Stormwater Management: Research Frontiers

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Water Environment Research Foundation (WERF)

UDFCD's Annual Seminar
Emerging Technologies and Practices in Urban Stormwater Management
April 28, 2005
Northglenn, Colorado

WERF STORMWATER PROGRAM

Presentation Overview

- Introduction
- Stormwater survey results
- Long range research plan
- Stormwater research efforts
- Closing

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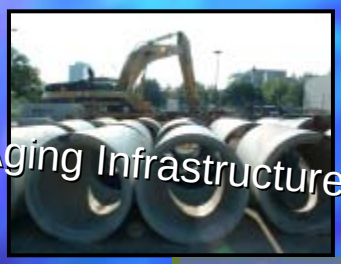
The Water Quality Problem

- An estimated 40 percent of U.S. waterbodies are still impaired by pollution and do not meet water quality standards.
- A leading source of this impairment is polluted runoff.

Drivers Influencing Stormwater Management

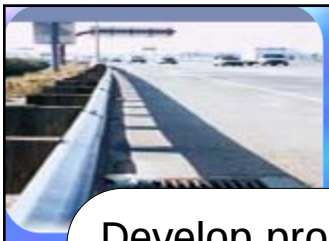
Drivers Influencing Stormwater Management (cont.)



WERF Stormwater Program

Dedicated research program initiated in 2001 *that :*

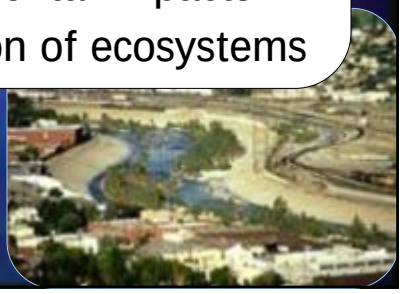
- Builds on WERF's Stormwater efforts to date.
- Complements WERF's ongoing research in Collection and Treatment Systems, Watershed and Ecosystem Management, and Human Health Effects.



WERF Stormwater Program Goal

Develop products that can be used by SW program managers and others for:

- Stormwater management
- Mitigation of environmental impacts
- Protection & restoration of ecosystems



Who Supports WERF Research?

- WERF is supported by Subscribers which include:
  - Public Agencies (e.g. SW and WW agencies),
  - Industries,
  - Corporations,
  - State Agencies, and
  - Equipment Manufacturers

- Subscriber funds are leveraged by grant funding from EPA.

WERF Stormwater Technical Advisory Committee (STAC)

- Robert Pitt, Ph.D., P.E., D.E.E. *University of Alabama, AL* (Chair)
- Christine Andersen, P.E., *City of Long Beach, CA*
- Gail Boyd, *URS Corporation, Portland, OR*
- Brian Marengo, P.E., *City of Philadelphia, PA*
- Charles Rowney, Ph.D.*Camp Dresser & McKee, Inc., FL*
- Ben Urbonas, P.E. *Urban Drainage and Flood Control District, CO*
- James Wheeler, P.E. *U.S.EPA, Washington, D.C.*

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2002 Stormwater Survey Results

To help assess and prioritize the research needs and interests of the stormwater research program, WERF issued a Stormwater Survey in Spring 2002.

Stormwater Survey Statistics

	Surveys		
Organization Category	**Sent**	**Received**	**Return Rate**
Public Agency (PA)	79	**32**	41%
Industry (I)/Equip. Man.(EM)	32	**10**	31%
Corporate (C)	64	**22**	34%
TOTAL	**175**	**64**	**37%**

Ranking by Mean Score of Stormwater Research Topics

All	PA	I / EM	C	
1	1	1	1	**Stormwater Controls (BMPs)**
2	2	2	2	**Receiving Water Effects**
3	3	4	4	**TMDLs**
4	3	5	5	**Source Identification and Control**
5	5	3	8	**Monitoring**
6	6	7	6	**Indicators**
7	11	6	3	**Modeling**
8	8	8	8	**Program Management**
9	10	9	7	**Conveyance and Storage**
10	7	11	10	**Land Use**
10	9	10	11	**Communication / Public Education**

