 0.5 m before treatment began and improved to about 1 to 1.5 m after treatment. The total phosphorus concentrations ranged from about 65 to 90 µg/L during periods of low levels of stormwater treatment, to about 40 to 60 µg/L during periods of high levels of stormwater treatment.

The annual average removals of phosphorus by the ferric chloride precipitation and clarification treatment system was 66 percent, with a maximum of 87 percent. The observed phosphorus concentration improvements in the lake were strongly dependent on the fraction of the annual stormwater flow that was treated. The annual average total lake phosphorus discharge and concentration reductions averaged about 36 percent, or about one half of the maximum expected benefit.

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Thursday, August 11, 1994

SESSION VIII: PROTOCOLS FOR MONITORING BMPs FOR EFFECTIVENESS

1. **"Monitoring Effectiveness of Non-Structural BMPs"**
   Roger Bannerman
   Wisconsin Department of Natural Resources

2. **"Monitoring of Wetlands, Wet Ponds & Grass Swales"**
   Thomas Grizzard, David Green and Clifford Randall
   OCCOQUAN Watershed Monitoring Laboratory

3. **"Monitoring the Effectiveness of Structural BMPs"**
   George Oswald
   Camp, Dresser & McKee, Inc.;
   Richard Mattison
   Kinnetic Laboratories, Inc.

MONITORING OF WETLANDS, WET PONDS, AND GRASSED SWALES

by

David Green[1], Thomas Grizzard[1,2] (M. ASCE), and Clifford Randall[2,3] (M. ASCE)

Introduction

The use of best management practices (BMPs) to minimize the impact of storm water flow often involves engineered features such as wet and dry ponds, created and natural wetlands, and grass swales. The main purposes of each of these types of BMP are essentially the same: to reduce peak flows; to remove suspended solids; to provide opportunity for natural systems to reduce concentrations of dissolved organic and inorganic pollutants; and to control erosion. Integral to the use of such systems is the need for a monitoring program to assess the effectiveness of these BMPs in reducing pollutant loads in discharged storm water. Federal and State regulations include specific requirements for industrial and municipal storm water monitoring programs that can be, and often are, labor and resource intensive practices. While the storm water regulations have specific requirements for monitoring of discharges, there remains a need to continue to develop representative and cost-effective monitoring systems that provide data to meet the needs of a variety of end users. This paper examines current monitoring requirements, key elements in the design of a monitoring program, and current methods for assessing the effectiveness of runoff controls.

Background

The 1987 amendments to the Clean Water Act (CWA) added section 402(p), which included provisions for the regulation of storm water discharges. Under CWA §402(p), the U.S. Environmental Protection Agency (EPA) was directed to promulgate regulations incorporating discharges of storm water into the National Pollutant Discharge Elimination System (NPDES) permit program.

In November 1990, EPA published regulations governing NPDES permit applications for storm water discharges (43). These regulations included

requirements for monitoring both dry weather (i.e., base flow) and storm-related flows to determine the concentration of various contaminants (specified in the regulations) in that discharge. EPA has published several guidance documents on developing and implementing such a monitoring program which provide greater detail on the specific elements required.

Under the Federal program, storm water sampling must begin (a) at a predetermined 0.1 inch of rainfall, and (b) no sooner than 72 hours after the last storm event. Two sampling protocols must be followed for storm water discharges. First, a grab sample of at least 100 mL must be collected during the first 30 minutes of discharge. Second, a flow-weighted composite sample must be taken. The flow-weighted composite sample must either be taken with a continuous sampler that proportions that amount of sample collected with the flow rate or be the combination of at least three sample aliquots, with each aliquot being volumetrically proportional to discharge flow. The collection of samples in this manner is problematic at best, requiring either automated equipment or the ability to have a sampling team in the field on very short notice.

Analysis of organic and inorganic compounds, microbiological species, and water quality parameters is required under the regulations. The specific constituents include the organics listed in 40 CFR Part 124 Appendix D, Table II; the toxic metals, cyanide, and total phenols listed in 40 CFR Part 124 Appendix D, Table III; and additional parameters specified in 40 CFR §122.26(a)-(c). The EPA guidance document *Guidance Manual for the Preparation of Part 1 of the NPDES Permit Applications for Discharges from Municipal Separate Storm Sewer Systems* (40) provides detail as to the parameters that should be addressed in a storm water monitoring program. Table 1 provides a summary of these recommended parameters.

The regulations also require the use of the analytical methods specified in 40 CFR Part 136. If there is no method specified for a particular compound, alternative methods meeting specified criteria can be utilized for the analysis. For the most part, standard laboratory methods exist for the contaminants listed; however, standardized field methods using remote sampling and analytical systems are not available. Thus, most monitoring programs using field sampling and analysis systems probably will require a method validation element.

The monitoring requirements of regulatory programs should always be considered in the design of a monitoring program for storm water BMPs. Incorporating these requirements into a study provides data adequate for two purposes: demonstration of compliance plus the data needed to determine how the design and operation of such systems can be improved.

Table 1

Recommended Monitoring Parameters

Conventional Water Quality Parameters	**Metals**
pH	Antimony
Total suspended solids	Arsenic
BOD_5	Beryllium
COD	Cadmium
Settleable solids	Chromium (total)
Temperature	Hexavalent chromium
Conductivity	Copper
	Lead
Nutrients	Mercury
Dissolved phosphorus	Nickel
Total phosphorus	Selenium
Soluble phosphorus	Silver
Total Kjeldahl nitrogen	Thallium
Nitrate/nitrite nitrogen	Zinc
Cyanide	
	Biological parameters
Organic Compounds	Fecal coliform
Oil and grease	Fecal streptococcus
Volatile organic compounds (VOCs)	Microtox®
Base/neutral organics/acids (BNAs)	*Daphnia* bioassay
Polychlorinated biphenyls/pesticides	Fish bioassay
Total phenols	

Adapted from *Automatic Stormwater Sampling Made Easy* by Thrush and DeLeon (38)

Design of a Monitoring Program

Any program to monitor the effectiveness of storm water BMPs must have clearly defined goals and carefully designed strategies to achieve those goals. In the case of a monitoring program for the types of BMPs discussed in this paper, the goals of the monitoring program should include:

- Estimating storm event flow and loading rates.
- Determining actual flow rates and identification and quantification of the influent and effluent pollutants of concern.

- Assigning the reduction (or increase) in a pollutant of concern to the appropriate physical, chemical, or biological system in a mass balance.
- Assessing possible impacts to other resources, especially groundwater.
- Assessing possible improvements in the design and operation of both the BMP and the monitoring program.

Integral to the design of a monitoring program is the need for a quality assurance (QA) program. Because environmental monitoring data are collected under often less than ideal conditions and a specific sampling event may not be repeated, researchers need to demonstrate that data collection and analysis procedures are based on accepted scientific practices. Typically, QA efforts focus on the laboratory analysis only; however, this is but one small part of the entire investigative process, and it is uncommon to see papers in the literature make specific reference to the entire QA protocol followed. One recommendation for all researchers conducting studies on the effectiveness of storm water BMPs is the use of an accepted protocol for incorporating QA into the monitoring program and to reference the QA program in their discussion. One model for integrating quality assurance into environmental monitoring programs was proposed by Clark and Whitfield (9). Briefly, this model proposes a system with fourteen elements:

(1) A careful study design to delineate the goals of the study and the methods to achieve those goals.
(2) A study plan documenting for all study participants the roles, responsibilities, and authorities of each participant.
(3) Written protocols or standard operating procedures to be followed during the course of the study.
(4) Careful preparation for all field activities before departing on a sample collection expedition.
(5) Field team-headquarters liaison to ensure communication of study activities, problems, and corrective actions taken between "headquarters" and field teams.
(6) Written procedures for sample collection including sampling location selection, sample collection, on-site analysis, and recording of data and observations.
(7) Written procedures for sample handling between the time of collection and receipt at the laboratory where the analysis will be conducted.
(8) Oversight of analytical laboratories in addition to incorporation of the "in-house" QA program of the analytical laboratory into the project QA plan.
(9) Ensuring data are supplied by the analytical laboratory in a usable manner that minimizes the need to reenter data.
(10) Data validation and statistical analysis of the data received to determine the accuracy and precision of the reported results.
(11) Procedures for data approval and the release of the validated data.

(12) Plans for providing the data to the public, regulatory agencies, or others in an established format useful to the recipient.
(13) Procedures for statistical analysis of the data to determine trends or specific relationships between data points or data sets.
(14) Procedures for reporting and interpretation of the data to determine if the goals of the study are fulfilled.

While this appears a cumbersome process and a burden on the investigator, use of a QA program such as is outlined by this model helps ensure that the data collected are of maximum utility, accuracy, and precision. Further, providing a reference in published works to the QA protocols followed may enhance the utility of research efforts that follow.

Estimation of Storm Event Flow Rate and Pollutant Loadings

There are two components to determining storm event flow rates and pollutant loading. First, one must estimate these characteristics in order to plan and implement a monitoring program. This is especially important for monitoring programs that will utilize automatic sampling or analysis devices. Second is the verification of those estimates, and refining of the sampling procedures through analysis of the results of the implemented program.

