Land Development and Soil Characteristics Affects on Runoff

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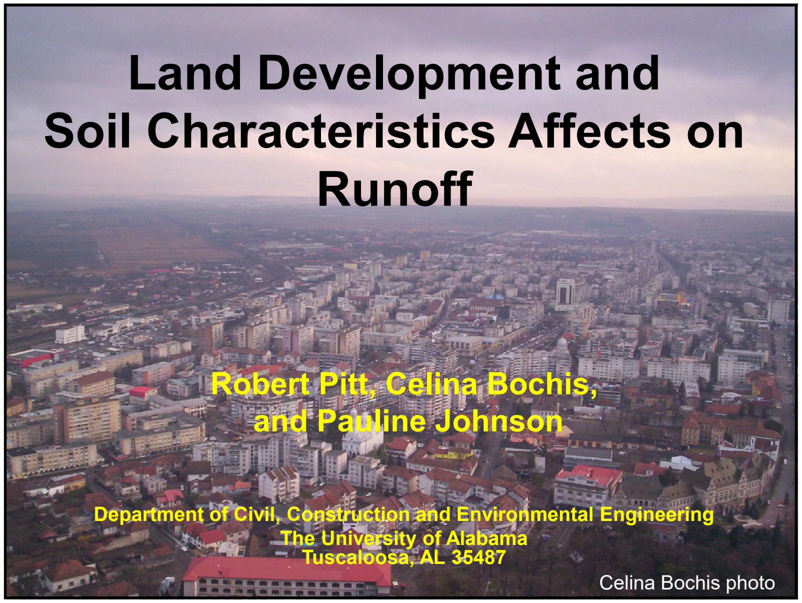

Celina Bochis photo

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Purpose of Data Collection

- Impervious surfaces have the greatest effects on runoff characteristics for most events (runoff volume and pollutant yields) and can be the major sources of many stormwater pollutants
- However, pervious surfaces can be very important for larger events

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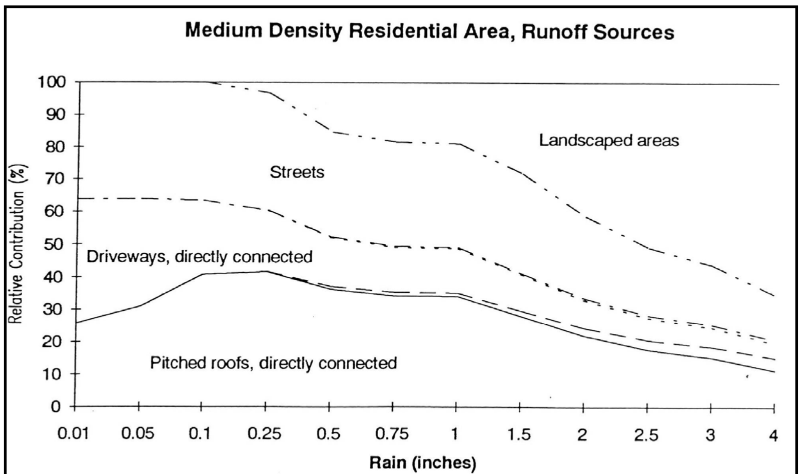

Directly connected impervious surfaces dominate flow sources during rains <0.5 inches
Disturbed urban soils can become very important runoff source areas during larger rains

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- Detailed impervious surface area information is lacking for most areas, especially concerning how those areas are connected to the drainage system. Available data are not reflective of detailed observations and can lead to modeling and other errors.
- Disturbed urban soils have infiltration characteristics that differ greatly from most published soil information sources. These actual characteristics must be considered in management and modeling decisions.

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Soil Compaction and Recovery of Infiltration Rates

- Typical site development dramatically alters soil density.
- This significantly reduces infiltration rates, especially if clays are present.
- Also hinders plant growth by reducing root penetration (New Jersey NRCS was one of the first groups that researched this problem).

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Urban Soils Compacted during and after Development

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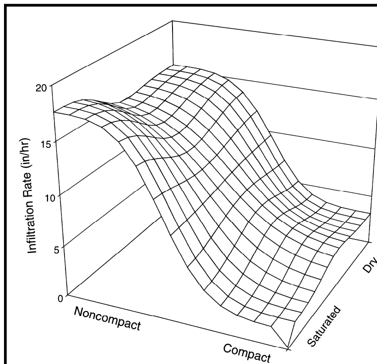
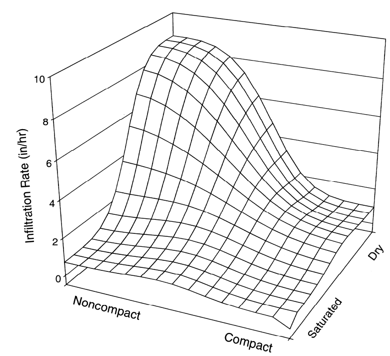


