Basic Stormwater Characteristics and Small Storm Hydrology

The Integration of Water Quality and Drainage Design Objectives

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Outline of Presentation

- Possible Beijing stormwater issues
- Stormwater quality characteristics
- Sources of stormwater pollutants
- First-flush of stormwater pollutants
- Beijing drainage design storms
- Urban stormwater hydrology
- Pavement hydrology
- Infiltration characteristics of compacted urban soils
- Sources of stormwater flows and pollutants; field monitoring
- TSS vs. SSC and PSD relationships
- Summary/Conclusions

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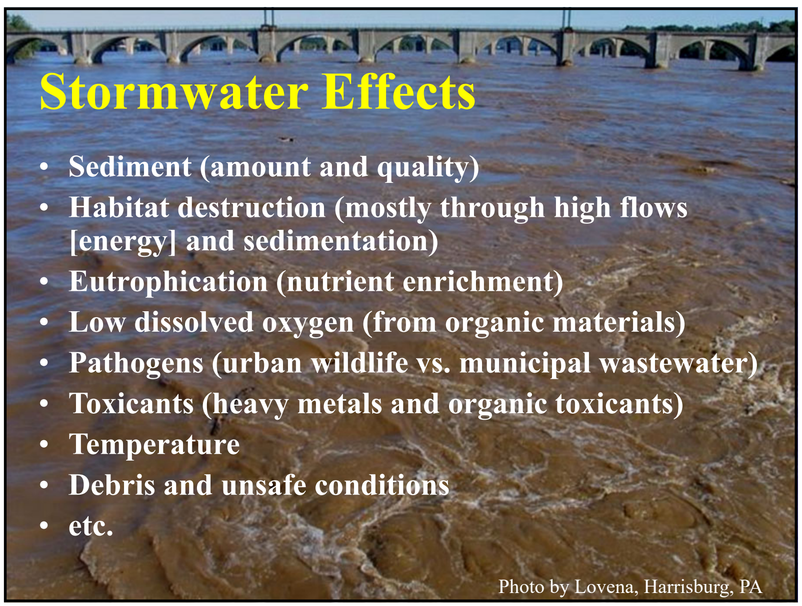

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Possible Stormwater Issues in Beijing

- High seasonal flows, long dry period
- High nutrient discharges
- First flush investigations
- Distributed infiltration to:
  - Reduce flow discharges to drainage system to reduce overflows and other drainage issues
  - Decreased discharges of nutrients to surface waters
  - Enhance water supply

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Data Origin for National Stormwater Quality Database (NSQD)

Source	Total Storms	Percentage
Phase I NPDES (MS4)	5,707	62.5
EPA's Nationwide Urban Runoff Program (NURP)	1,757	19.2
International BMP Database (influent data at outfalls)	883	9.7
Special Projects (USGS, state programs, and others)	783	8.6
TOTAL	9,130	100

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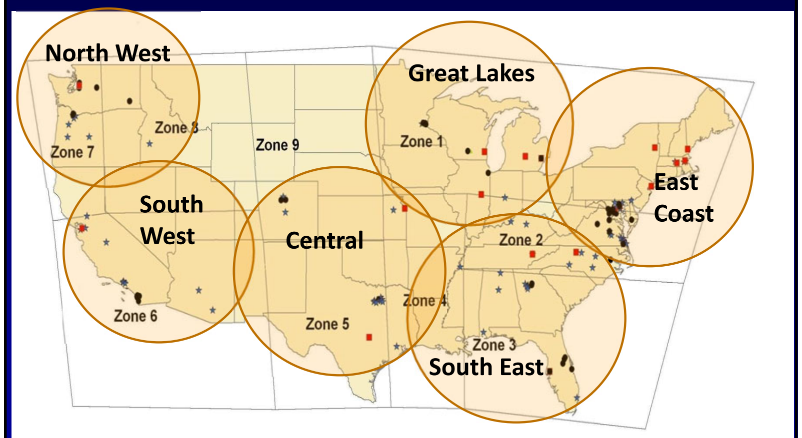
National Stormwater Quality Database by Regions



All models require calibration and verification. The NSQD data is a good place to start, but additional locally collected information is necessary for the greatest reliability.

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Constituents and Number of Observations Included in NSQD ver. 4 (having at least 50 observations; high-lighted constituents have at least 5,000 observations)

- **Total events: 9,130**
- **Precipitation depth: 5,172**
- Runoff depth: 2,591
- Hardness: 1,670
- Alkalinity: 525
- pH: 3,253
- Temperature: 1,251
- TDS, 4,158
- Conductivity: 1,517
- Chloride: 869
- Total solids: 100
- **Total suspended solids: 7,713**
- Turbidity: 936
- **BOD_5: 5,227**
- **COD: 5,290**
- DO: 192
- Fecal coliforms: 2,223
- Fecal streptococcus: 1,317
- Total coliforms: 282
- Total nitrogen: 1,213
- **Total Kjeldahl N: 7,044**
- Total organic N: 66
- Ammonia: 3,020
- Nitrate N: 1,028
- Nitrite N: 714
- **Nitrite + nitrate: 5,748**
- **Total phosphorus: 8,019**
- Filtered P: 4,051
- Ortho phosphate: 746
- Filtered ortho P: 244
- Total antimony: 1,584
- Filtered antimony: 641
- Total arsenic: 2,441
- Filtered arsenic: 770
- Total barium: 582
- Total beryllium: 1,509
- Filtered beryllium: 578
- Total cadmium: 4,105
- Filtered cadmium: 961
- Total chromium: 2,328
- Filtered chromium: 821
- **Total copper: 5,915**
- Filtered copper: 1,002
- Cyanide: 1,338
- Total iron: 608
- Filtered iron: 556
- Total lead: 363 (before 1984)
- **Total lead: 5,032 (since 1984)**
- Filtered lead: 1,016 (since 84)
- Total mercury: 1,702
- Filtered mercury: 706
- Total nickel: 2,164
- Filtered nickel: 807
- Total selenium: 1,737
- Filtered selenium: 682
- Total silver: 1,880
- Filtered silver: 766
- Total thallium: 1,423
- Filtered thallium: 653
- **Total zinc: 6,638**
- Filtered zinc: 984

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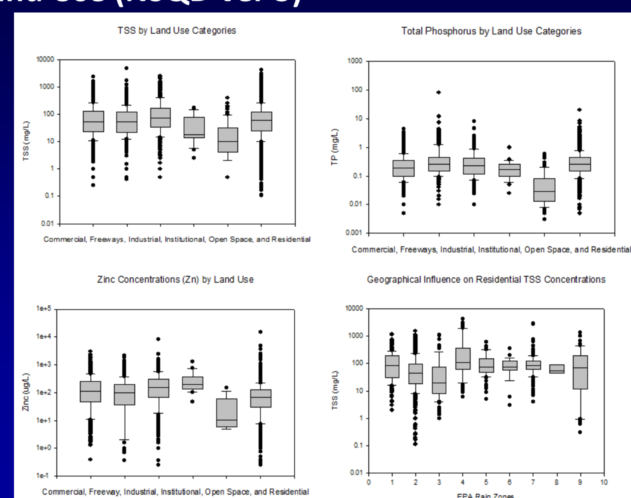
Stormwater Quality of Common Pollutants by Land Use (NSQD ver 3)



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Source Characteristics of Stormwater Pollutants

- Quality of sheetflows vary for different areas.
- Need to track pollutants from sources and examine controls that affect these sources, the transport system, and outfall.

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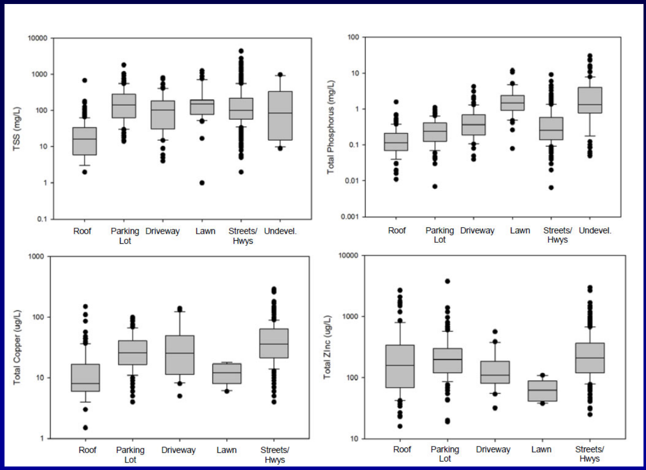
Sources of Common Stormwater Pollutants



The stormwater data collected by the Wisconsin Department of Natural Resources and the USGS between 1991 and 1997 for multiple research studies were compiled and analyzed as a single data set. The data include sampling locations at roofs, streets, driveways, parking lots, lawns, and undeveloped areas in residential, commercial, and light industrial land uses. (NRC 2015).

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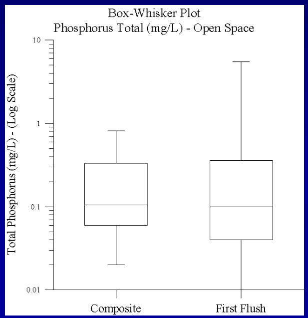
First flush analyses compared first 30 minute composite to complete storm composite samples for the 50 to 100 events in the NSQD having the data. Not all constituents or land uses exhibited first flush. Total phosphorus had significant first flush for commercial and residential areas, but not for industrial, institutional, or open space areas.



	n	Overall ratio
TSS, mg/L	90	1.85
TDS, mg/L	82	1.83
COD, mg/L	91	2.29
BOD_5, mg/L	83	1.77
Ammonia, mg/L	70	2.11
$NO_2 + NO_3$, mg/L	84	1.73
TKN, mg/L	93	1.71
P Total, mg/L	89	1.44
Cadmium Total, mg/L	74	2.15
Chromium Total, mg/L	47	1.67
Copper Total, mg/L	92	1.62
Lead Total, mg/L	89	1.65
Nickel, mg/L	47	2.4
Zinc, mg/L	90	1.93

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This investigation of first flush conditions indicated that a first flush effect was not present for all the land use categories, and certainly not for all constituents.