There are several critical elements to estimating storm event flow rates. First, there is a regulatory definition of a representative storm event, critical to estimating runoff volume for the purpose of determining compliance:

> *...[A] storm event that is greater than 0.1 inch and at least 72 hours from the previous measurable (greater than 0.1 inch rainfall) storm event. Where feasible, the variance in the duration of the event and total rainfall of the event should not exceed 50 percent from the average or median rainfall event in that area. [40 CFR §122.21(g)(7)].*

EPA provided only limited discussion of analytical techniques to use on precipitation data to determine what constituted a representative storm event in the document *Guidance Manual for the Preparation of Part 1 of the NPDES Permit Applications for Discharges from Municipal Separate Storm Sewer Systems* (40). A paper by Hamilton (15) discussed the approach used in conducting an evaluation to determine the criteria for a representative storm event in the Winston-Salem and Greensboro, North Carolina area. For the Winston-Salem area, the National Oceanic and Atmospheric Administration (NOAA) used the following parameters:

1. A storm was defined by a total rainfall accumulation of at least 0.1 inch, with rates averaging at least 0.01 inch per hour.
2. Data were recorded on at least an hourly basis.

3. The start of a rainfall event begins in an hour when at least 0.01 inch of rainfall is recorded.
4. The minimum dry period to signal the end of a rainfall event was 10 hours.
5. At least 10 years of data were required for analysis (data from 1948 to 1986 were actually used).

The City of Greensboro, North Carolina used the same data set, but used two different parameters:

1. The minimum dry period to signal the end of an event was 3 hours.
2. The minimum dry period prior to the start of an event was 72 hours (per the regulatory definition).

Even though the same data set was used for these studies, there was a significant difference in the values for representative storm events, with the NOAA approach yielding consistently higher values for duration, frequency, total precipitation, and average precipitation. This difference led the North Carolina Department of Environmental Management (NCDEM) to define a storm event as a storm having a precipitation depth of 0.2 to 0.8 inch and a duration of 3 to 13 hours. Guidance letters from NCDEM specifically recommended against the use of high-intensity, short-duration storms as a representative storm event.

Other studies used different methods for determining what constituted a representative storm. Thrush and DeLeon (38) recommended using data from the National Weather Service to determine an average storm by calculating the numeric average of all the storms during the period examined, or by using the frequency of return of a storm of a given intensity which met the regulatory definition. Brown (6) used average data for three years in a study conducted in Minnesota. Chang and Crowley (8) defined a storm event as "any rainfall event with no breaks for more than six consecutive hours in duration." Neither the Brown nor the Chang and Crowley paper explicitly stated that the regulatory definition was reflected in their determination of a storm event. Woftiw (51) developed a computer program to use weather radar by deriving storm intensity-duration curves. This technique is limited to use in areas where there are long-term precipitation data and a weather radar service, but offers promise as system to assess storm events.

Another point to consider is the potential for bias in precipitation data. This will be especially important if a researcher is collecting precipitation data as part of the monitoring program. A study by Legates and DeLiberty (23) suggests the typical gaging system used in the U.S. (i.e., a 324 cm^2 gage, 79 cm above ground level, without a wind shield) introduces a systematic bias into the data record. This bias results from a variety of factors including wind effects (especially on snow), wetting losses to the inner walls of the gage, evaporation, splashing, and other factors dependent of the specific gage being used. According to this study, this bias typically ranges from 10 to 40 percent below actual values, with the worst bias being introduced in the winter months. In the U.S., no correction factors are applied to account for such bias, so, researchers may wish to attempt to correct precipitation data using the methods discussed by Legates and DeLiberty. Poissant and Béron (34) encountered similar problems with the design and operation of an automatic sequential rainfall sampler they designed and tested. The areal distribution of the weather stations is also a potential source of bias. The U.S. Department of Agriculture (UDSA) technique for determining rain gage placement density (39) suggests 4 gages are required for a drainage area of 1 mi^2, 15 for a drainage area of 10 mi^2, and 50 for a drainage area of 100 mi^2. The high costs of such an extensive gaging system would need to be carefully weighed against the benefit derived from the additional accuracy of the data collected.

Once an estimate of the depth of precipitation from a representative storm has been made, the total runoff volume can, in turn, be estimated using a formula adapted from EPA's guidance document *Guidance Manual for the Preparation of Part 2 of the NPDES Permit Application for Discharges for Municipal Separate Storm Sewer Systems* (41):

$$V_r = P \cdot A \cdot 0.009 \cdot IMP + 0.05$$

Where:
V_r = runoff volume (l^3)
P = rainfall depth (l)
A = drainage basin area (l^2)
IMP = percentage of impervious area in drainage basin

Care must be taken when determining the value for the percentage of impervious area. Even small differences between the estimated impervious area and the actual impervious area can yield significant differences between estimated and actual storm event flow rates.

Once these parameters have been determined, they should be refined by analysis of actual data from the monitoring program. Typically, storm hydrographs are used to analyze the characteristics of a given storm. This analysis allows the researcher to determine the total and the peak flow as a function of time during the storm event. Should the values for the estimated flow and actual flow vary by more than a factor of 2, the estimating procedure should be revisited.

There are a variety of models for estimating storm water pollutant loading rates. Andrews (3) provides analysis of three such models: the model used in EPA's *Guidance Manual for Part 2 Applications for Dischargers from Large and Medium Separate Stormwater Systems* (41); the U.S. Geological Survey (USGS) Nationwide

Regression Equation (NRE); and the "P8" computer model developed by W.W. Walker. Andrews suggests that the selection of a model will depend mostly on the user's short- and long-term needs; however, his analysis suggests that although it is more complex, over the long term, the "P8" model will offer the greatest utility. Akan (1) also provides an analysis of several models to estimate pollutant loadings. Marsalek (25) suggests that planning-level evaluation of pollutant loads in storm water should also consider the impact of the environmental pollutants. It will suffice to say that estimates from these models will need to be refined once sampling results are available. Once actual data are available, a variety of models can be used to extrapolate such data to unmonitored areas.

Determining Efficiency of Storm Water BMPs

In order to assess the efficiency of a pond, wetland, or grass swale, it is necessary to accurately characterize the mass of pollutants entering and leaving the system. Although each of these systems has a different design basis, most of the pollutant removal mechanisms are similar. Pollutants entering the system are removed by washout without treatment, settling (especially in conjunction with suspended solids), biological uptake and/or conversion, volatilization, or infiltration. Water entering the system either flows out, infiltrates, or is lost through evapotranspirative processes. Expressed as a combined mass and water balance this relationship takes the form:

$$M_d + \frac{C_r}{V_r} + \frac{C_i}{V_i} = \frac{C_e}{V_e} + \frac{C_p}{V_p} + \frac{1}{V_e} + M_s + M_b + M_v$$

Where:
M_d = mass of constituent deposited directly from atmospheric sources (m)
C_r = constituent concentration in precipitation falling directly into system (m/l^3)
V_i = precipitation volume falling directly into system (l^3)
C_i = constituent influent concentration (m/l^3)
V_i = inflow volume (l^3)
C_e = constituent effluent concentration (m/l^3)
V_e = effluent volume (l^3)
C_p = constituent concentration infiltrating into ground (m/l^3)
V_p = infiltration volume (l^3)
M_s = mass of constituent deposited as sediment (m)
M_b = mass of constituent taken up by biota (m)
M_v = mass of constituent lost by volatilization (m)
V_e = volume lost by evapotranspiration (l^3)

Efficiency would then be described by the equation:

$$E = \frac{\frac{C_i}{V_i} - \frac{C_o}{V_o}}{\frac{C_i}{V_i}} \cdot 100\%$$

E = efficiency of system at pollutant removal, %
C_i = constituent influent concentration (m/l³)
V_i = inflow volume (l³)
C_o = constituent effluent concentration (m/l³)
V_o = effluent volume (l³)

Assessing Flow and Constituent Concentrations

Obviously, at least two stations are required to assess the effectiveness of a BMP at treating storm runoff: one immediately prior to, and one immediately following the BMP. However, additional sampling stations within the unit are advisable, and may yield valuable information as to the degree of treatment achieved as the flow passes through the system and may also assist in identifying the processes responsible. Establishing such a system is relatively easy; typically inflow to BMPs is from engineered collection systems serving a larger area that directly impacts the BMP through overland flow. For designs where overland flow is the main source of runoff entering the BMP, a diversion system is needed to channel the flow so it can be monitored and sampled.

There seems to be no standard practice for monitoring storm water flows or the collection of storm water samples. Researchers use weirs, flumes, and other primary devices to measure storm water flow past a given point in order to generate a hydrograph that either will allow manual combining of grab samples into a flow-weighted composite or will be used to trigger automatic sampling devices to directly collect flow-weighted samples. For example, Lynch and Corbett (24) used modified broad-crested Trenton weirs with a sharp-crested, 90-degree, V-notch in the center; McTernan *et al.* (28) used a type-H flume for primary flow control and a pressure transducer flowmeter; Izuno *et al.* (18) used 0.80-, 1.6-, and 2.4-cm diameter PVC pipes that had been calibrated to yield a known relationship between discharge and hydraulic head over the pipe; the Occoquan Watershed Monitoring Laboratory (OWML) (30) used Palmer-Bowlus and type-H flumes; and Higgins *et al.* (16) used 3-ft H flumes, culverts, broad-crested weirs, and 90-degree notch weirs. One study on an experimental plot of fescue with similar conditions to a grass swale conducted by Gross *et al.* (14) used a 0.76 by 1.0-m metal weir with a covered H-flume to measure runoff volumes and to collect samples for analysis.