PA = Public Agency, **I** = Industry, **EM** = Equip. Man., **C** = Consulting

Ranking by Mean Score of

Forces (Drivers) Influencing Stormwater Management

All	PA	I / EM	C	
1	1	2	1	Government Regulations
2	2	1	1	*Water quality concerns*
3	3	6	3	Urbanization
4	4	4	4	**Flood Control**
5	5	7	7	Population growth
6	6	5	5	Aging Infrastructure
7	7	3	6	Water Supply Issues

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Ranking by Mean Score of

Stormwater Pollutants of Concern

All	PA	I / EM	C	
1	1	2	2	**Sediment**
2	3	1	3	**BOD, TSS, oil, grease**
2	2	5	1	**Nutrients**
4	4	7	4	**Pathogens**
5	5	3	5	**Metals**
5	7	4	6	**Organics-PAHs, solvents, etc.**
7	6	7	7	**Pesticides**
8	8	6	8	**Trash**
9	9	9	9	**Thermal**

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Ranking by Mean Score of

Need for Information on Various Stormwater Controls (BMPS)

All	PA	I / EM	C	
1	3	4	1	**Wetland Basin**
2	1	5	12	**Non-Structural (eg street cleaning)**
2	2	7	4	**Grass filter / Swale**
4	8	8	1	**Wetland Channel**
5	6	11	3	**Detention Basin**
6	5	1	7	**Media Filter**
7	4	10	5	**Infiltration Basin**
8	8	3	6	**Inlet Filter / Trap**
9	10	2	8	**Hydrodynamic Device**
10	7	8	10	**Retention Pond**
11	11	6	11	**Porous Pavement**
12	12	12	9	**Percolation Trench / Dry Well**

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Ranking by Mean Score of

Need for Information on Various Aspects of Stormwater Controls (BMPs)

All	PA	I / EM	C	
1	1	1	1	**Effectiveness**
2	2	1	2	**Operation and Maintenance**
3	3	4	3	**Whole Life Costs**
4	4	3	3	**Performance Standards**
5	6	5	3	**Fate of Captured Pollutants**
6	5	5	3	**Mechanical vs. Natural Systems**
7	7	8	7	**Retrofitting**
8	8	7	8	**Regional vs. Smaller Systems**

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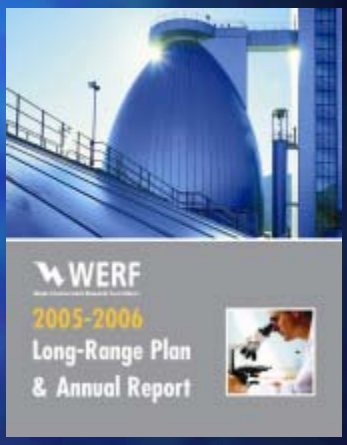
WERF LONG-RANGE RESEARCH PLAN

- The long-range plan provides strategic research direction.
- Issues and priorities are set through surveys, agenda setting meetings, research recommendations, etc.



STORMWATER RESEARCH ISSUES

- Stormwater Controls (BMPs)
- Receiving Water Effects
- Source Identification and Control
- Program Management
- Decentralized Approaches
- Monitoring

Stormwater Controls (BMPs)

Select Research Topics

- Effectiveness
- Whole life costs
- O&M
- Long-term fate of pollutants

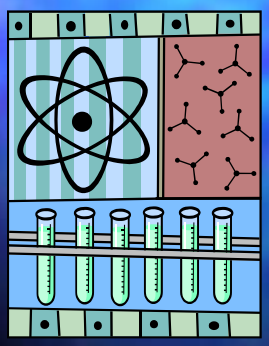
Receiving Water Effects

Select Research Topics

- Physical and chemical effects on surface waters
- Impacts on groundwater
- Snowmelt impacts
- Effects of systems of BMPs on receiving waters

Source Identification and Control

Select Research Topics



- Product substitution
- Pathogen sources
- Impacts of fertilizers, pesticides, fungicides, etc.

