Urban Stormwater Management in the United States

Water Science and Technology Board
National Research Council

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Statement of Task

- ❖ Clarify the mechanisms by which pollutants in stormwater discharges affect ambient water quality criteria and define the elements of a “protocol” to link pollutants in stormwater discharges to ambient water quality criteria.
- ❖ Consider how useful monitoring is for both determining the potential of a discharge to contribute to a water quality standards violation and for determining the adequacy of Stormwater Pollution Prevention Plans (SWPPPs).
- ❖ Assess and evaluate the relationship between different levels of SWPPP implementation and in-stream water quality, considering a broad suite of stormwater controls.
- ❖ Make recommendations for how to best stipulate provisions in stormwater permits to ensure that discharges will not cause or contribute to exceedances of water quality standards.
- ❖Assess the design of the stormwater permitting program.

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Committee on Reducing Stormwater Discharge Contributions to Water Pollution

Claire Welty, *Chair*, University of Maryland, Baltimore County
Lawrence E. Band, University of North Carolina
Roger Bannerman, Wisconsin Department of Natural Resources
Derek B. Booth, Stillwater Sciences, Inc.
Richard R. Horner, University of Washington
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Xavier Swamikannu, CalEPA, Los Angeles Regional Water Board
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William E. Wenk, Wenk Associates, Inc.

Laura A. Ehlers, NRC Study Director
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Committee Meetings/Presentations

Jenny Molloy, Linda Boornazian, and Mike Borst, EPA
City of Austin
King County, Washington, and the City of Seattle
Irvine Ranch Water District
Chris Crockett, City of Philadelphia Water Department
Pete LaFlamme and Mary Borg, Vermont DEC
Michael Barrett, University of Texas at Austin
Roger Glick, City of Austin
Michael Piehler, UNC Institute of Marine Sciences
Keith Stolzenbach, UCLA
Steve Burges, University of Washington
Wayne Huber, Oregon State University
Don Theiler, King County
Charlie Logue, Clean Water Services, Hillsboro, Oregon
Don Duke, Florida Gulf Coast University
Mike Stenstrom, UCLA
Gary Wolff, California Water Board
Paula Daniels, City of Los Angeles Public Works
Mark Gold, Heal the Bay
Geoff Brosseau, California Stormwater Quality Association
Steve Weisberg, Southern California Coastal Water Research Project
Chris Crompton, Southern California Stormwater Monitoring Coalition
David Beckman, NRDC
Eric Strecker, GeoSyntec

Washington, DC
Austin, TX
Seattle, WA
Irvine, CA
Washington, DC
Woods Hole, MA
January 22, 2007-
September 30, 2008

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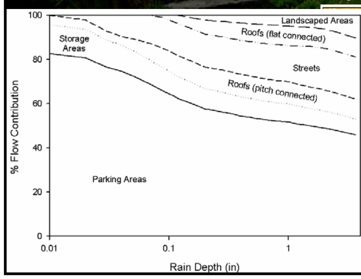
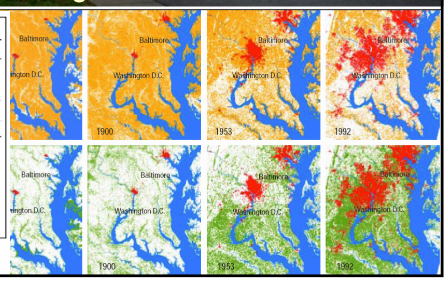
Stormwater Facts

- It is produced from everywhere in a *developed* landscape during storms (i.e., episodic)
- It accumulates and transports much of the collective waste of the urban environment
- U.S. population is growing at an annual rate of 0.9%. Urban land areas are growing even faster





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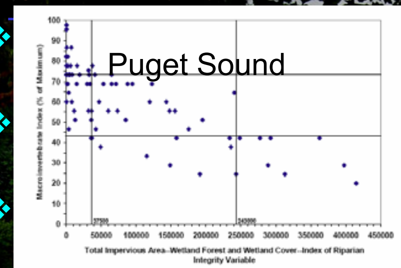
Stormwater Facts