Each of the types of primary devices has advantages and disadvantages. The advantages of weirs are that they are generally low cost, easily installed, and quite accurate. The disadvantages are that they can cause significant head loss in the flow stream and create a pool that may affect sediment transfer past the device. The advantages of flumes are that they are typically are self-cleaning due to higher flow velocities, there is no "dam" across the channel that will cause pooling, and operate with smaller head loss than weirs. The disadvantages are that they are more costly, more difficult to install, can be submerged by extremely high flows, and are often less accurate. However, the self-cleaning nature of a flume may be an important consideration in measuring storm water flows which are often high is suspended solids and flotsam. This intrinsic feature of flumes may minimize problems from the buildup of settled solids behind the structure or by flotsam occluding orifices. Ultimately, the selection of what type of flow measurement system to use will involve "professional discretion."

A secondary device such as a pressure transducer, flow meter, or other mechanical stage-height detector and stage-height recorder are required to record the flow as a function of time in order to apportion grab samples; however, this sampling technique has several drawbacks. First, it is labor intensive. Personnel will have to be available at very short notice to respond to storm events. In large scale sampling programs, commitment of personnel resources is also a major consideration. Second, to apportion grab samples, analysis of the hydrograph is required prior to compositing the sample. Finally, there is a practical limit as to the number of sample bottles that can be taken into the field. A schematic of this type of compositing technique looks like:

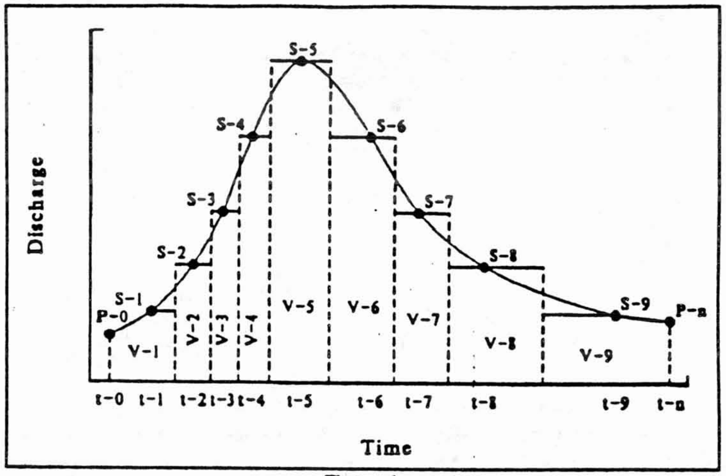

Figure 1
Schematic of Compositing of Grab Samples

The computation for compositing samples collected in this manner is given by:

$$V_i = \frac{V_i}{V_T} \cdot C \quad where, \quad V_T = \Sigma V_i$$

$$V_1 = \frac{q_0 + q_1}{2}(t_1 - t_0) + q_1 \cdot \frac{t_2 - t_1}{2}$$

$$V_{n-1} = \frac{q_{n-1} + q_n}{2}(t_n - t_{n-1}) + q_{n-1} \cdot \frac{t_{n-1} - t_{n-2}}{2}$$

$$V_i = q_i \cdot \frac{t_i - t_{i-1}}{2} + \frac{t_{i+1} - t_i}{2} \quad for\ i = 2\ to\ n-2$$

Where:
- V_i = aliquot volume for each sample, S_i, (l^3)
- C = desired final composite volume, (l^3)
- q_i = flow during time interval, t_i (l^3/t)
- t = time

Notes:
1. P_0 (*i.e.*, P-0 above) and P_n (*i.e.*, P-n) are the begin and end times for the event – no samples are taken.
2. S_i (*i.e.*, S-i) are the sample points.
3. V_i (*i.e.*, V-i) are incremental areas under the hydrograph.

Because of the drawbacks to apportioning grab samples, a flow measurement system should be associated with an automatic sampling device that will automatically collect a true flow-weighted sample. A schematic of an automatically integrated sample looks like:

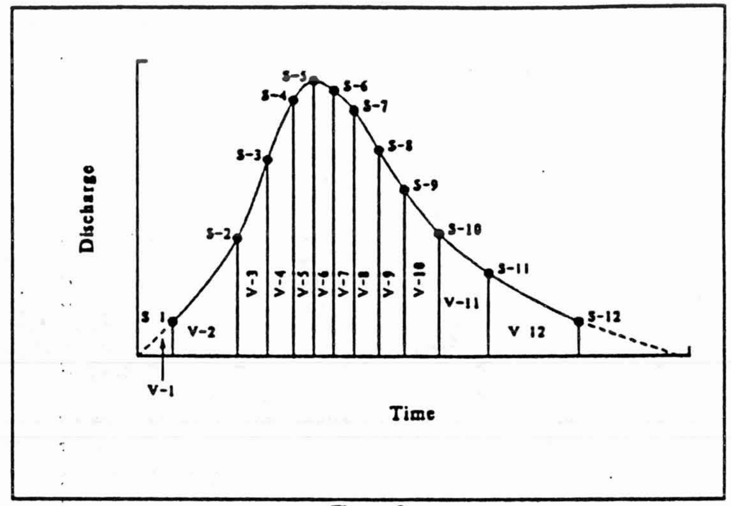

Figure 2
Schematic of Automatically Collected Flow-Weighted Samples

Notes:
1. With the exception of V_1 (*i.e.*, V-1 above), all V_i (*i.e.*, V-1) are equal.
2. If V_i is very small, the error induced by unequal volume represented by sample 1 and unsampled volume post sample 12, will also be small.
3. If V_i is small, a better representation of flow near peak is also obtained.

A variety of devices are discussed in the literature for use in collecting flow data and for sample collection. Kress and Turton (21) developed a magnetic trigger to activate automatic pumping samplers. In this system, a plexiglass disk with equally spaced magnets is attached to the water level recorder. As the water level recorder rotates, so does the plexiglass disk. When a magnet passes by a proximity switch as a result of the rotation, an automatic sampler is activated. The only reported problem was at low flows, when the disk tended to rotate back and forth, causing excessive triggering of the sampler. Another concern would be that this system would only trigger the sampler when there was a change in flow; at a continually high flow samples may not be collected in a manner proportional to the volume of water flowing past the sampling point. Riekerk (35) devised a vacuum-powered sequential storm flow sampling device controlled by a mechanical float. Several units are mounted across the direction of flow and are triggered by rising water levels during storm flow events. This system has the advantage of being simple, inexpensive, and lending itself to use in very remote locations. The drawback to this system is that trial results demonstrated a 20 per cent variation in water quality when compared to samples collected by an electronic time-controlled system. Drent and Kersting (12) used a magnetic valve triggered by an electric pump to collect proportional samples from the experimental ditch system they studied in the Netherlands. Owens *et al.* (31) used a 2:1 broadcrested weir with a rotating vane sampler. Whitfield and Wade (49) provide a discussion of their experience using electronic sensors to monitor weather, stage height, and water quality parameters such as temperature, pH, dissolved oxygen concentrations, oxidation-reduction potential, and conductance. The important observation in their paper was that electronic data collection in "real-time" allows monitoring of very short duration events that either would go completely undetected or would require such extensive commitment of manpower to monitor as to be economically impractical.

Another consideration in collecting samples is the need for vertical integration of the sample. This would be especially important if a contaminant of interest was immiscible in water, as is the case with many hydrocarbons. In this case the contaminant of interest may be found in a higher concentration at the surface or at some other level in the water column. Contamination of groundwater by dense non-aqueous phase liquids (DNAPLs) and the resulting difficulties associated with remediation of this type of contamination is another example. There are a variety of devices that will collect vertically integrated samples. Two passive types of systems are the multi-slot divisor and the Coshocton-type sampler. The disadvantage to using a multi-slot divisor is that a settling tank to remove large sediment particles is usually required to keep the device from becoming clogged. With a Coshocton wheel this typically is not a problem. In a Coshocton wheel water is discharged from a type-H flume onto a rotating water wheel. An elevated sampling slot on the wheel collects an aliquot sample as the wheel traverses the water pouring from the flume. In this way a vertically integrated sample is collected (39). There are also a variety of other more complex devices for collecting vertically integrated samples. Martin *et al.* (26) conducted a study comparing surface grab samples and a cross-sectionally integrated, flow-weighted sampling device. As has been well documented in the literature, there can be considerable cross-sectional variation in suspended sediment concentrations. This becomes important when one considers the pollutants sorbed onto these sediments. The study concluded that concentrations of suspended sediments and the associated pollutants were routinely lower in manually composited surface grab samples than in cross-sectionally integrated, flow-weighted samples. Generally, the magnitude of the difference increased with flow rate. One other observation was that grab samples consistently contained more fine-grained sediments than the integrated samples.