Commercial and residential areas were more likely to show first flushes, especially if the peak rainfall occurred near the beginning of the event.

It is expected that this effect will be more likely to occur in a watershed with a high level of imperviousness, but even so, the data indicated first flushes for less than half of the samples for the most impervious areas, most likely due to varying rain with time.

Complex drainage systems will also blend separate flows at different time steps, further obscuring first flushes.

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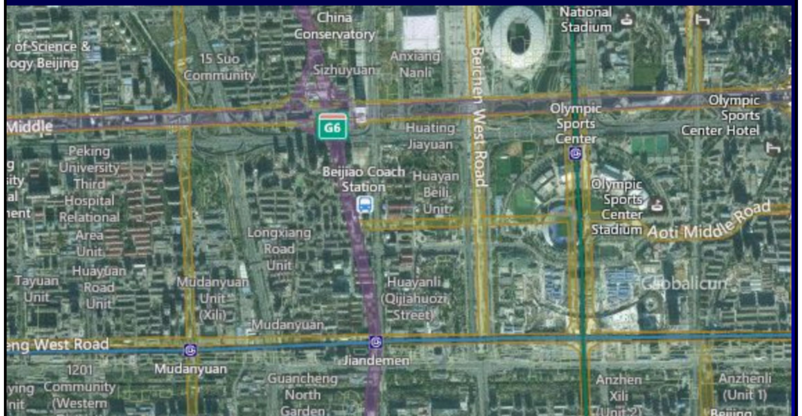
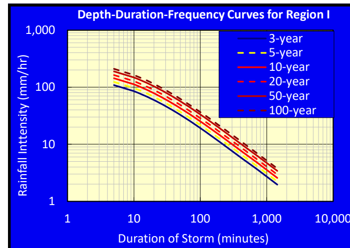
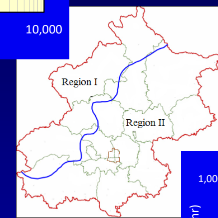
Typical Dense Urbanized Area in Central Beijing



Aerial photo from Google maps

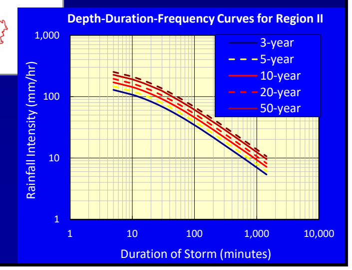


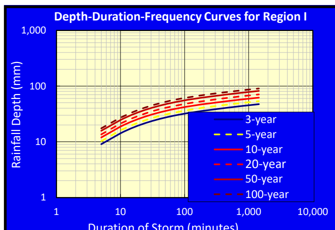
Traditional IDF design storms for design of stormwater collection systems, focusing on 3 to 100-yr reoccurring events (1 to 33% probability of occurring in any one year).



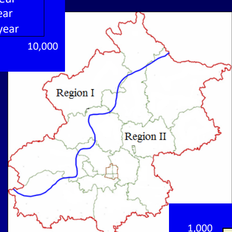
Flatter topography, lower elevations and closer to sea results in greater intensities in Region II compared to Region I, especially for longer duration events.

intensity (mm/hr) associated with:	5 yr rain frequency		20 yr rain frequency		100 yr frequency	
Beijing rain region:	1	2	1	2	1	2
short duration (5 minutes)	124	146	163	194	210	252
one hour (60 minutes)	32	54	43	72	55	92
one day (1440 minutes)	2.6	7.2	3	8.2	3.8	11

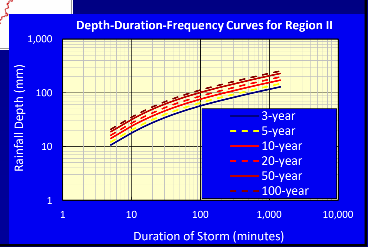




Similar plots showing rain depth vs. duration and reoccurrence interval.



rainfall depth (mm) associated with:	5 yr rain frequency		20 yr rain frequency		100 yr frequency	
Beijing rain region:	1	2	1	2	1	2
short duration (5 minutes)	10	12	14	16	18	21
one hour (60 minutes)	32	54	43	72	55	92
one day (1440 minutes)	54	148	71	197	91	254



Urban Stormwater Hydrology

- Early focus of urban stormwater was on storm sewer and flood control design using the Rational Method and TR-55 (both single event, "design storm" methods).
- The Curve Number procedure was developed in the 1950s by the (then) SCS as a simple tool for estimating volumes generated by large storm events in agricultural areas, converted to urban uses in mid 1970s (TR55 in SCS 1976). Data based on many decades of observations of large storms in urban areas, at Corps of Engineers monitoring locations. Data available from the Rainfall-Runoff database report prepared by the Univ. of Florida for the EPA.
- Water quality focus results form Public Law 92-500, the Clean Water Act, 1972. Stormwater quality research started in the late 1960s, with a few earlier interesting studies. Big push with Nationwide Urban Runoff Program (NURP) in late 70s and early 80s. Most still rely on earlier drainage design approaches. Distributed infiltration systems demonstrated in the 1960s.

Importance of Site Hydrology in the Design of Stormwater Controls

- Design of stormwater management programs requires knowledge of site hydrology
- Understanding of flows (variations for different storm conditions, sources of flows from within the drainage area, and quality of those flows), are needed for effective design of source area and outfall controls.

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Design Issues for Stormwater Quality Management

- Recognize different objectives of storm drainage systems
- Recognize associated rainfall conditions affecting different objectives
- Select appropriate tools for evaluation and design
- Example - 4 major rainfall categories for Milwaukee, WI (as monitored during NURP):
  - <0.5 in (<12 mm) (median rain by count)
  - 0.5 to 1.5 in (12 to 40 mm) (most of the runoff)
  - 1.5 to 3 in (40 to 75 mm) (few events)
  - >3 in (>75 mm) (drainage design and flooding)

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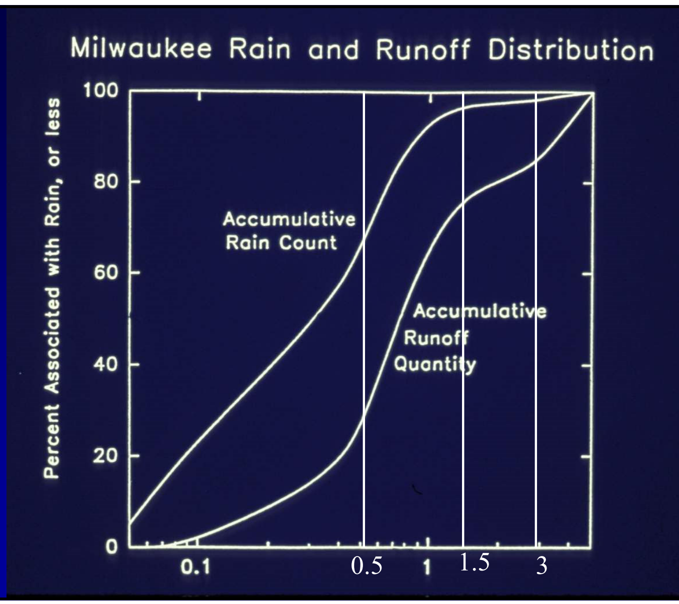

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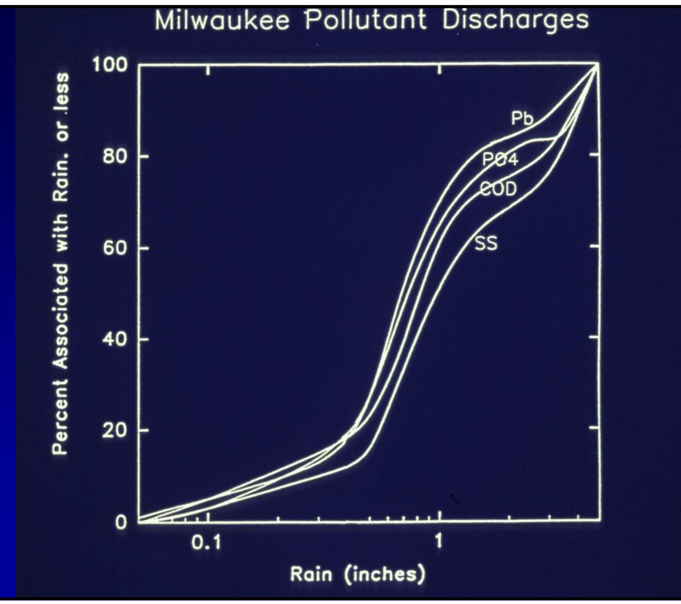