- Developed land use has increased from 0.43 to 0.49 acres/person between 1982 and 1997
- Urban stormwater is the "primary" source of impairment for 13 percent of assessed rivers, 18 percent of assessed lakes, and 32 percent of assessed estuaries

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Stormwater Facts

- It is produced from everywhere in a *developed* landscape during storms (i.e., episodic)
- It accumulates ... ive waste of the ur...
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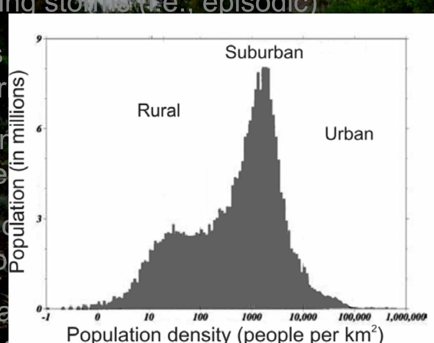

- Urban areas just 3 percent of the land mass of U.S.

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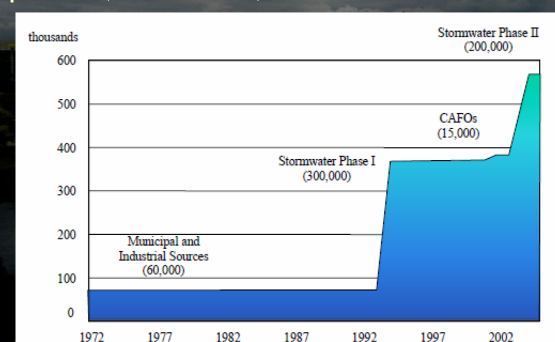
Federal Regulations, State Programs, and Local Codes (Chapter 2)

- EPA Stormwater Program: ~500,000s permits for municipalities, industries, construction



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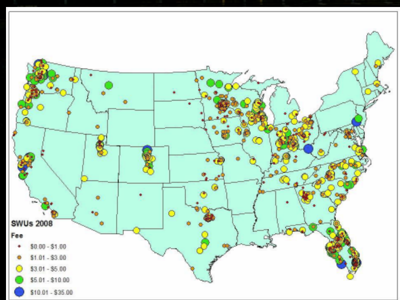
Federal Regulations, State Programs, and Local Codes (Chapter 2)

❖ EPA Stormwater Program: 100,000s permits for municipalities, industries, construction

❖ Committee survey to better understand monitoring requirements, compliance, staffing, etc.



Distribution of stormwater utility fees, $/capita/month (Western Kentucky University Stormwater Utility Survey, Campbell and Back 2008)

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Federal Regulations, State Programs, and Local Codes (Chapter 2)

❖ EPA Stormwater Program: 100,000s permits for municipalities, industries, construction

❖ Committee survey to better understand monitoring requirements, compliance, staffing, etc.

❖ Land management: zoning, local ordinances, and engineering standards

❖ Limitations of the Stormwater Program
- ❖ Regulating nonpoint sources with point source program
- ❖ Dilemma of self monitoring
- ❖ No regulatory prioritization
- ❖ Low to no funding
- ❖ Other Acts that could supplement the SW program

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Conclusions—Regulatory Issues

❖ EPA's current approach to regulating stormwater is unlikely to produce an accurate or complete picture of the extent of the problem, nor is it likely to adequately control stormwater's contribution to waterbody impairment.

❖ Flow and related parameters like impervious cover should be considered as proxies for stormwater pollutant loading.

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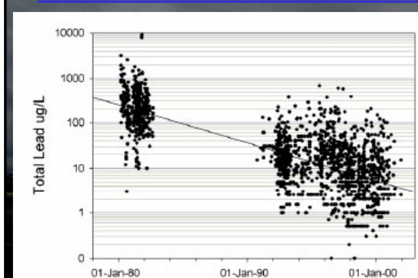
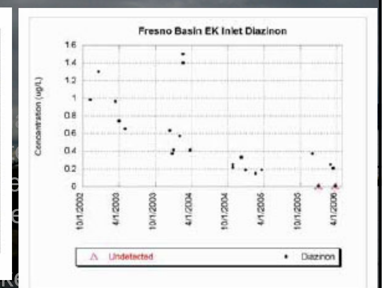
Conclusions—Regulatory Issues





be considered as proxies for stormwater pollutant loading.