One report discussing the use of microcomputers for flow measurement does, however, deserve additional discussion. The OWML (30) uses a system of an inexpensive microcomputer (either a RadioShack Model 102 or 202), an analog-to-digital converter, and a 10 psig submersible pressure transducer to monitor storm flow events. The computer receives a signal from the transducer (via the A/D converter) and calculates the stage using the following equation:

$$HT = \frac{PT}{1000} \cdot 4.614 \frac{ft}{volt}$$

Where:
HT = stage in feet
PT = pressure transducer signal in millivolts
4.614 is a constant to convert ft/psi to ft/volt

This value is then compared to a rating curve that is stored in the computer's random-access memory. Every minute, the value for the stage is compared to the value for the previous minute. If the stage has risen at least 0.1 foot over each of the last three successive minutes, a storm event is considered to have begun, and the computer starts continuous monitoring and triggering of an automatic sampling device to collect a flow-weighted composite sample. Base flow data are written to disk every hour and storm flow data every 10 minutes. The data record includes: date, time, stage, flow, discharge, incremental discharge, and whether a sample was collected. The data record is downloaded to an IBM-compatible format for analysis.

Using the value for total volume for a storm event, along with values for the number of samples to be collected and a known sample size for composited samples (both set by the investigator), the volume of storm water flow between collection of each sample can be calculated using the following relationship discussed by Thrush and DeLeon (38):

$$\frac{V_r}{FSI} = N = \frac{V_{sc}}{V_{s}}$$

Where:
V_r = runoff volume (l^3)
FQI = volume of flow per sampling interval (l^3)
N = number of samples
V_{sc} = volume of composited sample (l^3)
V_{s} = volume of each sample (l^3)

Typically, the volume of the composited sample should reflect the sum of the volumes required for each of the analyses conducted as part of the monitoring program, plus an appropriate safety factor. However, since it is common that storm event flows will not yield sufficient volume for all analyses, the researcher should be prepared to prioritize the tests to be performed on incomplete samples.

The sampling routine in the computer program used by OWML is controlled by a flow-totalizing subroutine. This routine is based on the following equation:

$$IV = \frac{Q_i + Q_{i-1}}{2} \cdot (t_i - t_{i-1})$$

Where:
IV = volume of flow during interval (l^3)
Q_i = discharge at present stage (l^3/t)
Q_{i-1} = discharge at previous stage (l^3/t)
t_i = time at present stage (t)
t_{i-1} = time at previous stage (t)

The values for IV are summed every minute, and when this value exceeds the value for V_w, a sample is collected. By analyzing the times when samples where collected against the hydrograph, the researcher can determine if the sample collected is truly representative of the entire storm event. Ideally, the hydrograph will show that sampling was conducted throughout the entire storm event, with the greatest number of samples being collected during the period of peak flow, and with the desired total sample volume being collected.

One issue that needs to be stressed in using remote and automated sensor and sampling systems is the need for quality assurance for these practices. One journal article by Whitfield and Wade (50) discussed the need to develop new QA procedures when using electronic logging devices and made several specific recommendations regarding QA procedures for electronic monitoring. These procedures fall into three areas: (1) sensor validation in the field, (2) time controls for data loggers, and (3) precision and accuracy of sensors over time.

According to this article, little can be done to verify the accuracy of a sensor using field instrumentation. This is because field instruments rarely are as accurate or precise as a laboratory system, while this is the degree of accuracy and precision required. Since field verification is not practical, Whitfield and Wade recommended operating electronic monitoring systems for a fixed number of day duty cycle, with calibration before the system is taken into the field and recalibration when the duty cycle ends. This allows a correction factor to be applied to the data. Unstated in their paper was the need for careful use of such correction factors. Careful analysis of the data collected is necessary to determine if the "drift" was consistent over time,

or whether a catastrophic failure occurred. In the latter case, application of the required correction factor to data collected prior to system failure would clearly be inappropriate.

Regarding time controls, Whitfield and Wade discovered that when more than one instrument is used to monitor a given parameter, strict time control (± 5 seconds), with weekly verification, is necessary to prevent generation of time artifacts. Further, a record of all adjustments must be kept to allow for use of correction factors on data collected. While this may not be necessary for systems where sampling is done over longer periods of time, it is critical during high-frequency, short-interval sampling programs, sampling when conditions are changing rapidly, and sampling where temporal correlation of data sets will be performed. For careful tracking of time, microcomputer-controlled systems with the ability to automatically access outside standard reference clocks (e.g., as is available through Loran-C) can be invaluable.

In the last area, precision and accuracy, Whitfield and Wade identified the need to adjust data to account for drift introduced by deterioration related to the age of the sensor. Their study showed that dissolved oxygen sensors were subject to the greatest degradation in performance. Oxidation-reduction potential and pH sensors demonstrated bias over time rather than degradation in sensor performance. As with the first case, knowing the calibration at the time a sensor is placed into service and the calibration at the end of a given service interval, corrections can be made to account for such fluctuations. Additional studies on how age affects other sensors such as pressure transducers, A/D converters, and other features of electronic monitoring systems would prove useful.

Infiltration Measurement and Collection of Samples of Infiltrated Water

Protection of groundwater resources is of such concern that in 1986 Congress amended the Safe Drinking Water Act (SDWA) to include a new program for wellhead protection. This desire to protect groundwater resources is mirrored in a variety of other Federal and State laws severely restricting or prohibiting the land disposal of hazardous waste. Because infiltration of storm water is the major contributor to groundwater recharge, storm water BMPs need to be designed and operated in a manner that will prevent, or at least minimize, contamination of groundwater. Given the high concentrations of some contaminants in storm water, application of design strategies such as are used for hazardous waste surface impoundments (e.g., use of impermeable clay or synthetic liners) may be advisable. Whipple (48) suggests a programmatic control strategy integrating storm water management and infiltration controls. This proposal suggests classifying areas based on the need to protect surface waters and groundwater; creating a "harmfulness index" for various runoff sources (e.g., industrial/commercial, residential, and undeveloped areas); and requiring specified BMPs depending on the land use and need for protection. Whipple also proposed some special types of BMPs that might be employed for storm water flows known to be contaminated by various classes of pollutants.

The rate of migration of waterborne or liquid pollutants into the ground depends primarily on the hydraulic conductivity of the underlying soil. Higher hydraulic conductivity allows more rapid movement of water into the ground, and allows pollutants to travel farther into the soil column before other processes, for example, adsorption, begin to retard the migration. Determining the rate at which water infiltrates into the ground (i.e., hydraulic conductivity) is accomplished using a permeameter or piezometric wells. The design and operation of these devices are well described in the literature and will not be discussed in detail. For a detailed discussion of the operation of these devices, the reader should refer to a text on hydrogeology, such as by Fetter (13) or Driscoll (11).

Tensiometers are used to determine the negative head exerted by the tendency of water to infiltrate into the ground. An adaptation of a tensiometer can be used to collect samples of infiltrated water. One study by the OWML (30) used a device constructed by attaching a porous cup (similar to those used on tensiometers) to one end of a five-foot-long PVC pipe, and a rubber plug (to create an airtight seal) to the other end. A sample collection tube was passed through the rubber plug and extended to the bottom of the porous cup and a second tube for applying pressure or vacuum to the system was passed through the rubber plug and extended halfway down the pipe. The device was placed into a bored hole approximately three feet deep, and packed into place with excavated soils to prevent surface water from passing down into the soil alongside the PVC pipe. Twenty-four hours prior to sampling, a vacuum was applied to the shorter tube in the system to reverse the negative pressure head and so draw water from the soil into the porous cup. Samples were collected from the device by applying pressure via the shorter tube, thus forcing the water up the longer tube and into the sample container.

There are many methods for estimating infiltration of storm water. The reader is directed to Driscoll (11) for an excellent discussion of these established methods. One new method to determine volume losses due to infiltration not described by Driscoll was developed by Kalita *et al.* (19). They described a mathematical method to model losses from the side walls and bottom of ponded fields under variable water table conditions. The field aspects of their study used an experimental plot are not readily adaptable to the study of systems such as ponds, wetlands, and swales. However, their results do suggest that vertical and lateral infiltration losses from ponded systems can be predicted with a high degree of accuracy, provided adequate hydrologic data are available. The specific factors that would need to be known include: soil-moisture characteristics, hydraulic conductivity, water table depth, evaporation rate, and pond depth.

Assessment of Deposition in Sediments

There are two reasons to monitor the deposition of sediments in storm water BMPs. First, one of the primary reasons for storm water management systems is to control erosive losses of soil into waterways, hence deposition of sediments in storm water BMPs can severely impact storage capacity. Striegl's study (37) of suspended sediments and metals removal by Lake Ellyn, a small lake outside Chicago, showed that in the course of 10 years, the lake accumulated 8,300 m^3 of sediments, a 13 per cent loss of storage capacity. Second, and equally important, is the cumulative effects of pollutants associated with sediments on the benthic community, rooted vegetation, and the land where spoils from dredging the BMP are ultimately disposed of. This last point is worthy of special comment. Studies by a variety of researchers show that toxic metals from urban runoff accumulate in sediments at relatively high concentrations. For example, Striegl's study found mean concentrations of copper, lead, and zinc were 275, 1,750, and 228 mg/kg dry weight, respectively. Nightingale (29) also found concentrations of lead as high as 1,400 mg/kg. These values for lead concentrations are of particular concern in that they exceed the 1,000 mg/kg concentration used by EPA as a guideline for remedial activities under Superfund. No data are available, but an interesting question arises as to how dredged sediment would fare if subjected to the Toxicity Characteristic Leaching Procedure (TCLP) test to determine if it is a characteristic hazardous waste under the Resource Conservation and Recovery Act (RCRA). Under the Federal RCRA program as described in 40 CFR §261.24, a waste demonstrates the characteristic of toxicity for lead if the TCLP extract concentration is greater than 5.0 ppm (mg/kg).