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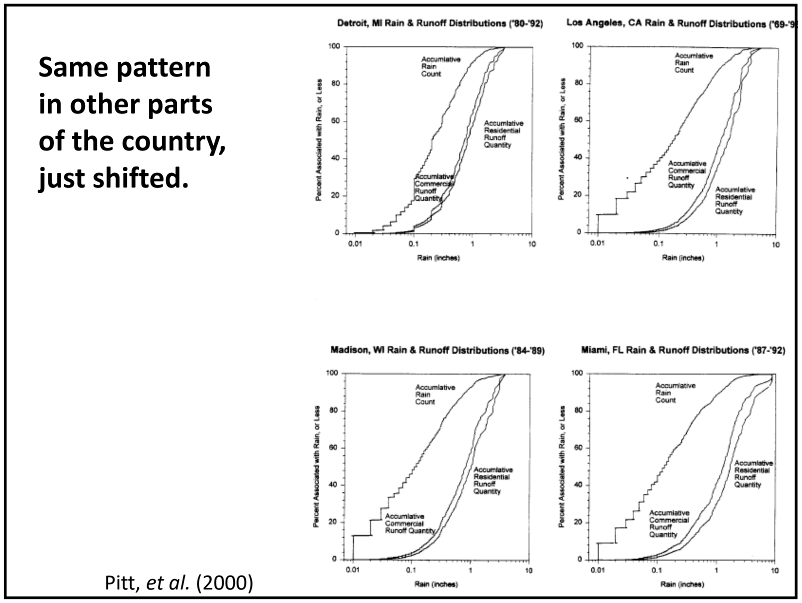
Same pattern in other parts of the country, just shifted.
Detroit, MI Rain & Runoff Distributions ('80-'92)
Los Angeles, CA Rain & Runoff Distributions ('69-'9
Madison, WI Rain & Runoff Distributions ('84-'89)
Miami, FL Rain & Runoff Distributions ('87-'92)
Pitt, et al. (2000)

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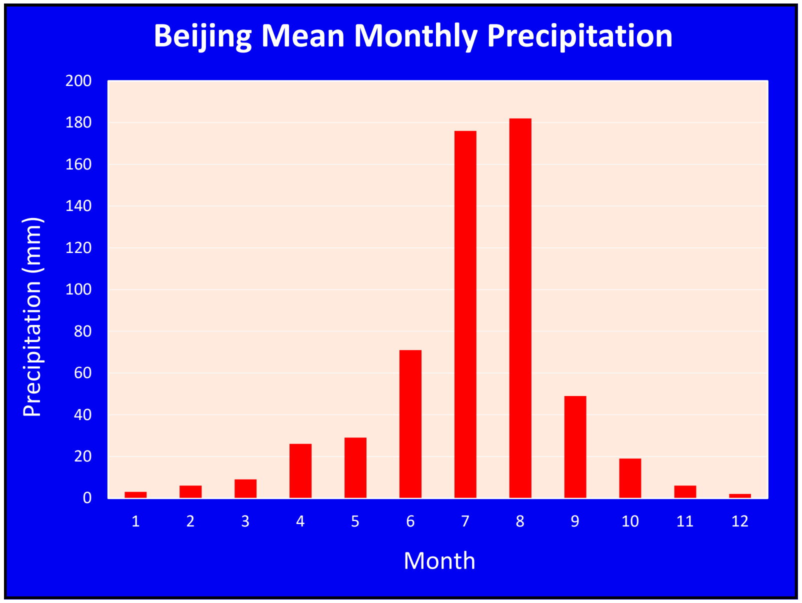
Beijing Mean Monthly Precipitation
Precipitation (mm)
Month

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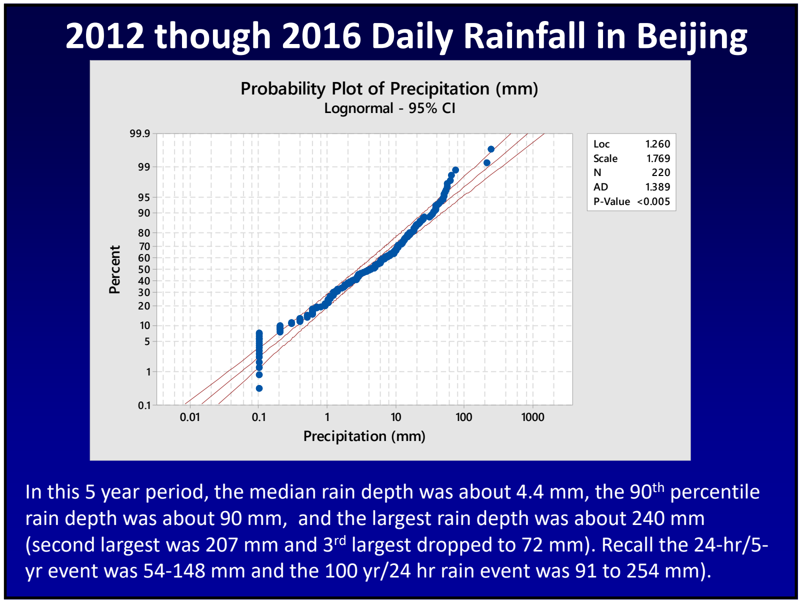
2012 though 2016 Daily Rainfall in Beijing
Probability Plot of Precipitation (mm)
Lognormal - 95% CI
Percent
Precipitation (mm)
Loc 1.260
Scale 1.769
N 220
AD 1.389
P-Value <0.005
In this 5 year period, the median rain depth was about 4.4 mm, the 90th percentile rain depth was about 90 mm, and the largest rain depth was about 240 mm (second largest was 207 mm and 3rd largest dropped to 72 mm). Recall the 24-hr/5-yr event was 54-148 mm and the 100 yr/24 hr rain event was 91 to 254 mm).

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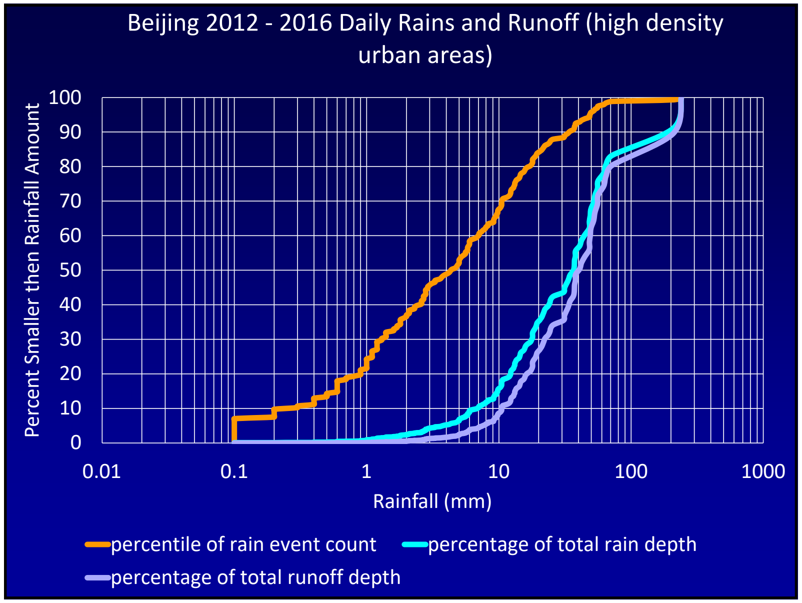
Beijing 2012 - 2016 Daily Rains and Runoff (high density urban areas)
Percent Smaller then Rainfall Amount
Rainfall (mm)
percentile of rain event count
percentage of total rain depth
percentage of total runoff depth

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Importance of Small and Intermediate Sized Rains

	Beijing 2012 through 2016 rains
% of rain events <10 mm depth:	70%
Rain depth associated with 10% of annual runoff:	<10 mm
Rain depth associated with 50% of annual runoff:	<40 mm
Rain depth associated with 80% of annual runoff:	<70 mm

Large rains >70 mm therefore contributed about 20% of the annual runoff for this 5 year monitoring period (unusually large?)

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Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.

2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

The SCS (NRCS) curve number method presented in TR-55 (and also used in WinTR-55 and many stormwater models) is the most common urban hydrology method used in the US. Typical curve number (CN) values for urban areas are shown on this table from TR-55. The same curve number is used for all storms in a given area.

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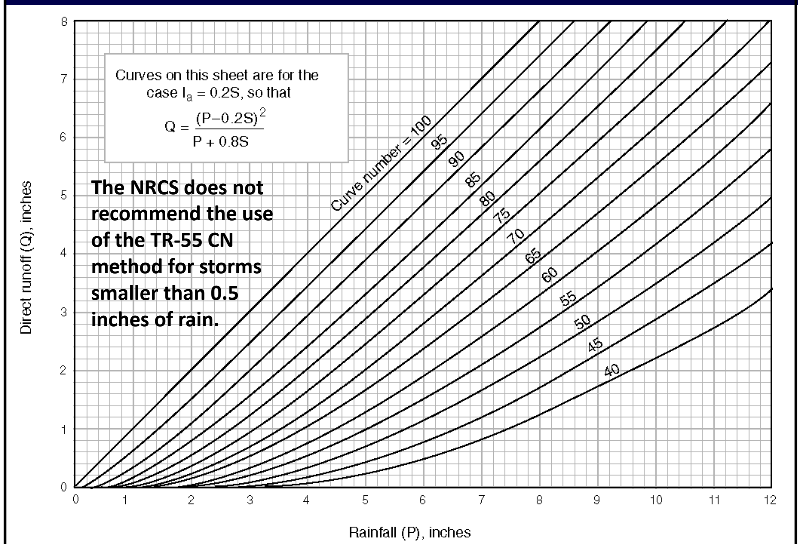
SCS (NRCS) TR-55 Curve Number Model of Rainfall vs. Runoff



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The following equation can be used to calculate the actual NRCS curve number (CN) from observed rainfall depth (P) and runoff depth (Q), both expressed in inches:

$$CN = 1000/[10+5P+10Q-10(Q^2+1.25QP)^{1/2}]$$

The following example plots use rainfall and runoff data from the EPA's NURP projects in the early 1980s (EPA 1983), and from the EPA's rainfall-runoff-quantity data base (Huber, *et al.* 1982).