❖ EPA should engage in much more vigilant regulatory oversight in the national licensing of products that contribute significantly to stormwater pollution.

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Conclusions—Regulatory Issues

TABLE 2-10 Comparison of Fiscal Year (FY) 02–03 Budget with FY 06–07 Budget for Water Quality Programs at the California EPA, Los Angeles Regional Water Board

Program	Funding Source	2002–2003	2006–2007
NPDES[1]	Federal	$2.8 mil	$2.6 mil
Stormwater	State	$2.3 mil	$2.1 mil
TMDLs	Federal	$1.47 mil	$1.38 mil
Spills, Leaks, Investigation Cleanup	State	$1.32 mil.	$2.87 mil.
Underground Storage Tanks	State	$2.78 mil.	$2.74 mil.
Non-Chapter 15 (Septics)	State	$0.93 mil.	$0.93 mil.
Water Quality Planning	Federal	$0.2 mil.	$0.21 mil.
Well Investigation	State	$1.36 mil.	$0.36 mil.
Water Quality Certification	Federal	$0.2 mil.	$0.23 mil.
Total		$17.1 mil.	$15.82 mil.

[1]The NPDES row is entirely wastewater funding, as there is no federal money for implementing the stormwater program. Note that the stormwater program in the table is entirely state funded.

- The federal government should provide more financial support to state and local efforts to regulate stormwater.

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Hydrologic, Geomorphic, and Biological Effects of Urbanization (Chapter 3)

- Urbanization has altered hydrology; waters experience radically different flow regimes than prior to urbanization
  - Loss of the water-retaining and evapotranspirating functions of the soil and vegetation in the urban landscape
- Hydrologic and geomorphic changes = Urban Stream Syndrome

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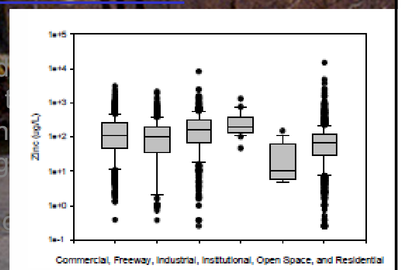
Hydrologic, Geomorphic, and Biological Effects of Urbanization (Chapter 3)



- Characteristics of stormwater, including its quantity and quality from many different land covers
- Correlative studies showing how parameters co-vary in important but complex and poorly understood ways

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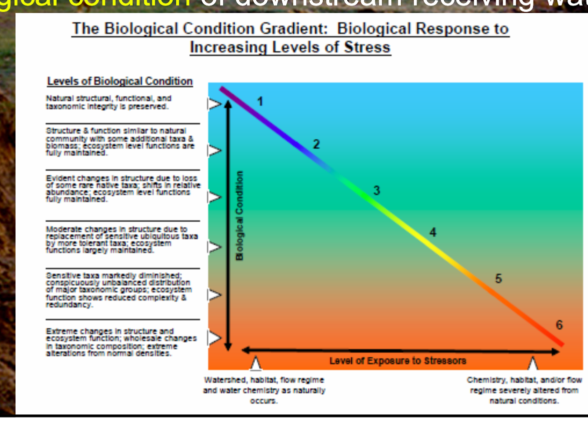
Conclusions—Effects of Urbanization

- Direct relationship between land cover and the biological condition of downstream receiving waters.