As was stated previously, the rate of migration of liquid or aqueous pollutants into the ground depends primarily on the hydraulic conductivity of the underlying soil. Higher conductivity allows more rapid movement of water into the ground, and consequently less time for degradative, filtering, or adsorptive processes to occur. Other factors, however, do play a major role in the ability of a pollutant to associate with sediment. Oxidation-reduction potential, pH, temperature, and presence of hydrous gels of iron or aluminum all play a role. Adsorption of pollutants onto sediment, however, is of particular concern. Adsorption is greatest when sediment particles have a high surface area/mass ratio; when sediment particles have negatively charged surfaces, as is the case for silts and clays; when the sediment has a high cation-exchange capacity; and when organic carbon fractions in the sediment are high.

As described in the EPA handbook *Remediation of Contaminated Sediments* (42), studies of sediments rely on a variety of sampling and analytical techniques to determine the mass of pollutants in sediments or the overall condition of the benthic community. Almost all involve collection of samples using digging tools such as spoons, scoops, and trowels or coring devices such as split-spoon samplers, piston-tube samplers, or augers. *Standard Methods* (2) provides detailed discussion of various sediment sampling devices, protocols, and analytical techniques. Each has its advantages and disadvantages. For example, the very nature of digging tools makes collection of similar samples from a variety of locations problematic and the disturbance of the sample by the collection method suggests that it may not be representative of actual near-bottom conditions. Coring devices are expensive, bulky, and often difficult to handle. Further, core samplers do not work well in sandy soil or in rock-laden areas. Coring devices can also breach the integrity of a engineered structure, opening a migration pathway for contaminants. Last, attributing pollutants concentrations in sediments to specific storm events can be difficult in any system other than a new construction. For these reasons, sediment sampling as part of an effectiveness study poses some serious challenges.

One method described in the literature that may prove a useful tool in the analysis of sediments is to collect the suspended particles that will become sediment before they settle. Walling and Woodward (45) described the design and use of a simple field-based water elutriation system for monitoring particle size and characteristics. Their system uses four glass sedimentation chambers (25-, 50-, 100-, and 200-mm diameter) linked by glass and flexible PVC tubing. A peristaltic pump provides suction to draw water directly from the channel being monitored into the 25-mm sedimentation chamber via a tube that extends nearly to the bottom of the chamber. Water is drawn off this chamber by means of a second tube positioned at the top of the chamber, and is directed to bottom of the 50-mm chamber. This process is repeated until the water has passed through all the chambers. This technique offers several advantages over traditional sampling techniques in that it provides the researcher the opportunity to assess the characteristics of the suspended sediment based on effective particle size. This does, however, require the assumption that the sediment collected in this manner is representative of the sediment accumulating at the bottom of the BMP. One possible modification to the operation of this system for collecting samples from the bottom would be to apply a microfilter to the collection tube, fill the system with filtered water taken near bottom, remove the filter, manually disturb the sediment, and then collect the sample. Another use would be to monitor the effectiveness of the BMP at removal of particles of various sizes as a function of distance from the inlet into the system.

Physical and chemical analysis of samples

The Federal regulations require the use of the standard analytical procedures described in 40 CFR Part 136 or the use of another accepted standard procedure such as those in the American Public Health Association reference *Standard Methods for the Analysis of Water and Wastewater*. There are, however, drawbacks to the use of these analytical methods.

First, the accepted analytical methods for metals yield total metals concentrations (a conservative approach that may not reflect actual impacts to aquatic organisms) rather than the quantity of metals that are readily bioavailable. Typically, the bioavailable forms are free metal ions or those metals weakly bound in inorganic complexes. Papers by Paulson and Amy (32 and 33) discuss the point that the majority of metals

in storm water are found sorbed to particulates or in strongly complexed organic forms that are not readily bioavailable. These studies showed that although storm water quality was quite variable, the relationship between bioavailable and total concentrations was consistent. The factors controlling the speciation between dissolved and bioavailable forms include: (1) suspended solids types, (2) pH of the water, (3) total metals concentration, and (4) dissolved organic carbon concentration and character. Paulson and Amy developed a computer model using the EPA's MINTEQA2 to predict the speciation of copper, zinc, and lead into bioavailable and nonbioavailable forms. The results of the modeling effort suggest that in addition to analysis of total metals, an estimate of the bioavailable concentration would be worthwhile in assessing potential impact to aquatic biota.

The second area of concern is that several of the analyses required under the regulations are nonspecific tests. For example, the test for "oil and grease" is non-specific. *Standard Methods* defines "oil and grease" as any compound recovered as a substance soluble in trichlorotrifluroethane or other solvents. This is not specific for hydrocarbons; chlorophyll, organic dyes, and other compounds will be included in the results from this test. If possible, in addition to these nonspecific analyses, it is recommended that during the first few sampling rounds analysis be conducted for a larger suite of specific constituents (for example, chlorophyll) than is required under the regulations. Once the initial rounds of sampling are completed, the suite of constituents can be winnowed down to a manageable and cost-effective suite by eliminating those compounds that are not detected. This is not to say that the nonspecific tests are not valuable tools; Wass (46) used the oil and grease method with moderate success in evaluating the effectiveness of a submerged-flow vegetated treatment system used to treat runoff from a vehicle maintenance yard. The only problem encountered with using this non-specific method occurred when cold-mix asphalt was used to construct berms to redirect runoff at the study site. An unusually heavy rain leached some of the constituents from the asphalt, causing a short term increase in the concentrations of oil and grease detected.

Biological Testing

Little definitive work has been published relating efficiency of storm water treatment to the growth of plants or other organisms, nor does there appear to be any definitive standard vegetative analysis for storm water BMPs. Most of the available work discusses either the results of simulated studies or the effects of various agricultural or silvicultural techniques of the quality of storm runoff in streams. For example, Gross *et al.* (14) conducted an interesting study of runoff and sediment losses from tall fescue under simulated rainfall. This study demonstrated that seeding density for turfgrass plays a major role in its ability to act as a sediment trap, and the conclusion was made that well-maintained residential turfgrass stands should contribute to decreasing total runoff volume and sediment loadings. Little other research has been done in recent years on the effectiveness of various grasses as sediment traps or on their ability to assimilate dissolved pollutants. Clearly, this is an area where additional research is needed. The use of reed beds for sludge dewatering was discussed by Kim (20). This study suggests that beds containing the reed *Phragmites* are an effective means of dewatering sludges from 1 to 10 percent solids, suggesting that this species may be a valuable means of promoting evapotranspiration from sediment-laden BMPs operated as dry ponds.

Standard Methods (2) provides an excellent discussion of accepted techniques for sampling macrophyton in method 10400. The reader is directed to this reference for the details of these sampling techniques. It is important to note that these techniques are not specifically developed for storm water BMPs; however, they should certainly be applicable.

Vegetation monitoring was conducted as part of the study by the OWML (30) discussed elsewhere in this paper. The vegetation analysis consisted of identification plant species and a biomass measurement. The biomass measurement was conducted by trimming to ground level the plants in randomly spaced circular plots with an area of 1 m^2. The harvested plants were separated by species, washed with a weak acid solution, and oven dried to constant weight. Below-ground biomass was estimated by excavating a 12 cm by 20 cm soil sample using a piece of PVC pipe. Plant material was manually separated from the soil, washed with a weak acid, and dried. Samples were collected throughout the growing season and the biomass measurement technique repeated to give an indication as to the rate of biomass production. A decomposition study was also conducted by placing a known amount of washed and dried plant litter from known species into 36 porous polyester bags and placing these bags in areas where those plants were dominant. Every month, six bags were removed at random and weighed to determine the quantity of plant material that had decomposed. The study did not attempt to correlate biomass production with pollutant removal efficiency, but these procedures allowed an analysis of the rate at which organic matter accumulated in the wetland under study.

Recent regulatory initiatives have seen the inclusion of toxicity testing requirements in NPDES permits, including those for storm water discharges. There are problems with toxicity testing for storm water flows. As pointed out by Isom (17), one "glaring deficiency" with toxicity testing is the lack of a national laboratory certification program. Collins *et al.* (10) pointed out that one of the most difficult problems with conducting toxicity testing on storm waters using fathead minnows or *Daphnia* stems from the 36-hour maximum holding time permitted. Because it can be difficult to determine when there will be a storm event (a fact borne out by local television weather forecasts across the U.S.), the laboratory may not have a ready supply of test organisms of the appropriate age. Further, these tests are expensive. Many researchers have examined the potential for microbial toxicity testing as a means of providing a more cost-effective assay; however, none of these tests have proven to be as effective as the standard test using fathead minnows or *Daphnia*. For example, Arbuckle and Alleman (4) assessed the potential for using the commercially available Microtox® test and a procedure using enriched nitrifier cultures. Their study showed

that neither test was as sensitive as the *Daphnia* test. *Standard Methods, 18th Edition*, contains two proposed methods for toxicity testing of aquatic plants. One technique is for Duckweed and the other for a variety of vascular plants. These are laboratory techniques and have not yet been approved, nor have these techniques been adapted to field use.