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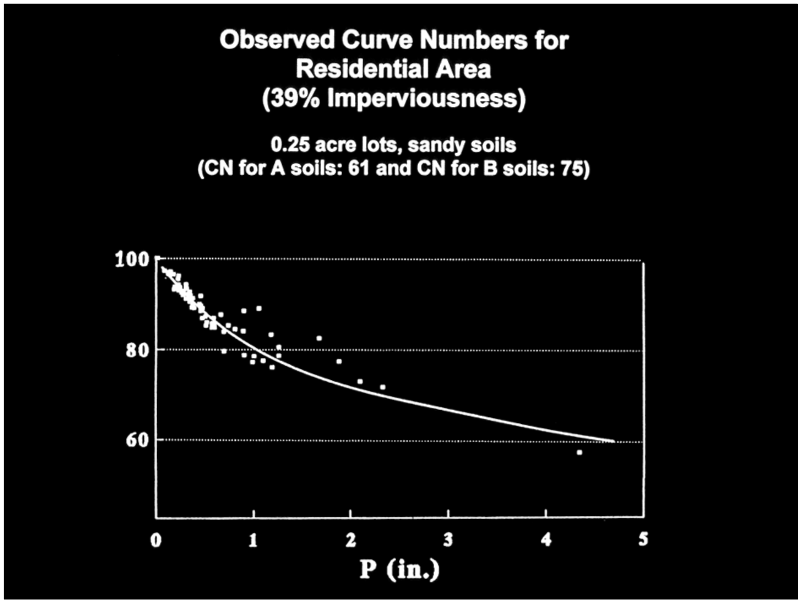

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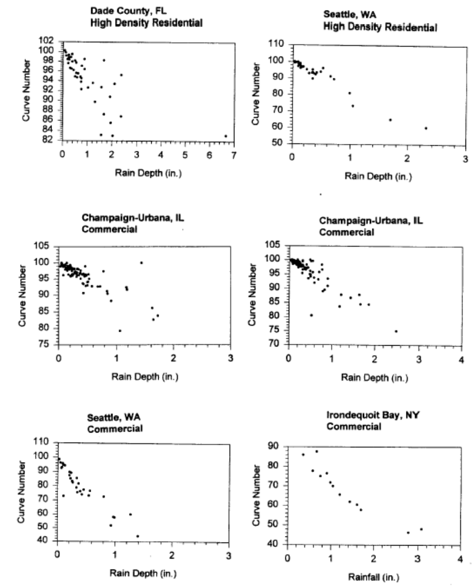
High Density Residential Sites



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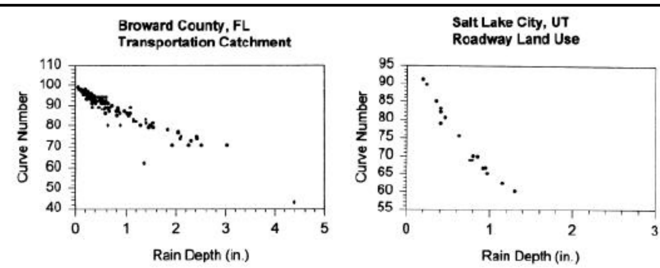
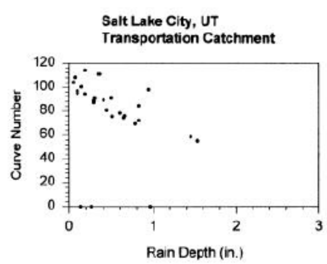


Highway Sites



Actual runoff relationships do not follow the commonly used NRCS curve number method. For small and intermediate rains, the actual curve numbers are much higher than the table values in TR-55 and only reach those assumed constant CN values as the rain depth approaches drainage design storm depths (as intended when the method was developed).

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Knowing the Runoff Volume is the Key to Estimating Pollutant Mass

- There is usually a simple relationship between rain depth and runoff depth.
- Changes in rain depth affect the relative contributions of runoff and pollutant mass discharges:
  - Directly connected impervious areas contribute most of the flows during relatively small rains
  - Disturbed urban soils may dominate during larger rains

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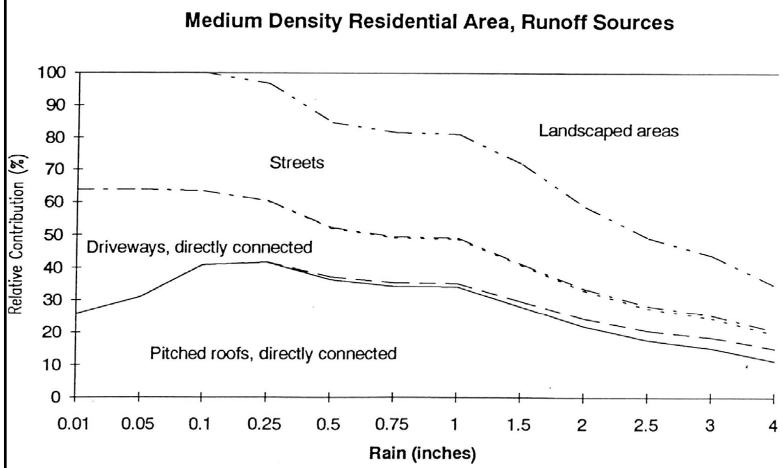
Example (varies for different development characteristics)



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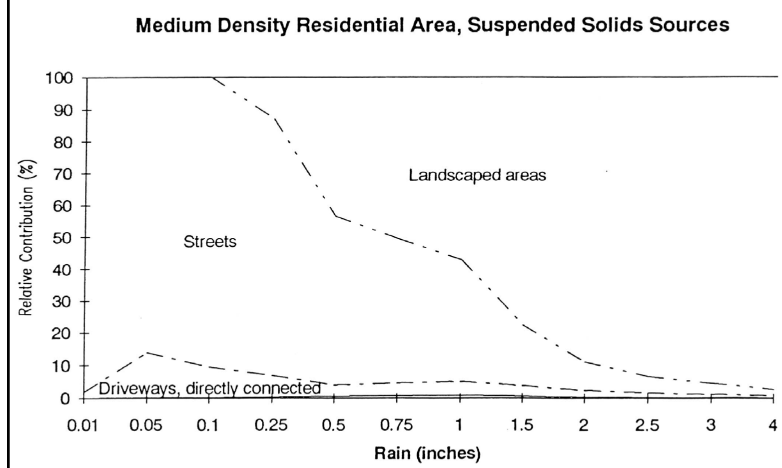
Example (varies for different development characteristics)



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Pavement Hydrology

Monitoring was conducted at many different scales, from several hectare isolated paved parking areas (and roofs) to smaller controlled areas.

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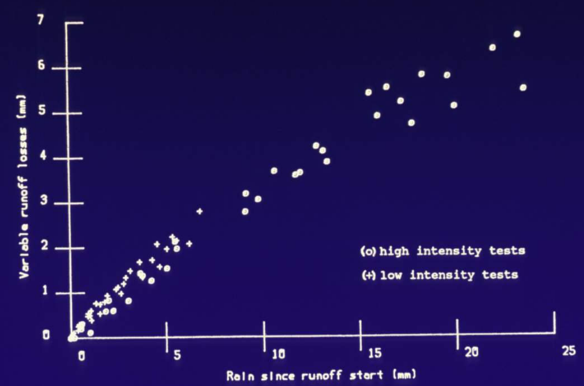
Variable Runoff Losses by Rain Depth



Significant infiltration observed at urban roadways for small rains. Maximum infiltration losses were about 10 mm (not important for large drainage design storms, but can be large fraction of smaller rains).

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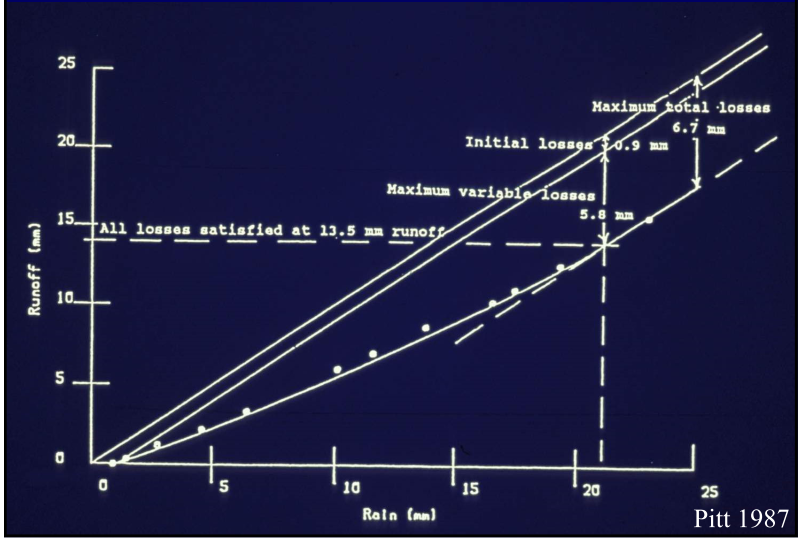
Runoff response curve for typical residential street, Toronto



Pitt 1987

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Pavement infiltration tests along interstate highway, Alabama. Test sites also had moisture sensors under the pavement and tipping-bucket rain gages (and extensive road safety!).

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Highway pavement test sections undergoing laboratory percolation tests (very little infiltration observed for these dense and thick pavements).

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Infiltration Characteristics in Compacted Urban Soils

Tests were conducted at many different scales at non-paved areas also.