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Conclusions—Effects of Urbanization

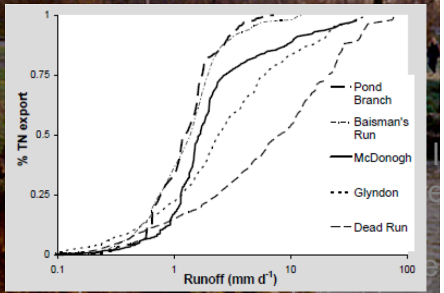
TABLE 3-3 Relative Sources of Parameters of Concern for Different Land Uses in Urban Areas

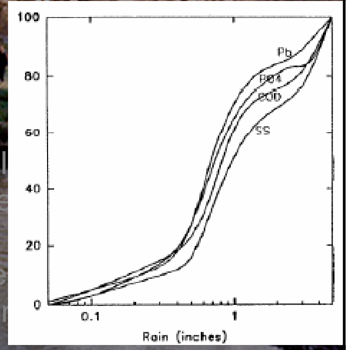
Problem Parameter	Residential	Commercial	Industrial	Freeway	Construction
High flow rates (energy)	Low	High	Moderate	High	Moderate
Large runoff volumes	Low	High	Moderate	High	Moderate
Debris (floatables and gross solids)	High	High	Low	Moderate	High
Sediment	Low	Moderate	Low	Low	Very high
Inappropriate discharges (mostly sewage and cleaning wastes)	Moderate	High	Moderate	Low	Low
Microorganisms	High	Moderate	Moderate	Low	Low
Toxicants (heavy metals and organics)	Low	Moderate	High	High	Moderate
Nutrients (eutrophication)	Moderate	Moderate	Low	Low	Moderate
Organic debris (SOD and DO)	High	Low	Low	Low	Moderate
Heat (elevated water temperature)	Moderate	High	Moderate	High	Low

NOTE: SOD, sediment oxygen demand; DO, dissolved oxygen.
SOURCE: Summarized from Burton and Pitt (2002), Pitt et al. (2008), and CWP and Pitt (2008).

❖ The protection of aquatic life in urban streams requires an approach that incorporates all stressors.

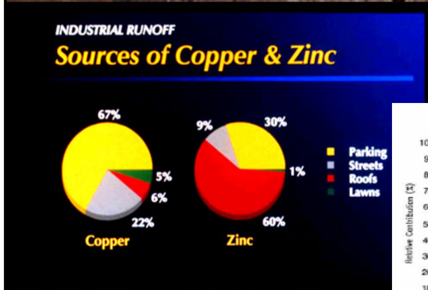
Conclusions—Effects of Urbanization

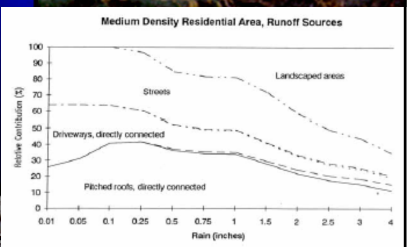




❖ The full distribution and sequence of flows (i.e., the flow regime) should be taken into consideration when assessing the impacts of stormwater on streams.

Conclusions—Effects of Urbanization





❖ Roads and parking lots can be the most significant type of land cover with respect to stormwater.

Monitoring and Modeling (Chapter 4)

❖ The monitoring requirements are variable and sparse. MS4s and particularly industrial dischargers suffer from a paucity of data and from requirements that are difficult to relate to compliance.

TABLE 2-8 Effluent Monitoring Requirements for Various Dischargers of Stormwater

Source Category	Type of Effluent Monitoring Required by EPA
Phase I MS4	Municipality must develop a monitoring plan that provides for representative data collection. This requires the municipality, at the very least, to select at least 5 to 10 of its most representative outfalls for regular sampling and sample for selected conventional pollutants and heavy metals in its effluent.
Phase II MS4	None
Small subset of highest risk industries, like hazardous waste landfills	Must conduct compliance monitoring as specified in effluent guidelines and ensure compliance with these effluent limits. Must also conduct visual monitoring and benchmark monitoring.
Larger subset of higher risk industrial dischargers	Benchmark monitoring: Must conduct analytic monitoring to determine whether effluent exceeds numeric benchmark values; compliance with the numeric values is not required, however. Must also conduct visual monitoring.
Remaining set of industry except construction	Visual monitoring: Must take four grab samples of stormwater effluent each year during first 30 minutes of a storm event and inspect the sample visually for contamination.
Construction (larger than 5 acres)	Visual monitoring: Must take four grab samples of stormwater effluent each year during first 30 minutes of a storm event and inspect the sample visually for contamination.
Construction (between 1 and 5 acres)	Visual monitoring: Must take four grab samples of stormwater effluent each year during first 30 minutes of a storm event and inspect the sample visually for contamination.