Conclusion and Recommended Directions for Research

There are many areas still to be explored in conducting research on monitoring of storm water BMPs. One of the most important areas where research could be focused is the development of standard methods for conducting studies of storm water BMPs. Currently, there are few standard practices in the field. This makes relating data from one study to another very difficult at best, and impossible at worst. A short list of proposals for research into standardizing protocols for storm water BMP evaluations follows.

1. Development of standard methods for the calibration and operation of remote sensors.

2. Development of standard methods for metering flow (i.e., use of standard designs of weirs, flumes, or other systems).

3. Development of a standard method for sampling infiltrated waters.

4. Development of standard methods for the collection and analysis of suspended sediments and deposited sediments.

5. Development of methods to relate vegetation assessments to treatment efficiency.

6. Development of a recommended list of analyses for bioavailable metals and development of standard analytical methods for those analyses.

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Protocols for Monitoring the Effectiveness of Structural Stormwater Treatment Devices

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Abstract

With the implementation of the NPDES regulations for stormwater discharges there has been a high level of interest in establishing reliable pollution control performance characteristics for structural treatment controls which may be applicable for managing the quality of runoff from urban land uses and industrial facilities.

This paper describes monitoring techniques and data analysis protocols for establishing the pollution control performance of structural treatment controls for stormwater runoff. These techniques are applicable for monitoring oil/grit separators, filtration basins, extended detention basins and wet-detention basins. The following monitoring considerations are addressed:

- General considerations for monitoring instrumentation
- Characterization of contributing drainage area
- Rainfall measurement
- Flow measurement for structure inflow and discharge
- Water quality sampling for analytical characterization of structure inflow and discharge
- Monitoring period of record and storm events rainfall depth distribution
- Structure overflow and bypassing
  - On-line/off-line configurations
  - Storage volume
- Data analysis
  - Hydrologic mass balance
  - Water quality constituent balance
  - Single event and long-term pollutant control performance

This information is organized to provide guidance for future monitoring activities so that municipalities and industries can implement cost-effective and technically sound BMP performance monitoring programs to support NPDES compliance and BMP specification development for future stormwater management applications.

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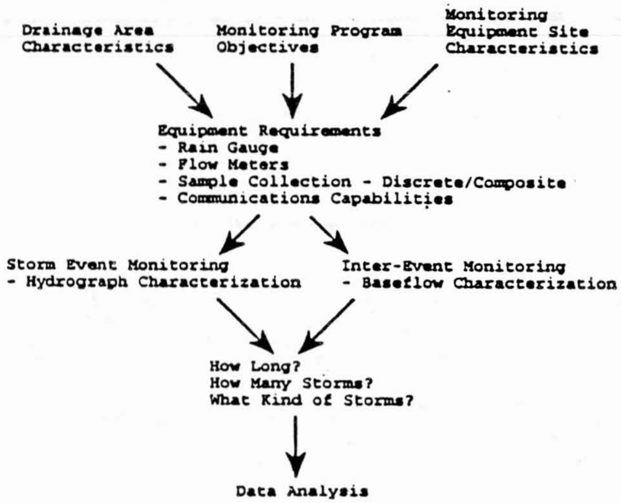
Introduction

The purpose of this paper is to provide guidance for the development and implementation of effective pollutant control performance monitoring programs for structural stormwater runoff treatment controls.

The monitoring of pollutant reduction performance of structural treatment controls for stormwater runoff presents numerous challenges. Typically, treatment structures such as oil/grit separators, filtration basins, extended dry-detention and wet-detention basins are designed and constructed to meet minimum capture volume/surface area specifications to meet prescribed regulatory requirements and to meet specific site physical constraints such as slope limitations, high ground water elevation, and integration with site plan layout demands. During structure design, little or no consideration is made for siting monitoring stations to characterize inflow and outflow flow rates and water quality improvement performance. Therefore, the usual challenge is to retrofit monitoring equipment to existing structures.

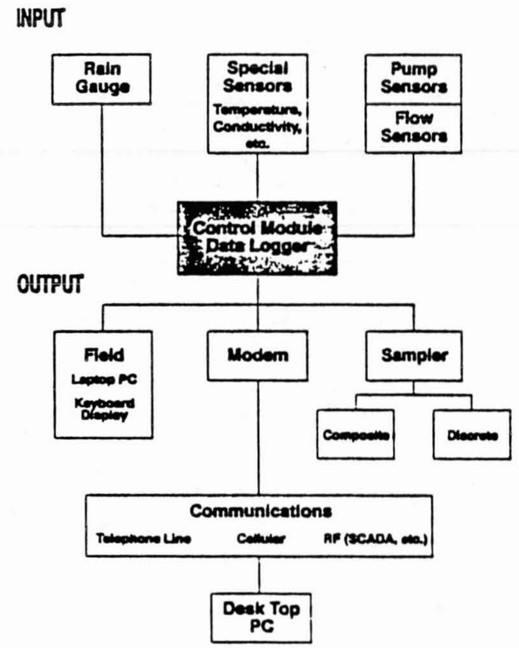
This reality typically dictates that each treatment structure selected for monitoring be evaluated individually to establish feasible methods for reliable flow measurement and water quality sample collection. Also, the basic flow configuration of the structure bears on the extent of monitoring required to characterize structure performance under the range of hydrologic events, both small and large, that occur in the location of the study. On-line structures can be subject to resuspension and washout of accumulated pollutant materials during large storm events and pollutant flux associated with dry weather baseflow can be significant. These occurrences can have a significant effect on long-term pollutant control performance. Properly designed off-line structures are not subject to extreme event "washout" processes; however, long-term performance monitoring of off-line structures must take into account bypassed volumes that do not receive any treatment. Also, the control performance of wet basins which combine complex physical, chemical and biological pollutant reduction mechanisms is significantly influenced by the variations in hydraulic residence time that occur in response to the normal variation in rainfall/runoff volume and inter-event time periods that are part of the expected "normal" hydrometeorologic cycle. Therefore, accurate characterization of the integrated, long-term pollutant reduction performance of these structures can require intensive sampling programs that address characterization of a wide range of wet weather and dry weather inflows and outflows.

The flow chart below presents the design and implementation steps required for an effective structural treatment control performance monitoring program. The remainder of this paper presents recommendations and guidance on how to address these requirements.



General Considerations for Monitoring Instrumentation

Because of the difficulties associated with timely field personnel mobilization and achieving consistent manual flow measurement and sample collection techniques for extended monitoring program periods, this paper is focused on the application of automated monitoring systems only. Therefore, a limited overview of automated systems is included to highlight the capabilities of these systems. The primary components and configuration relationship of an automated monitoring system are illustrated in the following diagram.



Automated Monitoring Station.

The major component of an automated system is the control module/datalogger microprocessor, which functions to interrogate and record input data from external sensing devices including the flow meter and rain gauge, can perform complex calculations based on these inputs and produce signals to drive ancillary devices, including the automatic sample collection unit and remote communications devices. This flexibility allows for these automated systems to detect storm flow conditions and initiate sampling with no human interaction.

Remote communications capabilities allow for: 1) sample collection rates to be reset to meet variable storm magnitude or baseflow conditions, 2) effective, real-time tracking of storm/hydrograph/sample collection progress, and 3) efficient direction of field crews for sample recovery. Additional equipment considerations for rainfall and flow measurement are included in later sections of this paper.

Characterization of Contributing Drainage Area

It is important to characterize the contributing drainage area tributary to the treatment structure in order to: 1) establish anticipated peak flow rates for the range of storms to be monitored, and 2) identify all significant tributary areas to the structure.

Establishing the anticipated peak flow rate is important for selecting and sizing the inflow primary flow measurement device, such as a weir or flume. Since storms of a depth less than the 2-year return period storm typically account for more than 90% of annual rainfall, designing the flow measurement device to meet the 2-year storm peak flow criteria is a good target. Standard hydrologic methods such as SCS TR-55 can be used to estimate peak flows and total design storm runoff volume based on tributary area, soil type, slope, and land use. It is also recommended that hydrographs be generated for the smaller more frequent storms, such as the 3-month and 6-month events, to establish the nominal flow metering range to allow adequate characterization of these more frequent storms.

A structure may have multiple inflow points, which will require multiple monitoring sites, or may have significant overland sheet flow contributions to the basin between the inlet and outlet. There are additional equipment and operation costs associated with the increase in monitoring sites, and increased pollutant control performance data analysis uncertainty associated

with characterizing inflows associated with unmonitored direct overland flow contributions.

Assuming that performance monitoring of structural treatment controls will be coordinated with other land use related discharge quality monitoring activities, information on land use distribution, percent impervious cover, and age of development should be compiled so that the inflow characterization data is useful for establishing land use related stormwater quality impacts.