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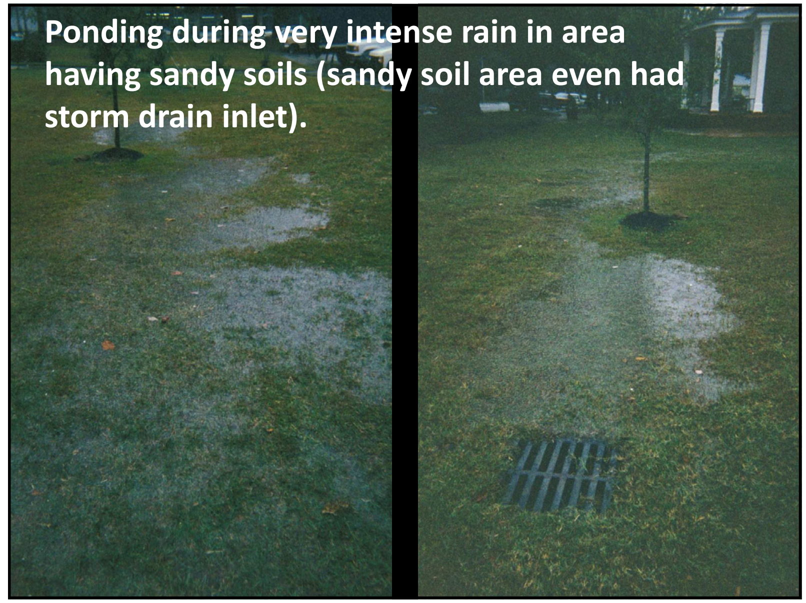

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Disturbing urban soils during land development totally mess up the natural soil structure

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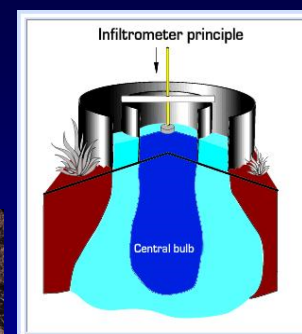
One type of infiltration test: Double-Ring Infiltrometer – ASTM D3385 (we typically have used clusters of small Turf-Tec double-ring infiltrometers to measure local variability)



Currently we rely more on larger trench and borehole tests that have less edge effects and better correspond to conditions that occur during actual rains.

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Soil modifications can result in greatly enhanced infiltration in marginal soils.

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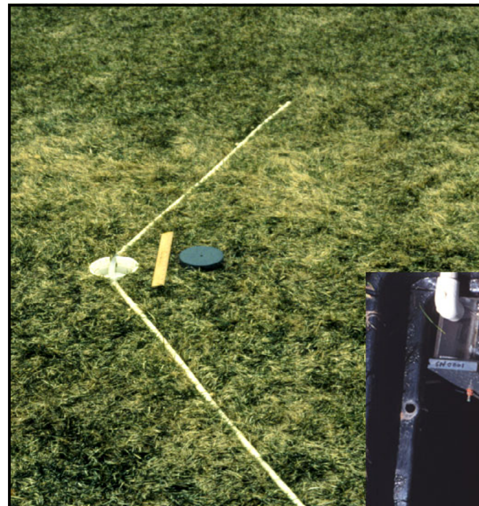
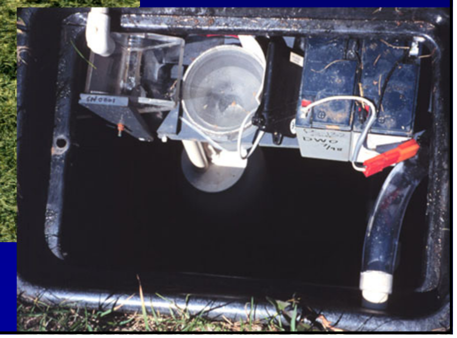


Direct measurements of turf runoff for different soil conditions during rains.



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Field Infiltration Tests

- Previous research identified significant reductions in infiltration rates in disturbed urban soils.
- More than 150 tests were conducted in predominately sandy and clayey urban soils in the Birmingham and Mobile, Alabama, areas.

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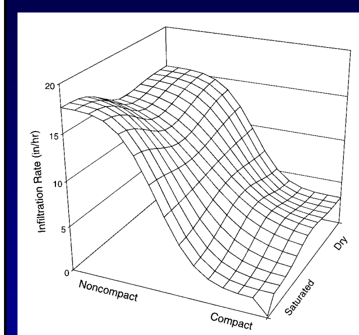
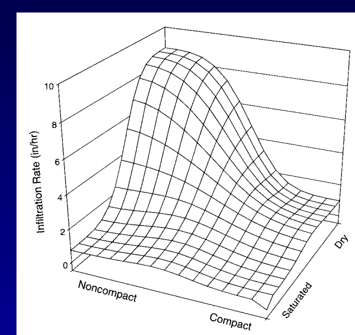
Infiltration Rates in Disturbed Urban Soils (AL tests)



Sandy Soils



Clayey Soils

Infiltration rates of urban soils are more strongly influenced by compaction than by moisture for sandy soils and by both compaction and moisture in clayey soils.

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Infiltration Rates during Tests of Disturbed Urban Soils

	Number of tests	Average infiltration rate (mm/hr)	COV
Noncompacted sandy soils	36	330	0.4
Compacted sandy soils	39	36	1.3
Noncompacted and dry clayey soils	18	250	1.5
All other clayey soils (compacted and dry, plus all wetter conditions)	60	5	2.4

49

Laboratory Infiltration Rate Tests for Different Soil Mixtures and Compaction

- These lab tests were run for up to 20 days, although most were completed (when steady low rates were observed) within 3 or 4 days.
- Initial soil moisture levels were about 8% (sand was about 3%), while the moisture levels after the tests ranged from about 20 to 45%.
- Three methods were used to compact the test specimens: hand compaction, plus two Proctor test methods.
- Both Modified and Standard Proctor Compactions follow ASTM standard (D 1140-54).

50

Laboratory Column Tests

The media layer was about 0.5 m (1.5 ft) thick.

Four liters of challenge water was poured into each lab column that was filled with one of the media mixtures. Clean water was used for the flow test.

The surface ponding depths in the columns ranged between 28 cm (11 in.) and 36 cm (14 in.) to correspond to the approximate maximum ponding depths at biofilters.

Effluent samples were collected from the bottom of the columns at the beginning, middle, and end of the drainage time and composted in clean 1 L bottles for the lab analyses.

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Compaction Methods

- Hand compaction (gentle hand pressing to force the soil into the column section with as little compaction as possible),
- Standard Proctor Compaction (24.4 kN hammer dropped 25 times form 300 mm on each of 3 soil layers).
- Modified Proctor Compaction (44.5 kN hammer dropped 25 times from 460 mm on each of 5 soil layers).

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15 Test Mixtures used in Laboratory Tests

	Sand	Clay	Silt	Sandy loam	Clayey loam	Silty loam	Clay mix
% sand	100			72.1	30.1	19.4	30
% clay		100		9.2	30.0	9.7	50
% silt			100	18.7	39.9	70.9	20

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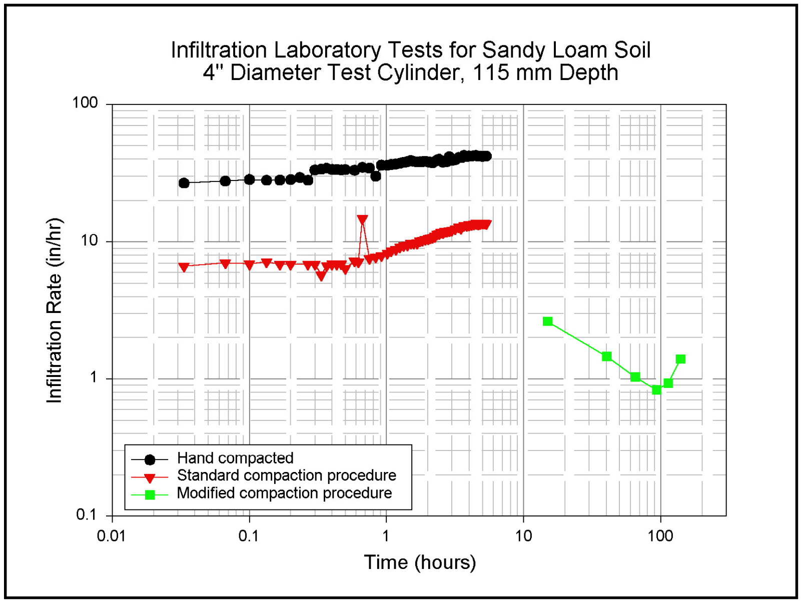

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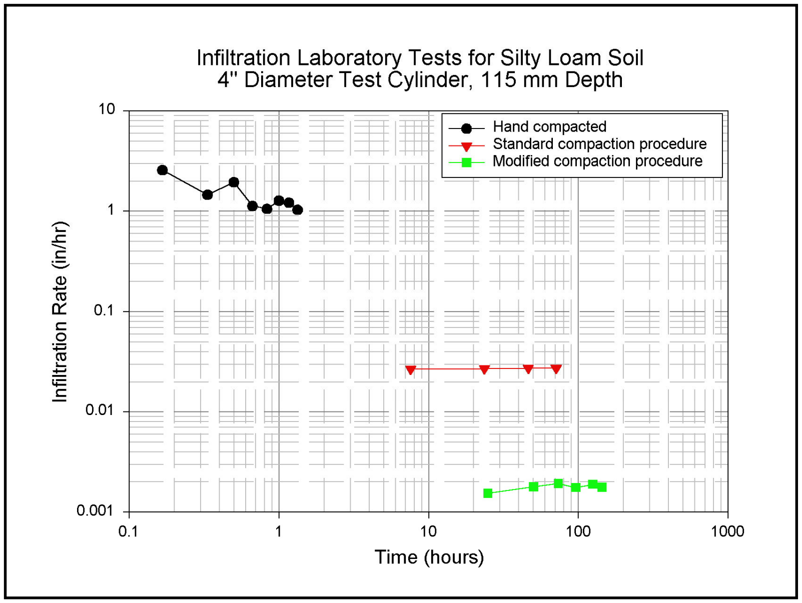