Note: State regulators can and sometimes do require more—see Appendix C.

Monitoring and Modeling (Chapter 4)

FIGURE 4-1 Sampling Locations for Data Contained in the National Stormwater Quality Database, version 3.

❖ … and sp… …argers su… …ments tha…

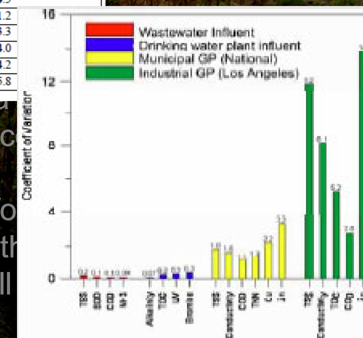
❖ Because of a 10-year effort to collect and analyze monitoring data from MS4, the quality of stormwater from urbanized areas is well characterized.

Monitoring and Modeling (Chapter 4)

TABLE 3-5 Annual Storm Drainage Mass Discharges from Toronto-Area Industrial Land Use

Measured parameter	units	annual mass discharges from industrial drainage area	stormwater annual discharge ratio (industrial compared to residential and commercial mixed area)
Runoff volume	m^3/hr/yr	6,580	1.6
total solids	kg/ha/yr	6,190	2.8
total phosphorus	kg/ha/yr	4,320	4.5
TKN	g/ha/yr	16,500	1.2
COD	kg/ha/yr	662	3.3
Cu	g/ha/yr	416	4.0
Pb	g/ha/yr	595	4.2
Zn	g/ha/yr	1,700	5.8

SOURCE: Pitt and McLean (1986).



…suffer from a paucity of data that are difficult to relate to c…

❖ Because of a 10-year effo… monitoring data from MS4, th… from urbanized areas is well…

❖ Similar effort is needed for industry to establish benchmarks and technology-based effluent guidelines.

Monitoring and Modeling (Chapter 4)

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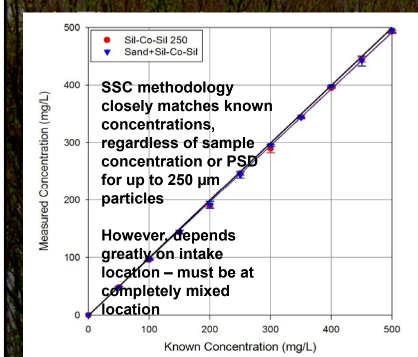


… benchmarks and techn…

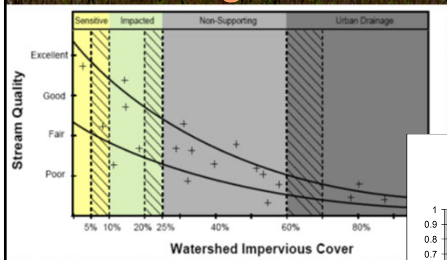
❖ Continuous, flow-weighted sampling methods best

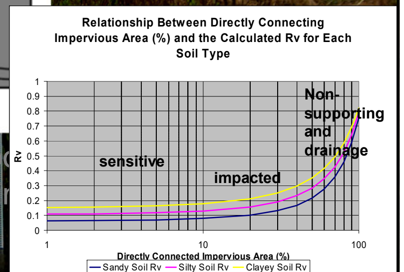
Monitoring and Modeling (Cont.)