Rainfall Measurement

Although rainfall measurement is not specifically required to measure structural control performance, acquisition of incremental rainfall data in the tributary watershed area is strongly recommended because inflow runoff quality may be influenced by rainfall intensity, depth, and duration and, most importantly, rainfall records are necessary to establish the range of storms for which structural control performance has been monitored. It is recommended that rainfall be recorded with a tipping bucket rain gauge with a minimum sensitivity of 0.01 inch with input to a datalogger.

Flow Measurement - Inflow and Outflow

Flow measurement can be accomplished using any of a number of primary measurement devices such as weirs and flumes. A good reference on these devices is the ISCO Open Channel Flow Measurement Handbook (1992). Flumes are recommended over weirs because of their self-cleaning capability, lower head loss, and reduced influence from approach velocity. Weirs must be periodically cleaned to remove deposits of sediment or other solids upstream of the weir or accuracy will be affected. However, weirs are generally recognized as being more accurate than flumes. Properly installed and maintained, most types of weirs and flumes will produce better than ±10 percent accuracy.

The primary factors which affect the selection of type and sizing of the primary flow device are the minimum and maximum range of flow rates to be measured and any limitations associated with the existing site physical configuration. Sizing of the primary flow device for inflow is based on the hydrologic analysis of the inflow monitoring point tributary drainage area discussed previously. Sizing of the primary flow device for outflow should be based on level pool routing of inflow hydrographs for wet-detention basins and design drawdown flow rates for extended detention and filtration basins. Since oil/grease separators generally have a small storage volume, inflow rate is typically assumed equal to outflow rate and only one flow monitor is installed and is used to provide flow information to drive both the inflow and outflow automatic samplers.

For example, Palmer-Bowlus flumes are recommended for round pipes because of ease of installation. H-flumes have been effectively used at pipe/culvert outfall locations. Weirs typically are best suited for measurement of open-channel flow where low approach velocities can be achieved by increasing weir height and removal of accumulated materials from the upstream face is practicable. Also, compound weirs can be configured to provide very broad flow ranges beyond the capacity of a single flume or simple weir. If a weir is employed under non-"ideal" siting conditions (i.e. inadequate crest height, high velocity of approach), or if better than ±10 percent accuracy is desired for normal installations, it is recommended that a specific rating curve be developed based on independent volumetric flow measurements such as timed gravimetric, tracer dilution, or velocity-area techniques.

In addition to weirs and flumes, several manufacturers offer instrument systems which combine an electromagnetic or sonic-doppler velocity sensor with a flow depth sensor to determine flow rate through a velocity-area continuity computation. These types of systems are costly and it is best to conduct independent flow verification calibration to correlate velocity measurements with actual average flow velocity. Properly installed and calibrated, these devices can produce flow measurements within ±2 percent accuracy for flow velocity up to 20 feet/second.

Flow measurement by weir, flume or velocity sensor requires concurrent depth of flow measurement. Recommended instrumentation includes direct contact electronic pressure transducers, bubbler/isolated pressure transducer combinations, and electronic ultrasonic water surface level sensors. The bubbler and pressure transducer are located in the flow stream, whereas the ultrasonic level sensor is a top-down sensor that measures the distance to the water surface from a mounting location in the airspace above the flow path.

All of these level sensors provide reliable operation and are capable of sensitivities of ±0.1 inch in typical applications.

Water Quality Sampling for Analytical Characterization

Because of the time variation of both flow rate and water quality constituent concentrations that occur in stormwater runoff during storm events and in the outflow from treatment structures, pollutant control performance monitoring requires the collection of flow-weighted composite samples over both the inflow and outflow hydrographs. Additionally, if dry weather inflow is present, inter-event (between storms) flow monitoring and sampling is required for on-line structures such as wet-detention basins in order to quantify water quality constituent flux under dry weather-baseflow conditions.

Storm Event Monitoring. Flow-weighted composite samples should be collected using an automatic sampler driven by time integrated flow measurements (flow paced) to produce either a single collection container direct composite sample or to produce flow-paced discrete samples in separate containers. Both methods have distinct advantages. Direct compositing allows for frequent flow-paced samples to be taken over a storm hydrograph to assure development of an event mean concentration (EMC) composite that is based on many sample aliquots throughout the rising, falling and peak flow periods of the runoff hydrograph or treatment structure discharge hydrograph. Laboratory analytical costs are minimized in comparison to discrete sampling since only a single composite requires analytical characterization.

In comparison, discrete sampling allows the characterization of pollutograph effects during storm events because the individuality of each flow-paced sample aliquot is maintained by separate containers. This permits water quality constituent characterization of each individual sample to identify the time variation of concentration (pollutograph) and/or the mathematical compositing of individual sample aliquot analytical values to produce EMC values. This method also allows for the flexibility to prepare a flow-weighted, manually composited sample from a portion of the individual sample aliquots and reservation of the aliquot remainder for individual analytical characterization. As an example, this approach can be used to produce pollutographs for lower cost indicator parameters such as conventional pollutants and making a manual composite EMC determination for the more costly toxic organic constituents.

A good target for hydrograph water quality constituent characterization is to collect aliquots over at least 80 percent of the total storm hydrograph volume.

The initial sample of treatment structure inflow should be collected early in the rising limb of the hydrograph to capture any initial flush effects. Automated sampling systems incorporate the ability to initiate sampling at a predetermined depth level and to convert level into flow rate for flow-paced sampling throughout the inflow or outflow hydrograph. The pacing of sample collection should be based on anticipated storm runoff volume conditions. This can be accomplished by developing a table of flow-pacing rates (i.e. cubic feet of flow/ sample aliquot) as a function of anticipated rainfall amount to produce the desired direct composite volume or number of discrete sample aliquots. It is important that the sample aliquot collection rate not exceed the mechanical capacity of the automatic sampler. Typically, samplers can cycle (system purge and sample collection) as often as once every 60 seconds. It is also recommended that a minimum of eight (8) aliquots be collected of treatment structure storm related inflow and outflow for meaningful EMC or pollutograph characterization. It is best if these samples represent the initial, peak and recession regions of the hydrograph.

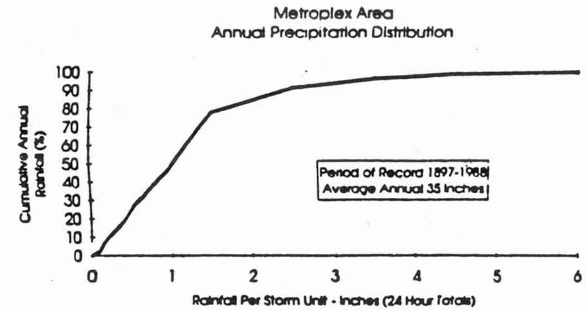
Since treatment structure outflow rates are attenuated from inflow rates because of storage volume dampening, outflow hydrographs can be extended over significantly longer time periods than inflow hydrographs, so sample aliquot collection must occur over a longer time period.

It is recommended that minimum analytical characterization include TSS, BOD, COD, nutrients (total phosphorus, dissolved phosphorus, TKN, NO_2+NO_3), and total and dissolved metals (copper, lead, zinc, cadmium).

<u>Inter-Event Monitoring</u>. For wet-detention basins, significant outflow flux of algal materials and associated oxygen demand, nitrogen and phosphorus can occur under inter-event baseflow conditions. Therefore, for structural treatment basins which are subject to significant inter-storm event baseflow throughput, it is important to gain an understanding of water quality constituent flux during these low flow periods. This can be accomplished by collecting weekly or daily inflow and outflow flow composite samples during inter-event periods using the same automated monitoring system put in place primarily for storm event monitoring. Sample collection flow-pacing parameters can be reset during inter-event periods to collect adequate characterization samples. These long-term inter-event monitoring activities typically target a limited number of indicator pollutants.

<u>Monitoring Period of Record and Storm Event Distribution</u>

It is desirable that the monitoring program include a distribution of sampled events that is representative of the average annual rainfall event depth distribution. The following figure is an example 24-hour total rainfall event distribution for Dallas, TX which illustrates that 50% and 90% of average annual rainfall occurs for storms of a depth less than 1 inch and 2½ inches, respectively.

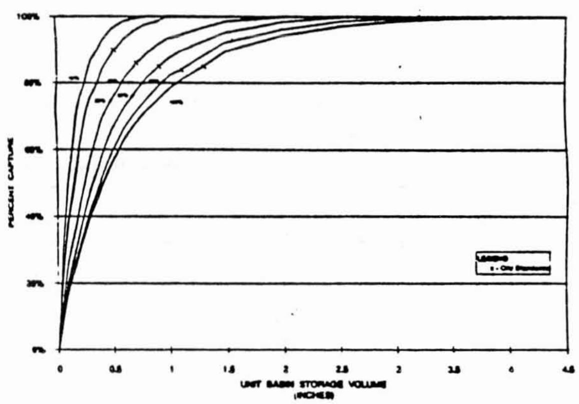


Having actual monitored event-specific rainfall data at hand, the investigator can make astute decisions on future target storms for priority monitoring, or to assess what the previously accumulated control performance data set represents with respect to average annual conditions. Target storm identification should also address identification of seasonal storms (wet/dry, winter/summer) for monitoring through review of long-term monthly average rainfall totals.