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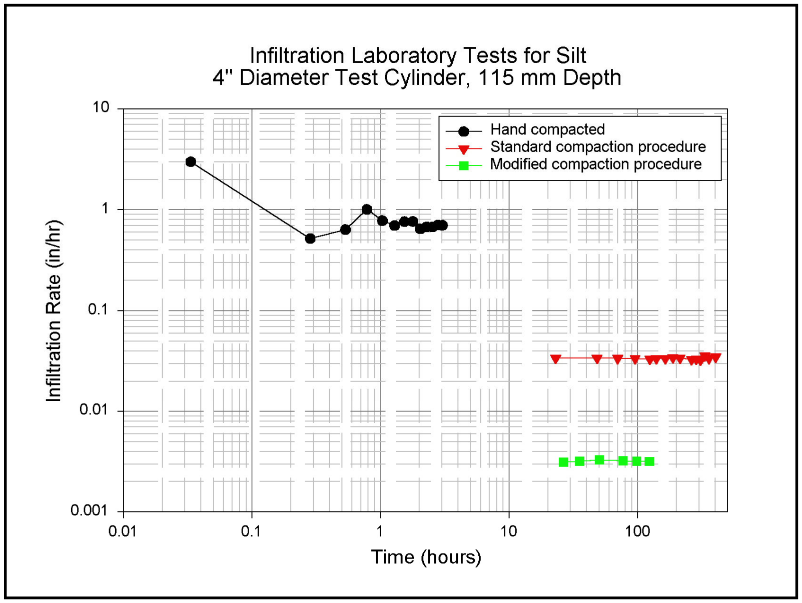

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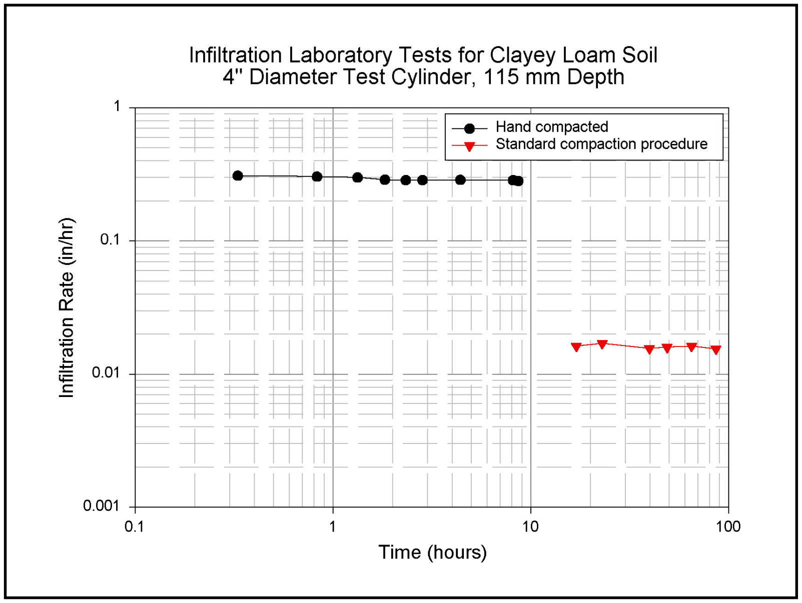

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Example Long-Term Sustainable Average Infiltration Rates

Soil Texture	Compaction Method	Dry Bulk Density (g/cc)	Effects on Root Growth (per NRCS)	Long-term Average Infilt. Rate (mm/hr)
Sand	Hand	1.451	Ideal	Very high
	Standard	1.494	Ideal	Very high
	Modified	1.620	May affect -	2,000
Silt	Hand	1.508	May affect	450
	Standard	1.680	May affect +	23
	Modified	1.740	Restrict	2.0
Clay	Hand	1.241	May affect	76
	Standard	n/a	n/a	0
	Modified	n/a	n/a	0

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Long-Term Sustainable Average Infiltration Rates (cont.)

Soil Texture	Compaction Method	Dry Bulk Density (g/cc)	Effects on Root Growth (per NRCS)	Long-term Average Infilt. Rate (mm/hr)
Sandy Loam	Hand	1.595	May Affect	900
	Standard	1.653	May Affect	230
	Modified	1.992	Restrict	38
Silt Loam	Hand	1.504	May Affect	33
	Standard	1.593	May Affect	0. 7
	Modified	1.690	May Affect +	0.04
Clay Loam	Hand	1.502	May Affect	7.4
	Standard	1.703	Restrict	0.38
	Modified	1.911	Restrict	0

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Stormwater Bioinfiltration Site Studies in Tuscaloosa Areas Devastated by Tornado

- The test sites are all located adjacent to fire hydrants for easy access to large quantities of water and are located in the city's right-of way.
- A 1 m diameter auger was used to drill holes about 1 to 1.5 m ft deep.
- An approximate 1.5 to 2 m length of Sonotube was inserted in the bore holes to maintain structural integrity and had a several cm layer of coarse gravel placed on the bottom to protect the native soil.

Bore Hole Drilling, Double-ring and Bore Hole Infiltration Measurement Installations (Intersection of 21st Ave. E. and University Blvd E).

60

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Field Tests for Stormwater Bioinfiltration Construction Sites, Cont'd

- During the tests, these bore holes were filled with water from the fire hydrants and the water elevations were measured with time until the infiltration rates reached an approximate steady rate.
- The effects of different compaction levels on the infiltration rates through the soil (obtained at the surface and subsurface locations at the test sites) were examined during laboratory column experiments.

Bore Hole Drilling, Double-ring and Bore Hole Infiltration Measurement Installations (Intersection of 21st Ave. E. and University Blvd E).

61

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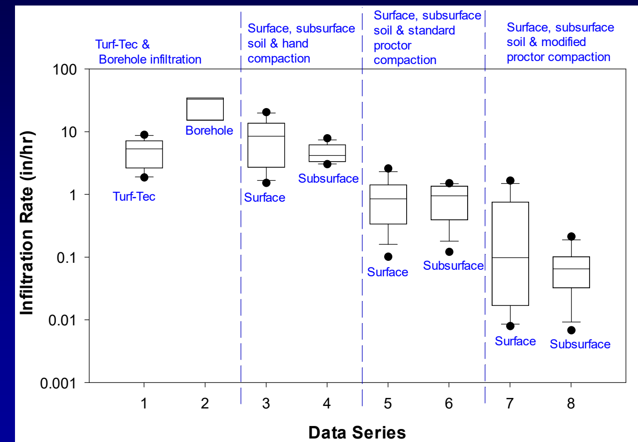
Summary of Surface, Subsurface, and Laboratory Infiltration Data for Bioinfiltration Sites



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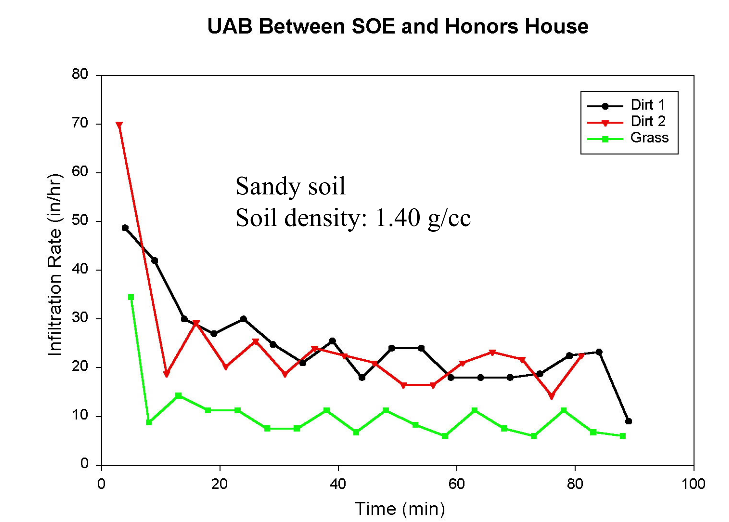
Compaction Measurements

Soil Density Measurements

63



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67

Amended Soil Compared to Unamended Soil

Constituent	Surface Runoff Mass Discharges	Subsurface Flow Mass Discharges
Runoff Volume	0.09	0.29
Phosphate	0.62	3.0
Ammonia	0.56	4.4
Nitrate	0.28	1.5
Copper	0.33	1.2
Zinc	0.061	0.18

68

Water Quality and Quantity Effects of Amending Urban Soils with Compost

- Surface runoff rates and volumes decreased by five to ten times after amending the soils with compost, compared to unamended sites.
- Unfortunately, the concentrations of many pollutants increased in surface runoff from amended soils, especially nutrients which were leached from the fresh compost.
- However, the several year old test sites had less, but still elevated concentrations, compared to unamended soil only test plots.