❖ Current capability of models to link dischargers to water impairments, from simple to involved mechanistic models

Model	Common Use	Typical Scale	Complexity	Data Requirements	Ground-water	SCM	Reference
SWMM	Urban runoff, pollutant loading, hydraulic design	Small to large	Medium to complex	Land use, soil texture, meteorological time series, drainage system details, SCM type and sizing	Simple linear reservoir?	Infiltration practices, ponds, street cleaning	http://www.epa.gov/ednnmrl/models/swmm
PCSWMM	Same as above	Same as above	Same as above	Same as above	Same as above	Enhanced SCM compared to SWMM	(proprietary) http://www.computationalhydraulics.com/Software/PCSWMM.NET
WinSLAMM	Urban runoff, pollutant loads	Small to large	Intermediate	Land cover, land use, development characteristics, soil texture, compaction, rainfall event time series, monthly PET, monthly water evaporation, SCM type and sizing	Mounding under infiltration controls	Comprehensive evaluation of SCM systems	(proprietary) http://www.winslamm.com/prod01.htm
SWAT	Rural runoff, loading	Medium to watershed	Intermediate	Land cover/land use, soil texture, precipitation, temperature, humidity, solar radiation time or PET series	Simple subbasin reservoir	Impoundments, agricultural conservation practices, nutrient management, buffers	http://www.epa.gov/waterscience/BASINS/bsnsdocs.html#swat
HSPF	Comprehensive watershed evaluation, receiving water dynamics	Medium to watershed	Complex	Land cover/land use, soil texture, precipitation, temperature, humidity, solar radiation or PET time series	Subbasin reservoir	Infiltration, ponds	Bicknell et al. (2005) http://www.epa.gov/ceampubl/swater/hspf/index.htm http://www.epa.gov/waterscience/BASINS/bsnsdocs.html#hspf

Monitoring and Modeling (Cont.)





- Current capability of mo… water impairments, from s… mechanistic models
- Watershed models are useful tools for predicting some downstream impacts from urbanization and designing mitigation to reduce those impacts

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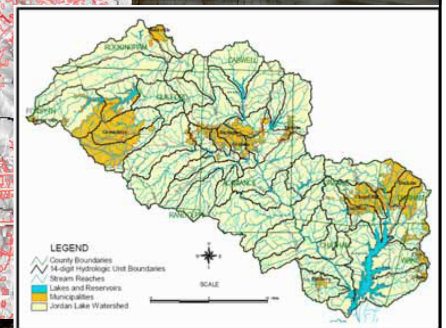
Monitoring and Modeling (Cont.)



- Difficult to assign to a source a specific contribution to impairment because of the uncertainty in the modeling and the data (including its general unavailability), the scale of the problems, and the presence of multiple stressors

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Stormwater Control Measures (SCMs) (Chapter 5)

- 20 broad categories of SCMs
  - Characteristics, applicability, goals, effectiveness, cost
- Organized as they might be applied from rooftop to stream

TABLE 5-1 Summary of Stormwater Control Measures—When, Where, and Who

Stormwater Control Measure	When	Where	Who
Product Substitution	Continuous	National, state, regional	Regulatory agencies
Watershed and Land-Use Planning	Planning stage	Watershed	Local planning agencies
Conservation of Natural Areas	Site and watershed planning stage	Site, watershed	Developer, local planning agency
Impervious Cover Minimization	Site planning stage	Site	Developer, local review authority
Earthwork Minimization	Grading plan	Site	Developer, local review authority
Erosion and Sediment Control	Construction	Site	Developer, local review authority
Reforestation and Soil Conservation	Site planning and construction	Site	Developer, local review authority
Pollution Prevention SCMs for Stormwater Hotspots	Post-construction or retrofit	Site	Operators and local and state permitting agencies
Runoff Volume Reduction—Rainwater harvesting	Post-construction or retrofit	Rooftop	Developer, local planning agency and review authority
Runoff Volume Reduction—Vegetated	Post-construction or retrofit	Site	Developer, local planning agency and review authority
Runoff Volume Reduction—Subsurface	Post-construction or retrofit	Site	Developer, local planning agency and review authority
Peak Reduction and Runoff Treatment	Post-construction or retrofit	Site	Developer, local planning agency and review authority
Runoff Treatment	Post-construction or retrofit	Site	Developer, local planning agency and review authority
Aquatic Buffers and Managed Floodplains	Planning, construction and post-construction	Stream corridor	Developer, local planning agency and review authority, landowners
Stream Rehabilitation	Postdevelopment	Stream corridor	Local planning agency and review authority
Municipal Housekeeping	Postdevelopment	Streets and stormwater infrastructure	MS4 Permittee
Illicit Discharge Detection and Elimination	Postdevelopment	Stormwater infrastructure	MS4 Permittee
Stormwater Education	Postdevelopment	Stormwater infrastructure	MS4 Permittee
Residential Stewardship	Postdevelopment	Stormwater infrastructure	MS4 Permittee

Note: Nonstructural SCMs are in italics.