Although it is always desirable to acquire as much treatment structure inflow and outflow data as possible, allowable study time and fiscal constraints must be considered in setting realistic data acquisition targets. It is recommended that monitoring programs target acquisition of between 10 and 20 storm event inflow/outflow and baseflow data sets over a two- to three-year period. In the urban land use environment, storm depth must typically exceed 0.2 inch before sufficient runoff/inflow is produced to allow treatment structures inflow/outflow automated sample collection. Of course, this generalization is influenced by site-specific land use/impervious cover conditions. The collected treatment performance data should be reviewed for consistency (i.e. good inflow/outflow water balance, storm volume characterization >80%) and representation of local hydrologic conditions; then, judgements made for future monitoring data needs as necessary.

<u>Effects of Treatment Structure Overflow and Bypassing on Monitoring Requirements</u>

Treatment structure overflow and bypassing impact long-term pollutant control performance. Off-line structures such as extended detention basins and filtration basins are designed to isolate and treat a specific design volume of stormwater runoff. Runoff volumes which exceed the storage volume capacity of the structure are bypassed untreated. In assessing the long-term control performance of off-line structures, bypassing must be taken into consideration. To illustrate this impact, the following figure presents annual capture efficiency curves for off-line basins with 40-hour basin drawdown as a function of storage volume and tributary area percent impervious cover.



These curves were developed for Austin, TX using 50 years of hourly rainfall data and field-verified runoff coefficients. The percent of annual runoff that is not captured is bypassed untreated. This can be

addressed in a monitoring program by conducting inflow/outflow water balance calculations to quantify bypasses, or a third flow monitor can be installed downstream of the off-line flow splitter to quantify bypasses directly.

As previously mentioned, wet-detention basins typically function in an on-line configuration and, as such, all surface discharge from the basin is overflow. Since hydraulic residence time affects the dissolved pollutant conversion processes associated with rooted plant and algal biological uptake, water column chemical conversion, and water column/sediment interaction, it is important that performance monitoring programs target a range of storm event and inter-event sample collection activities to address this highly varied range of basin operating conditions. This is important in order to establish the average and expected variation in control performance under the influence of the local hydrologic cycle. For example, extreme events which produce high flow rates can resuspend settled materials and produce "negative" pollutant removal efficiencies, hydraulic short-circuiting of flows can occur if basins are designed without sufficient baffling or length to width ratios and, thus, greatly reduce pollutant control performance. Additionally, inter-event flows can convey significant pollutant mass loads.

Also, dry basins such as extended detention and filtration basins which are configured on-line are also subject to resuspension/washout during extreme storm events and target storms for the monitoring program should attempt to quantify this occurrence. *Therefore, the performance variability associated with on-line treatment structures is much higher than off-line systems and this should be addressed through more extensive monitoring plans.*

<u>Data Analysis</u>

Basic data analysis for each monitored storm event should include: 1) water quality constituents inflow/outflow EMC determination from the analytical laboratory results in combination with the inflow/outflow flow data if time-paced discrete sample collection was employed, and 2) performance of an inflow/outflow water mass balance calculation to assure that inflows and discharges have adequately accounted for any gains or losses and to make any necessary assumptions. All storm data sets are then used together to calculate period of record pollutant removal control efficiency.

EMC Determination. Determination of EMC is a straightforward procedure. Obviously, for direct composite sampling, the analytical laboratory results are the EMCs. For discrete aliquots that are equally flow-paced, EMC is determined by summing the discrete concentration values and dividing by the total number of samples. Time-paced or variable flow-paced discrete aliquots must be mathematically weighted by the percentage of total flow each represents over the hydrograph.

Water Balance. Inflow/outflow water balance calculations allow the investigator to determine if flow monitoring equipment is operating accurately and to account for miscellaneous inflows and losses such as groundwater infiltrative losses or gains, evaporation in wet ponds, and any tributary drainage area between the inflow and outflow monitoring locations. Each of these considerations is site-specific; however, water balance accounting and subsequent follow-up investigation and subsequent assumptions to establish the fate or source of flows and associated water quality constituent loads is important when establishing accurate pollutant load reductions for treatment structures.

Pollutant Control Performance. Ideally, monitoring studies will generate a flow and water quality constituent database consisting only of paired inflow and outflow data resulting from the same storm events or baseflow periods. For characterization of long-term control performance, it is important that evaluation be based on long-term data (multiple years) which quantifies pollutant loadings at the inflow and outflow points over a wide range of hydrologic conditions. Although single event removal efficiencies can be calculated, it is strongly recommended that long-term inflow and outflow records be combined to establish representative long-term performance.

Calculation of Removal Efficiencies. The effectiveness of treatment structures is usually expressed as an efficiency in terms of the relative change between input and output of the structure. As an equation, it takes this form:

$$\text{Efficiency} = \left(1 - \frac{\text{output}}{\text{input}}\right) \times 100$$

There are several methods for developing removal efficiencies. Each method is dependent on the monitoring arrangement for the treatment structure site, as well as the suitability of the data set for analysis.

Where possible, paired inflow and outflow storm data should be used in computing pollutant removal rates for the selected constituents. Before calculating removal efficiencies, it is useful to assess the monitoring data and eliminate storms with anomalous data. Data inspection can be performed graphically (histograms, box plots, scatter plots, etc.) and/or through the use of simple statistics such as mean, median, standard deviation, and coefficient of variance.

Data should be reviewed for any inconsistencies between inflow and outflow volumes and concentrations. A storm may be eliminated if there are documented monitoring problems. Note other outlying data points and eliminate those events from analysis.

Long-Term Removal Efficiency. Of greatest interest to engineers and planners is the typical long-term removal efficiency for a given treatment structure, since the variation in efficiency for individual storm events can often be significant. Mass loadings measured entering and leaving the pond over the entire monitoring interval are summed separately and evaluated using the formula:

$$\text{Efficiency} = \left(1 - \frac{\text{total outflow load}}{\text{total inflow load}}\right) \times 100$$

This method is only appropriate for storm events and baseflow periods with paired inflow and outflow data which exhibit an accurate flow balance. Significant error can be introduced by using unpaired data and/or data records which have significantly different inflow and outflow volumes (poor water balance).

Median Loading Rate Reduction. Past experience has shown that most runoff processes are lognormally distributed and that comparisons of the median values will provide an adequate estimate of the pollutant removal efficiency. An alternative approach for calculating removal efficiencies also uses the entire paired storm data set generated at each monitoring station. In this method, the event mean concentration (EMC) for each storm is multiplied by the total storm flow. Statistically analyze the entire population of inflow and outflow storm loads for all events to determine the median storm event loading at the inlet and outlet of the treatment structure. Removal rates are computed using the following formula:

$$\text{Median Efficiency} = \left(1 - \frac{\text{median outflow load}}{\text{median inflow load}}\right) \times 100$$

Accounting for Bypasses. To estimate control performance for off-line treatment structures, the effects of bypassing must be taken into consideration. If the inflow and outflow monitoring data is solely for the treatment structure and does not include quantification of bypass flows, then long-term pollutant control efficiencies should be reduced based on estimates of percent annual runoff bypassed developed from estimates of percent annual capture for treatment as presented previously. Using this technique, measured basin efficiency is reduced by the product of basin average annual runoff volume capture fraction, as follows:

$$\text{Actual Efficiency} = \text{Basin Efficiency} \times \begin{matrix}\text{Annual Runoff} \\ \text{Capture Fraction}\end{matrix}$$

Summary

Monitoring the pollutant control performance of structural treatment controls for stormwater runoff quality management is a complex process which requires simultaneous measurement of flow rates into and out of the structure, with concurrent collection of water quality samples. Typically, monitoring stations must be retrofit to existing inflow and outflow structures and site physical constraints may not allow for "ideal" flow metering conditions to be attained. Under these conditions, development of *in situ* primary flow measurement device rating curves is recommended. Also, if there are significant water gains or losses between the inflow and outflow monitoring locations, flow and quantity estimating techniques should be employed to "close" the water balance for each monitored event or monitoring period if baseflow is included.

In comparison to off-line structures, on-line structures require more extensive monitoring to characterize performance under the normal range of hydraulic residence time variations and both extreme storm high flow and low flow dry weather conditions to which these devices are exposed under local hydrometeorological conditions. Off-line structures, while not subject to the full range of hydrologic variation of an on-line device, do allow bypassing of untreated runoff in excess of basin storage volume. Bypass must be taken into consideration when establishing effective pollutant reduction efficiency for off-line devices.

Establishing long-term pollutant control performance for structural treatment controls requires a long-term paired inflow and outflow database. There are no shortcuts. Monitoring plans should consider the local average annual depth distribution of rainfall events to identify "target" storm magnitudes and wet/dry seasonal differences. Dry weather baseflow, if significant, requires a sampling plan for inter-event periods to quantify pollutant inflow/outflow flux during non-storm periods.

Control performance should be evaluated based on reduction in water quality constituent mass loads from long-term paired inflow and outflow data sets with good water balance data or with water balance resolved through accounting estimates for water quantity and quality.

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Key Words

Stormwater
Quality
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Monitoring
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Pollution
Efficiency

Engineering Foundation Conferences

STORMWATER NPDES RELATED MONITORING NEEDS

Crested Butte Hotel
Crested Butte, Colorado
August 07 to August 12, 1994

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