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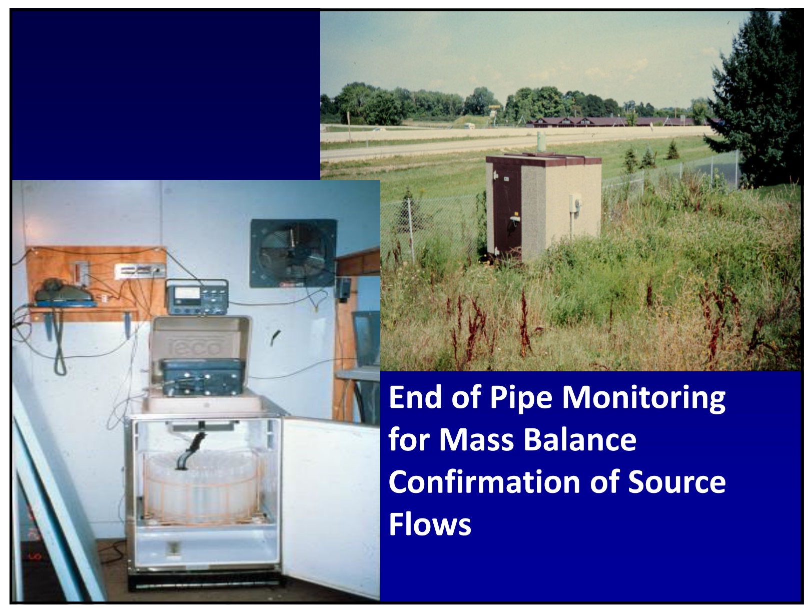
Sources of Stormwater Flows and Pollutants; Field Monitoring

70

71



72


Bioretention Facility Monitoring Project (WI DNR and USGS)
Engineered Soil Layer (12, 24, & 36 inch Depth)
ISCO Sampler & Control Panel

73


Source Area Sampling (WI DNR and USGS)
6/11/2003

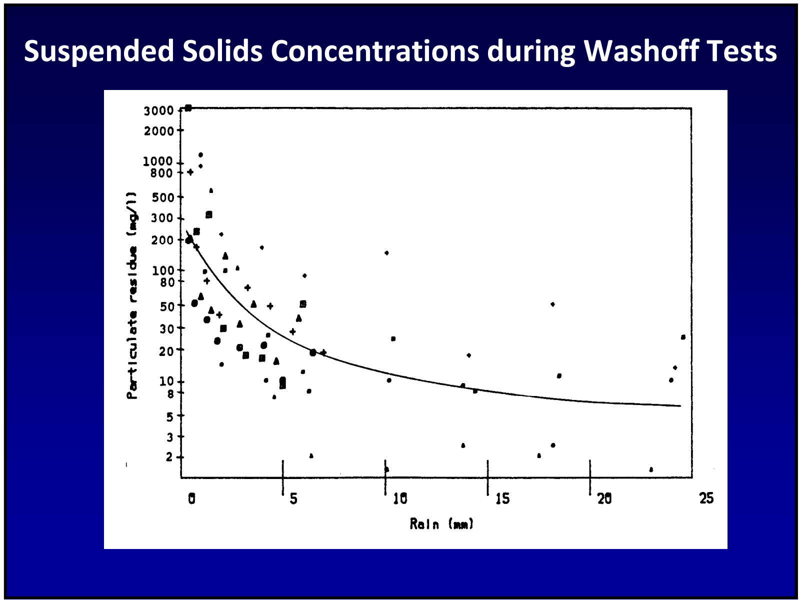
74


Harper Madison WI: Residential
Marquette Michigan: Res/Comm. (288 acres)
Maintenance Yard Madison WI: 4 acres
Syene Industrial Park, Madison WI: 114 acres

75


Street dirt washoff and runoff test plot, Toronto
Pitt 1987

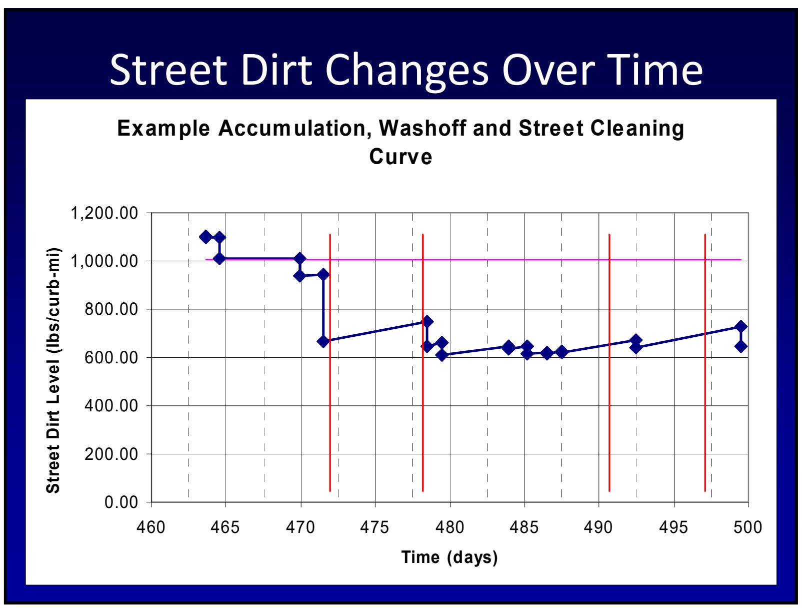
76


Suspended Solids Concentrations during Washoff Tests
Particulate residue (mg/l)
3000
2000
1000
800
500
300
200
100
80
50
30
20
10
8
5
3
2
0
5
10
15
20
25
Rain (mm)

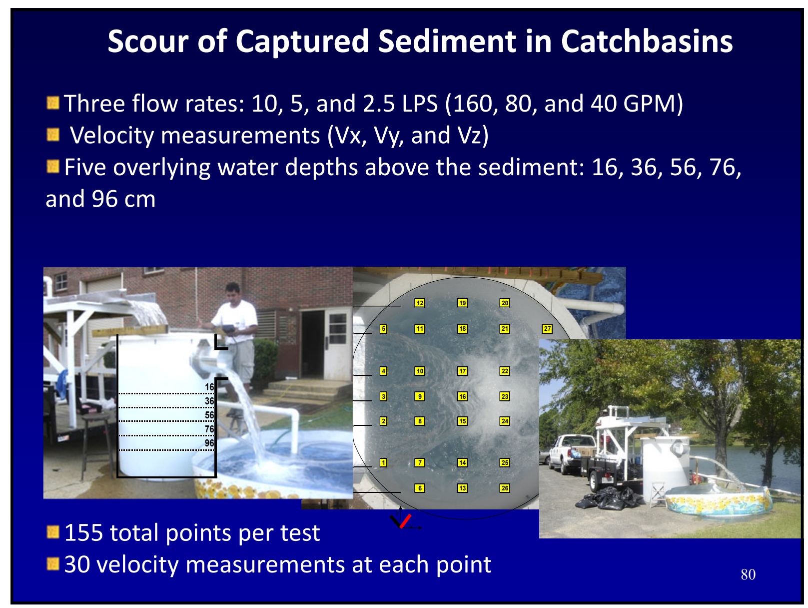
77


Full-scale street cleaning tests using conventional and high-energy street cleaners (street dirt loading and washoff monitoring and outfall water quality monitoring) (WI DNR and USGS)
78

78


Street Dirt Changes Over Time
Example Accumulation, Washoff and Street Cleaning Curve
Street Dirt Level (lbs/curb-mi)
1,200.00
1,000.00
800.00
600.00
400.00
200.00
0.00
460
465
470
475
480
485
490
495
500
Time (days)

79


Scour of Captured Sediment in Catchbasins
Three flow rates: 10, 5, and 2.5 LPS (160, 80, and 40 GPM)
Velocity measurements (Vx, Vy, and Vz)
Five overlying water depths above the sediment: 16, 36, 56, 76, and 96 cm
155 total points per test
30 velocity measurements at each point
80

80

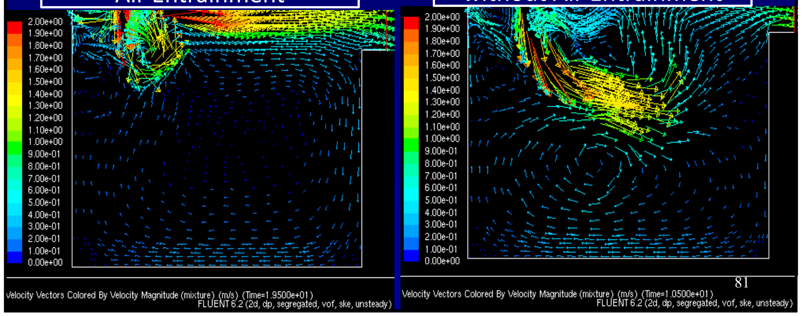
CFD Modeling to Calculate Scour/Design Variations

- Used CFD (Fluent 6.2 and Flow 3D) to determine scour from stormwater controls; results being used to expand WinSLAMM analyses after verification with full-scale physical model

- This is an example of the effects of the way that water enters a sump on the depth of the water jet and resulting scour

Calibrated CFD Model with Air Entrainment

Uncalibrated CFD Model without Air Entrainment



81

TSS vs. SSC and PSD Relationships

Two separate issues:

- sampling to obtain representative water samples and
- laboratory processing to represent all particles.

Most problems result in loss of large particles. The combination of methods used affects modeling approach, especially the particle size distributions.

82

Sampling Effects on Particulate Solids Characteristics

- Sampling issues associated with stratified flows and bedload.
  - Sampler intakes on bottom of pipe may collect more bedload than represented in well-mixed sample, and
  - sampler tube velocity may not be able to transport large particles to sample bottles

These are two opposite problems that seldom cancel each other out nicely.

83

Results of Verification Monitoring of Popular Hydrodynamic Separator by USGS and WI NDR (Madison, WI)

Sampled solids load in	**1623 kg**
Sampled solids load out	**1218 kg**
Trapped by difference	**405 kg (25% removal)**
Actual trapped total sediment	**536 kg (33% actual removal)**
Fraction total solids not captured by automatic samplers	**8% (131 kg missed by sampler, out of 1623 kg in sampler)**

Standard automatic water samplers with single intakes at bottom of pipes. Influent samplers are affected by large particles while effluent samplers should not be, assuming the stormwater control is capable of removing the larger particles that stress the samplers.