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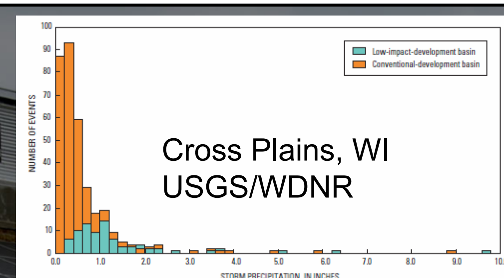
Stormwater Control Measures (Chapter 5)



- Case studies illustrates SCMs in specific settings; a particular SCM can have a measurable positive effect on water quality or a biological metric

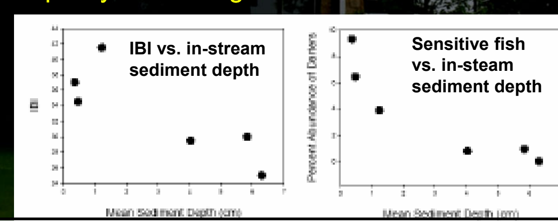


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TABLE 5-7 Applicability of Stormwater Control Measures by Type of Development

Stormwater Control Measure	Low-Density Greenfield Residential	Urban Redevelopment	Intense Industrial Redevelopment
Product Substitution	○	●	●
Watershed and Land-Use Planning	■	■	○
Conservation of Natural Areas	■	♦	○
Impervious Cover Minimization	■	♦	♦
Earthwork Minimization	■	♦	♦
Erosion and Sediment Control	■	■	■
Reforestation and Soil Conservation	■	●	●
Pollution Prevention SCMs	♦	●	■
Runoff Volume Reduction—Rainwater Harvesting	■	■	●
Runoff Reduction—Vegetated	■	○	●
Runoff Reduction—Subsurface	■	○	♦
Peak Reduction and Runoff Treatment	■	♦	○
Runoff Treatment	●	●	■
Aquatic Buffers and Managed Floodplains	●	♦	○
Stream Rehabilitation	○	♦	♦
Municipal Housekeeping	○	○	NA
IDDE	○	○	○
Stormwater Education	●	●	●
Residential Stewardship	■	●	NA

NOTE: ■, always; ●, often; ○, sometimes; ♦, rarely; NA, not applicable.

- Enough is known to design systems of SCMs, on a site-scale or local watershed scale, that can substantially reduce the effects of urbanization
  - watershed: Greenfields, redevelopment, intense industrial

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Conclusions—SCMs

- Nonstructural SCMs (product substitution, better site design, downspout disconnection, conservation of natural areas) can dramatically reduce the volume of runoff and pollutant loading from a new development
- SCMs that harvest, infiltrate, evapotranspirate stormwater are critical to reducing volume/pollutant loading of small storms
- Performance characteristics are needed for some structural and most nonstructural SCMs
- Retrofitting: unique opportunities/challenges.

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Conclusions—SCMs

- Combinations of controls are needed in treatment train arrangements, from small sites to large watersheds.
- It is not possible to infiltrate all of the runoff, and treatment is needed to reduce contaminated discharges during larger events. Energy must also be reduced during large events to prevent stream degradation.
- Critical source area controls are needed to pre-treat stormwater before infiltration to protect groundwater in most commercial and industrial areas.