Program Management

Select Research Topics

- Evaluating program effectiveness
- Integrated urban water management
- Public education techniques and effectiveness

Decentralized Approaches

Select Research Topics

- Effectiveness of low impact development techniques
- Development incentives to encourage reduced runoff
- Limits to urban density

Monitoring

Select Research Topics

- Appropriate designs to assess stormwater water quality impacts
- New technology for monitoring, modeling, and information exchange
- Sampling and analysis protocols

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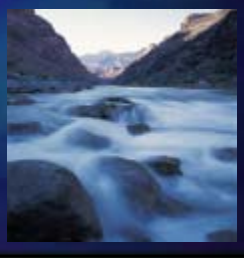


WERF Stormwater Research

- Over 60+ ongoing and completed stormwater projects to date valued at $15+ million

Select WERF Stormwater Research Projects

Project Title	Total Cost
Innovative Metal Removal Technologies for Urban Stormwater	$536,000
Water Quality Models: A Survey and Assessment	$183,000
Tools to Measure Source Control Program Effectiveness	$322,000
Evaluation of the Functions and Effectiveness of Riparian Forest Buffers	$342,000
Physical Effects of Wet Weather Flows on Aquatic Habitats	$123,000
Strategies for Sustainable Water Resource Management	$327,000
Mitigating the Thermal Effects of Stormwater in Urban Watersheds	$445,200
Post Project Monitoring of BMPs/SUDS to Determine Performance and Whole Life Costs	$737,000
Critical Assessment of Stormwater BMP Selection Issues	$300,000
Risk Assessment of Stormwater Microorganisms	$300,000
Protocols for Studying Wet-Weather Impacts of Urbanization Patterns	$150,000
Decentralized Stormwater Controls for Urban Retrofit & CSO Reduction	$175,000
Managing Stormwater: Trade-offs Between Infiltration and Discharges to Surface Waters	$75,000
International BMP Database	$120,000
Successful Integration of Stormwater BMPs into the Urban Landscape	$175,000
Improved Monitoring Methods for Stormwater-borne Solids	$75,000

WERF Products: 97-IRM-2

- Metals Removal Technologies for Urban Stormwater (Stock Number D33409)

WERF Products: 99-WSM-5

- Water Quality Models: A Survey and Assessment (CD-ROM) (Stock Number D13209)

Demonstration:

WERF Products: 98-WSM-2

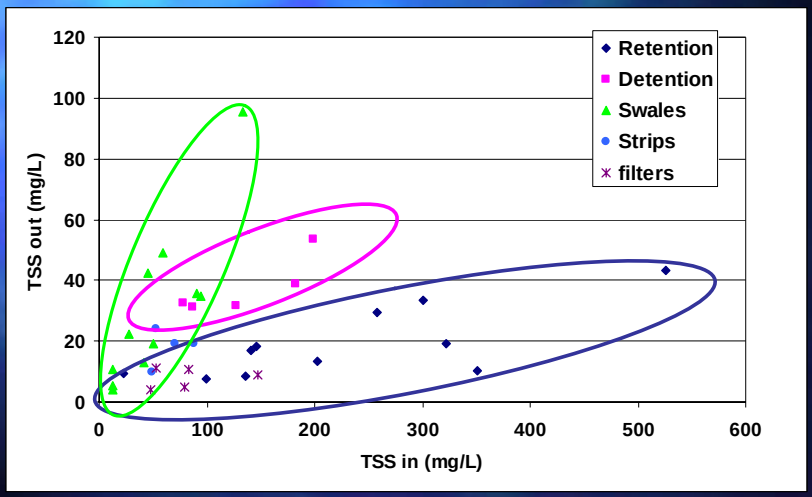
- Tools to Measure Source Control Program Effectiveness (Stock Number D00302)

Ongoing Project: BMP/SUDS Study (01-CTS-21T)

- Co-funded by UKWIR and AwwaRF
- $700k Total
- Phase 1 completed:
  - *Post-Project Monitoring of BMPs/SUDS to Determine Performance and Whole Life Costs* (Stock No. 01CTS21T)
    - Literature Review
    - Performance Protocols & Study Plan
- Phase 2 to be published mid-2005:
  - Investigates:
    - BMP Performance
    - Whole Life Costs
    - O&M Practices

BMP/SUDS Study:
TSS Performance Comparison

Source: Michael Barrett, University of Texas



BMP/SUDS Study:
Whole Life Cost (WLC) Model

- Identify future costs and refer them back to the present day
- Spreadsheet models for:

  Retention Ponds, Extended Detention Basins, Swales, and Permeable Pavement
- Range of costs include:

  Design, Capital, Discount Rate, Operation, and Maintenance (Routine, Corrective, and Infrequent) Costs

Demonstration:

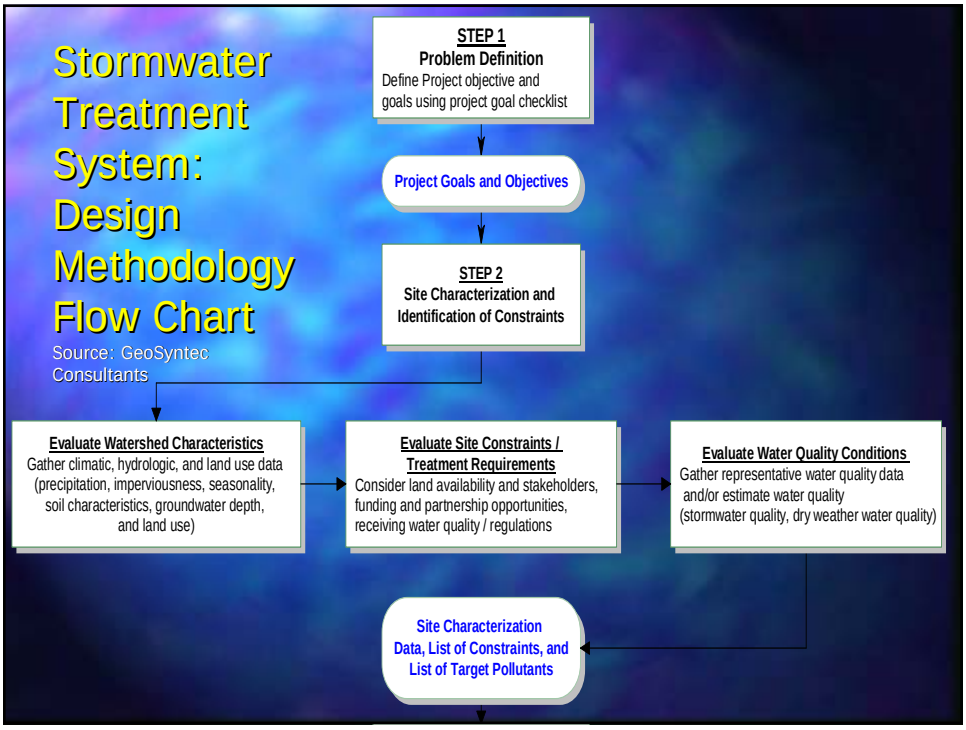
Ongoing Project: Stormwater Control Selection Issues (02-SW-1)

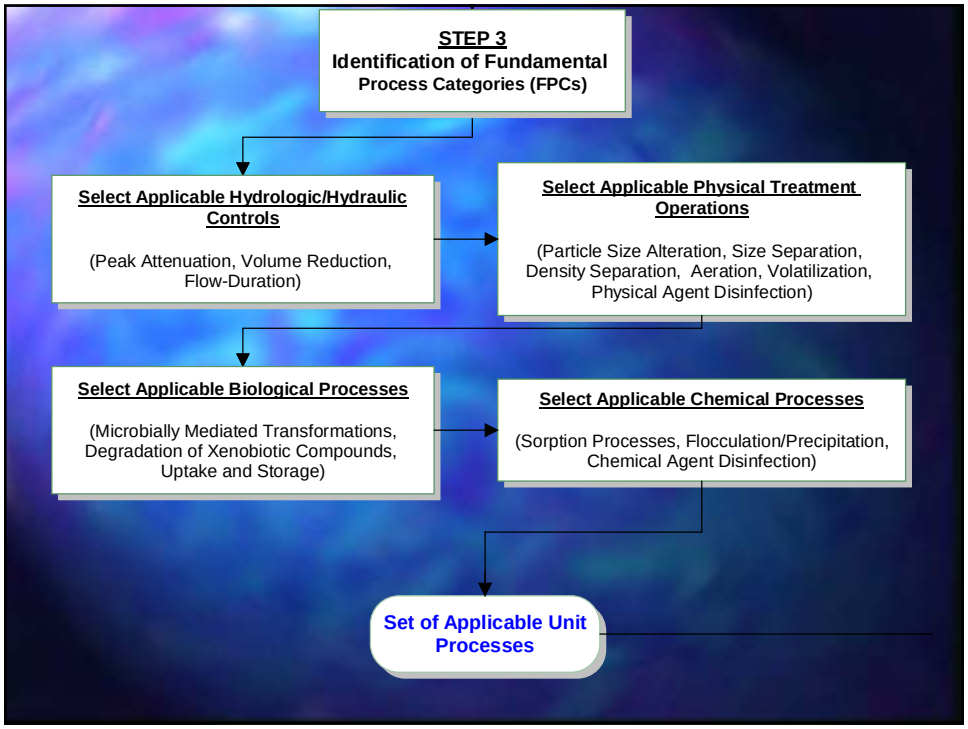
- To be published mid-2005
- Objective:

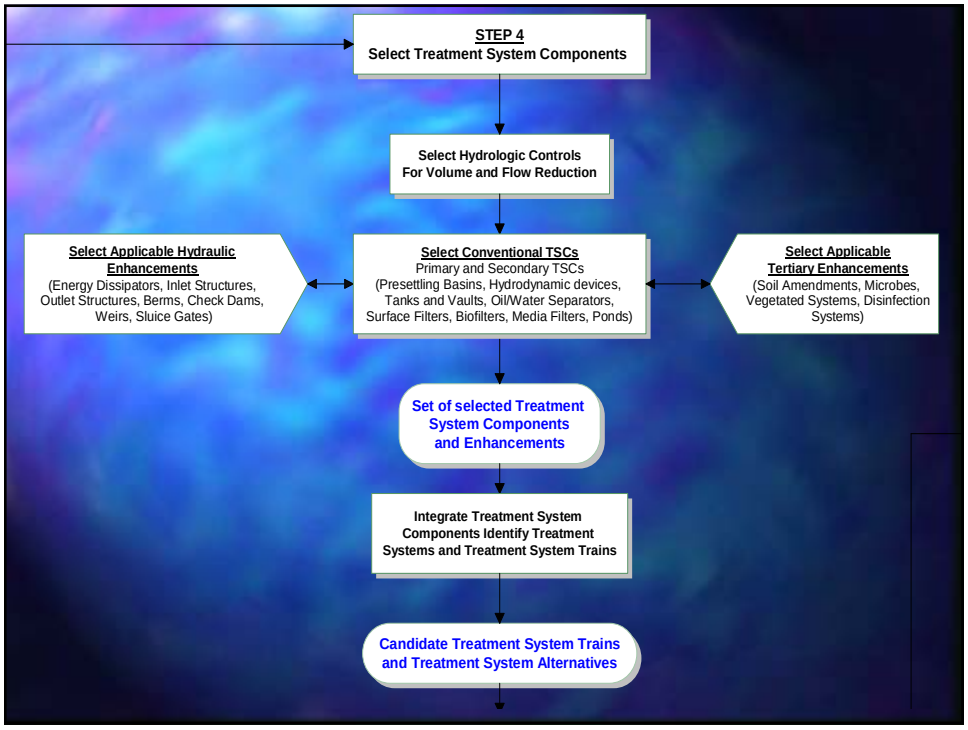
  To apply fundamental environmental engineering principles of unit operations to evaluation and selection of BMPs for urban areas.