84

Bed load in storm drainage compromised about 4% of Madison area total solids discharges (WI DNR and USGS) monitoring).

85

Bedload in corrugated stormdrain and mound of settleable material at discharge into wet detention pond after many years of operation at ski resort at Snowmass, CO (drain from several acre resort parking area having sand applications for traction control).

86

Simple methods to obtain representative sample: create cascading and well-mixed flow at sampling location (well-mixed flow with bedload and no stratification). Examples shown for gutter and pipe flow installations.

87

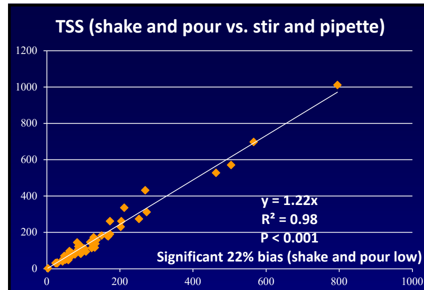
Comparison of Three TSS/SSC Analytical Methods

EPA TSS 160.2 Shake sample bottle vigorously then pour aliquot into graduated cylinder	Standard Methods TSS 2540D Use stir plate and wide bore pipet at mid-depth in bottle and midway between wall and vortex	USGS SSC D3977-97B Use entire sample and pour from original bottle

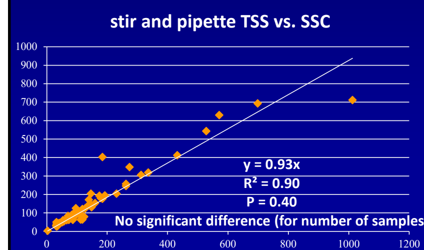
88

USGS/Dekaport cone splitter used to separate sample into smaller volumes for different analyses (the best $1200 you can spend to increase the quality of your lab results).

89



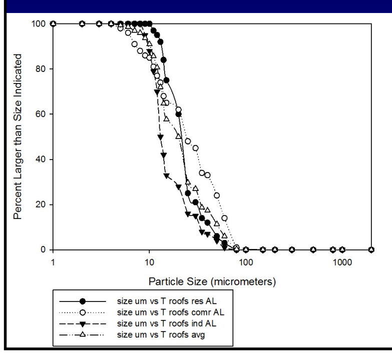
t-Test: Paired Two Sample for Means	Shake and Pour TSS	Stir and Pipette TSS
Mean	133	160
Variance	19818	31015
Observations	59	59
Pearson Correlation	0.99	
Hypothesized Mean Difference	0	
df	58	
t Stat	-4.99	
P(T<=t) one-tail	2.92E-06	

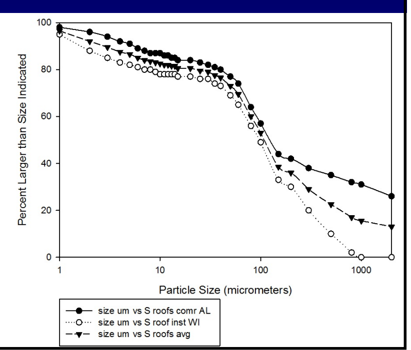


t-Test: Paired Two Sample for Means	Stir and Pipette TSS	SSC with cone splitter
Mean	160	158
Variance	31016	26096
Observations	59	59
Pearson Correlation	0.95	
Hypothesized Mean Difference	0	
df	58	
t Stat	0.26	
P(T<=t) one-tail	0.40	

90

Roof runoff particle size distributions (for TSS shake and pour on left and for TSS stir and pipette and SSC on right)





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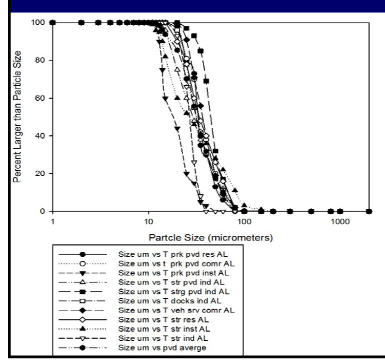
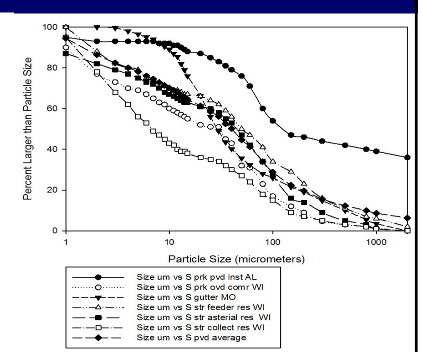
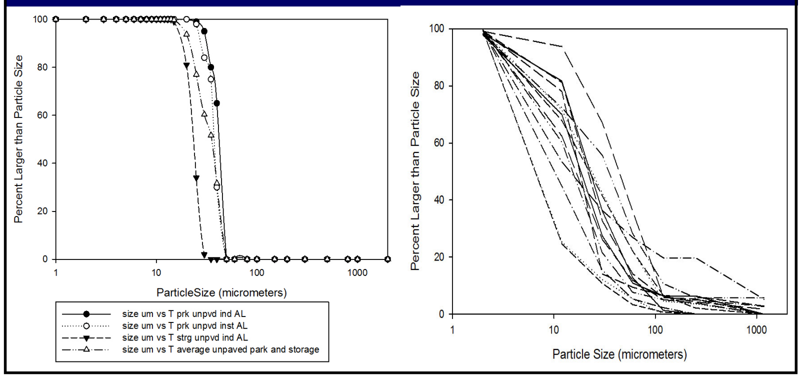
Paved parking, storage, loading dock, vehicle service area, and street runoff particle size distributions (for shake and pour TSS on left and for stir and pipette TSS and SSC on right)





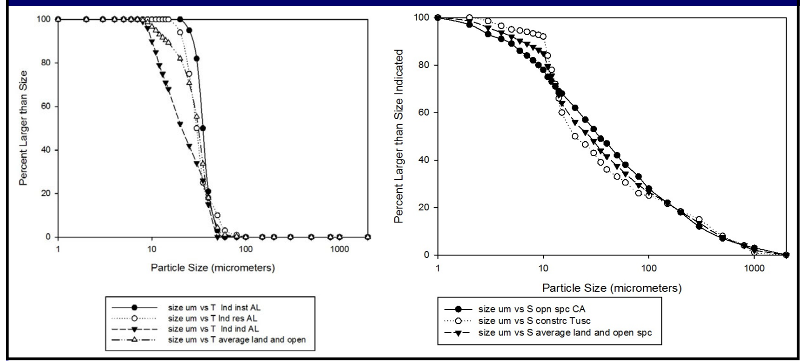
92

Non-paved parking and storage area runoff particle size distributions (for shake and pour TSS on left; SSC on right)



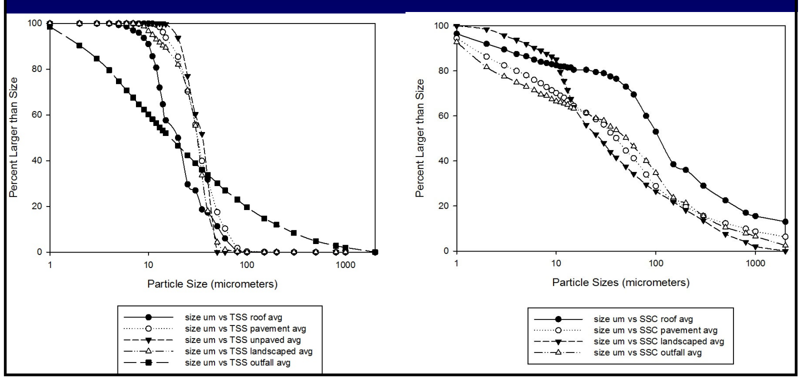
93

Landscaped, open space, and construction site runoff particle size distributions (for shake and pour TSS on left and for stir and pipette TSS and SSC on right)



94

Average particle size distributions for different source area categories (for shake and pour TSS on left and for stir and pipette and SSC on right)



95

Summary and Conclusions

- Beijing has highly seasonal rains with long interevent periods. Literature suggests nutrient discharges are the greatest concern. First flush investigations of local stormwater, and sources of stormwater pollutants are also described in the literature. Desire to use distributed infiltration to reduce discharges.
- Much data are available in the NSQD that has been used to understand stormwater characteristics, mainly land use and geographical influences.
- First flushes are not consistent for all land uses and pollutants. Most important for simple drainages that are mostly paved; less obvious for complex drainages with separate source areas.
- Beijing drainage design events indicate a significant trend across the city, with more severe conditions to the east.

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Summary and Conclusions, cont.

- Conventional drainage design approaches do not work well for the smaller rains that are of most significance in annual pollutant and flow discharges.
- Most of the Beijing rains (by number) as less than 10 mm in depth, while those rains only result in about 10% of the annual runoff. About 80% of the runoff occurs for rains less than 70 mm in depth.
- Pavement hydrology measurements indicate that substantial fractions of smaller rains can infiltration through typical city streets, while bed compacted and thicker pavements have no appreciable infiltration losses.
- Disturbed urban soils have much less infiltration than expected due to typical compaction.

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Summary and Conclusions, cont.

- Small-scale monitoring should be used to verify performance characteristics of stormwater controls, and large-scale monitoring is needed to verify their usefulness when applied throughout an area.
- Different sampling and laboratory methods for solids analyses can result in different particle size distributions which affect calculations pertaining to stormwater control performance.

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