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Stormwater Permitting (Chapter 6)

Base all stormwater and other wastewater discharge permits on watershed boundaries instead of political boundaries

- Responsibility and authority for implementation of watershed-based permits: municipal lead permittee working in partnership with other municipalities in the watershed as co-permittees
- Avoid further degradation of designated beneficial uses
- Impact source analysis/Aquatic Resources Conservation Design
- New monitoring program structured to assess progress toward meeting objectives
- Market-based trading of credits among dischargers to achieve overall compliance in efficient manner and adaptive management
- Pilot program: work through some of the more predictable impediments to watershed-based permitting

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Stormwater Permitting (Cont.)

- Integration of the three permitting types, such that construction and industrial sites come under the jurisdiction of their associated municipalities (pretreatment program)
- To improve the industrial, construction, and MS4 permitting programs in their current configuration, EPA should:
  - issue guidance on what constitutes a design storm for water quality purposes
  - issue guidance on methods to identify high-risk industries for program prioritization such as inspections
  - develop numerical expressions of MS4 standard of MEP

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Stormwater Permitting (Cont.)

TABLE 6-2 Expectations for Different Urban Subwatershed Classes

Lightly Impacted Subwatersheds (1 to 5% IC)	• Consistently attain scores for specific indicators for hydrology, biodiversity, and geomorphology that are comparable to streams whose entire subwatersheds are fully protected in a natural state (e.g., national parks). Should provide for healthy reproduction of trout, salmon, or other keystone fish species.
Moderately Impacted Subwatersheds (6 to 10% IC)	• Consistently attain scores for specific stream indicators that are comparable to the highest 10 percent of streams in a population of rural watersheds in order to maintain or restore ecological structure, function, and diversity of the streams. The "good to excellent" indicator scores for this category of subwatersheds will be the benchmark against which the relative quality of more developed subwatersheds will be measured.
Heavily Impacted Subwatersheds (11 to 25% IC)	• Consistently attain good stream quality indicator scores to ensure enough stream function to adequately protect downstream receiving waters from degradation. • Function is defined in terms of flood storage, in-stream nutrient processing, biological corridors, stable stream channels, and other factors.
Non-Supporting Subwatersheds (26 to 60% IC)	• Consistently attain "fair to good" stream quality indicator scores. • Meet bacteria standards during dry weather and trash limits during wet weather. • Maintain existing stream corridor to allow for safe passage of fish and floodwaters.
Urban Drainage Subwatersheds (61 to 100% IC)	• Maintain "good" water quality conditions in downstream receiving waters. • Consistently attain "fair" water quality scores during wet weather and "good" water scores during dry weather. • Provide clean "plumbing" in upland land uses such that discharges of sewage and toxics do not occur.

(continued for many other examples)

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Stormwater Permitting (Cont.)

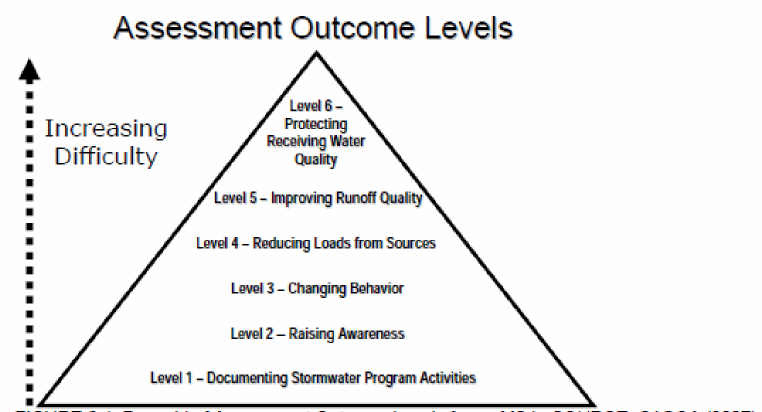

FIGURE 6-1 Pyramid of Assessment Outcome Levels for an MS4. SOURCE: CASQA (2007).

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Last Thoughts

- Enormous potential for doing good. 42% of urban land will be redeveloped by 2030
- Current program funding for wastewater much greater than for stormwater, even though there are 5 times more stormwater permitees. Additional resources for program implementation could come from shifting existing programmatic resources. However, securing new levels of public funds will likely be required.

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