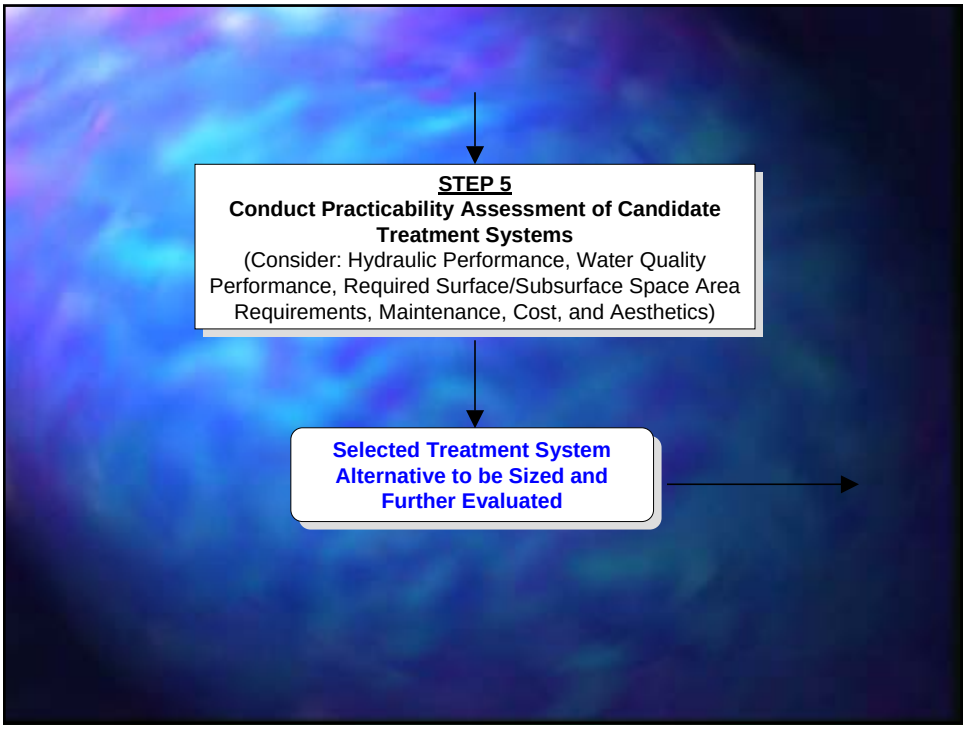
Stormwater Treatment System: Design Methodology Flow Chart

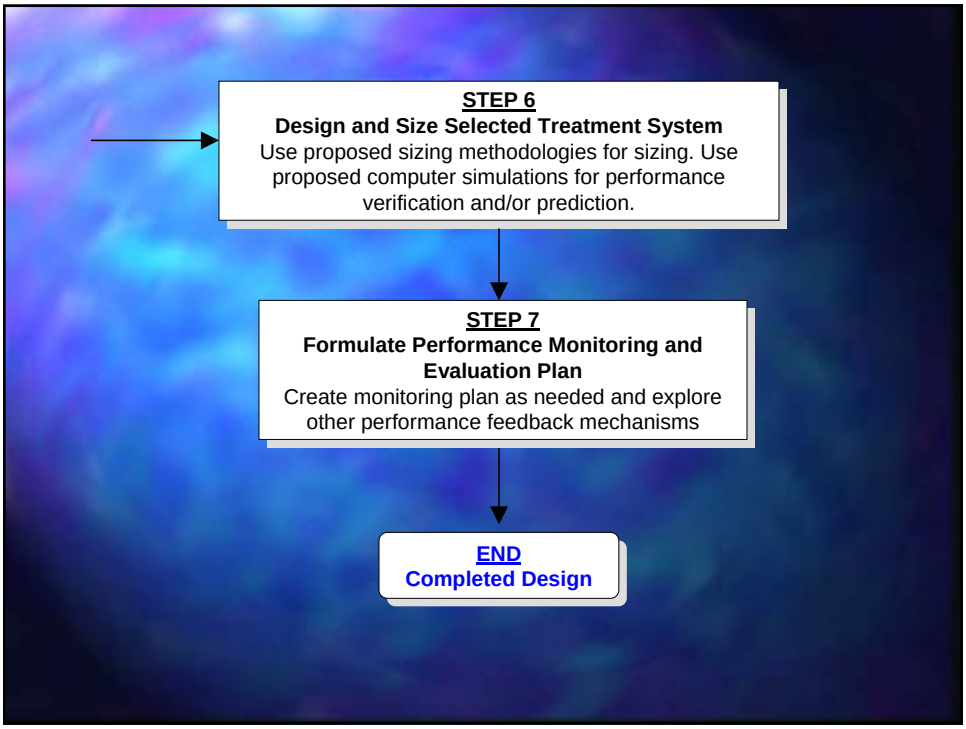
Source: GeoSyntec Consultants




STEP 3
Identification of Fundamental
Process Categories (FPCs)
Select Applicable Hydrologic/Hydraulic Controls
(Peak Attenuation, Volume Reduction, Flow-Duration)
Select Applicable Physical Treatment Operations
(Particle Size Alteration, Size Separation, Density Separation, Aeration, Volatilization, Physical Agent Disinfection)
Select Applicable Biological Processes
(Microbially Mediated Transformations, Degradation of Xenobiotic Compounds, Uptake and Storage)
Select Applicable Chemical Processes
(Sorption Processes, Flocculation/Precipitation, Chemical Agent Disinfection)
Set of Applicable Unit Processes


STEP 4
Select Treatment System Components
Select Hydrologic Controls For Volume and Flow Reduction
Select Applicable Hydraulic Enhancements
(Energy Dissipators, Inlet Structures, Outlet Structures, Berms, Check Dams, Weirs, Sluice Gates)
Select Conventional TSCs
Primary and Secondary TSCs
(Presettling Basins, Hydrodynamic devices, Tanks and Vaults, Oil/Water Separators, Surface Filters, Biofilters, Media Filters, Ponds)
Select Applicable Tertiary Enhancements
(Soil Amendments, Microbes, Vegetated Systems, Disinfection Systems)
Set of selected Treatment System Components and Enhancements
Integrate Treatment System Components Identify Treatment Systems and Treatment System Trains
Candidate Treatment System Trains and Treatment System Alternatives


STEP 5
Conduct Practicability Assessment of Candidate Treatment Systems
(Consider: Hydraulic Performance, Water Quality Performance, Required Surface/Subsurface Space Area Requirements, Maintenance, Cost, and Aesthetics)
Selected Treatment System Alternative to be Sized and Further Evaluated


STEP 6
Design and Size Selected Treatment System
Use proposed sizing methodologies for sizing. Use proposed computer simulations for performance verification and/or prediction.
STEP 7
Formulate Performance Monitoring and Evaluation Plan
Create monitoring plan as needed and explore other performance feedback mechanisms
END
Completed Design

Pollutant Fact Sheets

Source: GeoSyntec Consultants

Copper (Cu)

Treatability and available unit operations and processes

Treatability is a function of partitioning (particulate vs. aqueous); if aqueous, treatability is a function of concentration and speciation, and if particulate-bound, treatability is a function of distribution across the gradation. Once complexed in aqueous solution, uncharged aqueous complexes (i.e. $CuCO_3$) are very difficult to remove unless precipitated or advanced unit operations such as reverse osmosis are applied. Complexation or partitioning can be reversible; particulate-bound Cu can be a chronic threat especially in a cyclic redox environment. Cu can partition to both the aqueous and particulate phases as a function of rainfall-runoff chemistry, hydrodynamics and residence time.

The important forms of copper from a treatability and regulatory perspective are total, dissolved, and particulate-bound copper. If bound to organic or inorganic particles, viable unit operations include sedimentation and filtration either as separate unit operations or in combination with coagulation/flocculation as pre-treatment to these operations. If present as a complex, precipitation can be effective. If present as an ionic species such as Cu^{2+}, then surface complexation (including adsorption) can be effective.

Form	Unit Operation or Process
Particulate-bound	Sedimentation, filtration, coagulation-flocculation
Dissolved	Adsorption, surface complexation, ion exchange, precipitation

Description and properties

Copper is a reddish-brown, odorless metal which becomes dull when exposed to air. It is malleable, ductile, and an excellent conductor of heat and electricity, being second only to silver in terms of its high conductivity. Common forms in surface waters include complexes with organics (CuDOM), carbonate ($CuCO_3$), hydroxide ($CuOH^+$), sulfates ($CuSO_4$), , and dissolved ionic forms (Cu^{2+}), and (and to lesser degrees, Cu^+ and depending on Cl levels, CuCl where this species can become significant in coastal areas and areas subject to road de-icing salts containing chlorides). The relative percentages of these species are a function of rainfall-runoff chemistry and to a lesser degree hydrology. Of these, complexes with organics (CuDOM) and carbonate ($CuCO_3$) are predominant in urban rainfall-runoff.

Species	Molecular weight	Specific gravity	Solubility (g/100ml)
Cu (metal)	63.6	9.0	Solid metal
$CuCO_3$	187.1	4.4	Variable
$CuSO_4$	159.6	3.6	75.4
CuCl	99.0	4.1	0.0062

Natural sources

Copper is a common element, naturally occurring in rocks, soil, waters, plants, animals, and humans. Besides small amounts of metallic copper, copper is found as sulfide or oxide ores.

Point sources

Emissions to air, soil and water may result from mining and primary extraction processes (mineral processing, smelting, electrolytic processing, leaching and solvent extraction), and from manufacturing of products using and/or containing copper (electrical goods, pipes, alloys, etc.).

Diffuse sources and consumer products containing copper

Diffuse sources include agricultural and commercial applications, gardening applications, leaching from paint on vessels and infrastructure. Automobile brakes generate abraded copper metal or alloyed copper during their normal use, contributing to copper metal in dry or wet deposition. Consumer products containing copper include coins, cigarettes, jewelry, electrical appliances, cookware, some unwashed agricultural products, some commercial gardening products, some vitamin / mineral dietary supplements, and treated wood products.

Environmental fate and transport

Copper can partition to particles and organic matter, but can also be largely dissolved (ionic and complexed) in urban rainfall-runoff depending on rainfall-runoff chemistry, other species and residence time. Re-partitioned particulate-bound copper is distributed across the particle-size gradation. Copper can be transported as particles released into the atmosphere or as dissolved compounds in natural waters. Soluble and free ionic copper are easily taken up by plants. Finely-abraded metallic Cu or Cu-alloy particles are subject to aerodynamic and waterborne transport. Once contacted by poorly-buffered and acidic rainfall or runoff these finely-abraded particles undergo leaching and dissolution. Copper in soils can precipitate with hydroxide, phosphate, carbonate, and silicate to become a component of the amorphous fraction of soil. It can also be adsorbed on the negatively charged sorption sites of clay minerals and Cu can form both soluble and insoluble complexes with components of soil organic matter.

Aquatic toxicity

Low pH, soft water, and high temperatures are known to increase toxicity of copper. Mixtures of copper and zinc are known to be additive or synergistic in toxicity to many aquatic organisms. The freshwater and saltwater criteria for dissolved copper are shown below.

CTR Criteria*	Freshwater (100 mg/L hardness)	Saltwater
Acute (instantaneous maximum)	13 µg/L	4.8 µg/L
Chronic (4-day average)	9.0 µg/L	3.1 µg/L

* California Toxics Rule, Federal Register May 2000

Ongoing Project: International Stormwater BMP Database (03-SW-1CO)

- Coalition
  - WERF, ASCE-EWRI, APWA, FHWA, EPA
- Co-PIs
  - Jon Jones, WWE
  - Eric Strecker, GeoSyntec Consultants
- Will Add 30-40 New Datasets in 2005
- Will Develop Protocols to Add LID
- www.bmpdatabase.org

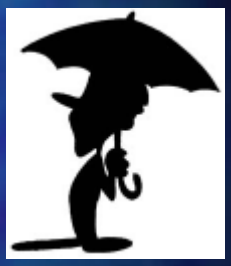
WERF
ASCE
EWRI
EPA
U.S. Department of Transportation
Federal Highway Administration
APWA

WERF Stormwater Research: Other Ongoing Projects

- Risk Assessment of Stormwater Microorganisms (03-SW-2)
- Protocols for Studying Wet-Weather Impacts of Urbanization Patterns (03-WSM-3)
- Decentralized Stormwater Controls for Urban Retrofit and CSO Reduction (03-SW-3)
- Managing Stormwater: Trade-offs Between Infiltration and Discharges to Surface Waters (03-SW-4)

WERF Stormwater Research: New Projects

- Successful Integration of Stormwater BMPs into the Urban Landscape (04-SW-1)
- Improved Monitoring Methods for Stormwater-borne Solids (04-SW-4)



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- WERF will continue to identify and prioritize key stormwater research needs, develop and enhance its strategic research plan, and conduct research to address the needs through its stormwater program.
- Information all projects is available at: www.werf.org.
- For information on joining WERF, contact Jane Knecht: jknecht@werf.org, 703-684-2470
- For more information the Stormwater Program, contact Jeff Moeller: jmoeller@werf.org, 703-684-2461