Infiltration Rates in Disturbed Sandy Urban Soils



Infiltration Rates in Disturbed Clayey Urban Soils

Pitt, *et al.* 1999

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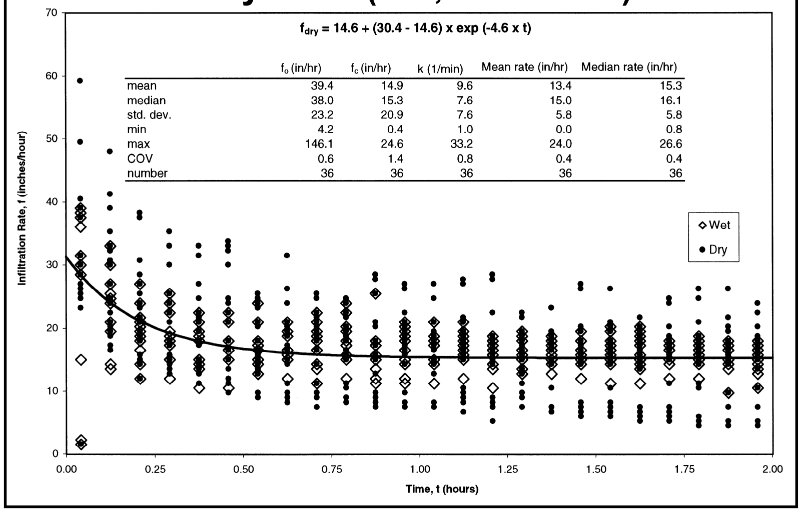
Infiltration Measurements for Noncompacted, Sandy Soils (Pitt, *et al.* 1999)



	f_o (in/hr)	f_c (in/hr)	k (1/min)	Mean rate (in/hr)	Median rate (in/hr)
mean	39.4	14.9	9.6	13.4	15.3
median	38.0	15.3	7.6	15.0	16.1
std. dev.	23.2	20.9	7.6	5.8	5.8
min	4.2	0.4	1.0	0.0	0.8
max	146.1	24.6	33.2	24.0	26.6
COV	0.6	1.4	0.8	0.4	0.4
number	36	36	36	36	36

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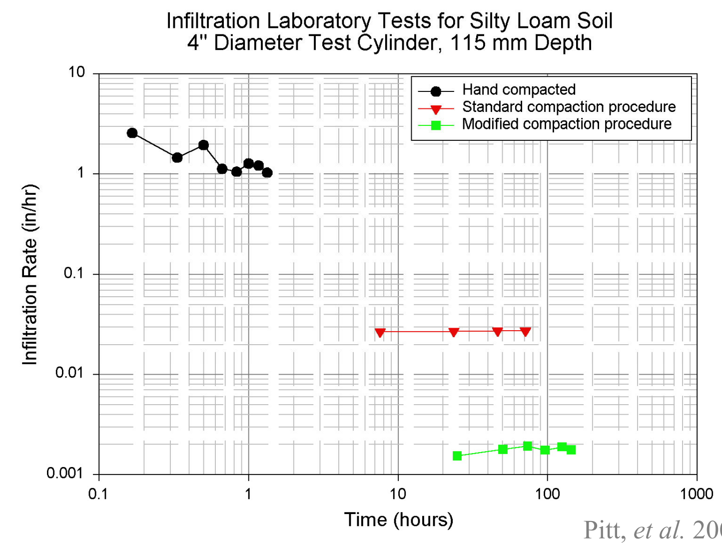

Pitt, *et al.* 2002

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Long-Term Sustainable Average Infiltration Rates

Soil Texture	Compaction Method	Dry Bulk Density (g/cc)	Long-term Average Infilt. Rate (in/hr)
Sandy Loam	Hand	1.595	35
	Standard	1.653	9
	Modified	1.992	1.5
Silt Loam	Hand	1.504	1.3
	Standard	1.593	0.027
	Modified	1.690	0.0017
Clay Loam	Hand	1.502	0.29
	Standard	1.703	0.015
	Modified	1.911	<<0.001

Compaction, especially when a small amount of clay is present, causes a large loss in infiltration capacity.

Pitt, *et al.* 2002

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Compaction Measurements

Soil Density Measurements

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Types of Solutions to Infiltration Problems

- Use organic soil amendments to improve existing soil structure or restore soil structure after construction
- Remove soil layer with poor infiltration qualities
- Replace soil with improved soil mix
  - Mix sand, organic matter, and native soil (if no clay)
- Use deep rooted plants or tilling to improve structure (but only under correct moisture conditions)
  - Chisel plow, deep tilling, native plants
- Pre-treat water
- Select different site

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Typical household lawn aerators are ineffective in restoring infiltration capacity in compacted soils.

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Natural processes work best to solve compaction, but can take decades.

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Soil modifications for rain gardens and other biofiltration areas can significantly increase treatment and infiltration capacity compared to native soils.

(King County, Washington, test plots)

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Enhanced Infiltration with Amendments

	Average Infiltration Rate (in/h)
UW test plot 1 Alderwood soil alone	0.5
UW test plot 2 Alderwood soil with Ceder Grove compost (old site)	3.0
UW test plot 5 Alderwood soil alone	0.3
UW test plot 6 Alderwood soil with GroCo compost (old site)	3.3

Six to eleven times increased infiltration rates using compost-amended soils measured during long-term tests using large test plots and actual rains (these plots were 3 years old).

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Changes in Mass Discharges for Plots having Amended Soil Compared to Unamended Soil

Constituent	Surface Runoff Mass Discharges	Subsurface Flow Mass Discharges
Runoff Volume	0.09	0.29 (due to ET)
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

Increased mass discharges in subsurface water pollutants observed for many constituents (new plots).

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Water Quality and Quantity Effects of Amending Urban Soils with Compost

- Surface runoff rates and volumes decreased by six to ten eleven after amending the soils with compost, compared to unamended sites.
- Unfortunately, the concentrations of many pollutants increased in surface runoff from amended soil plots, 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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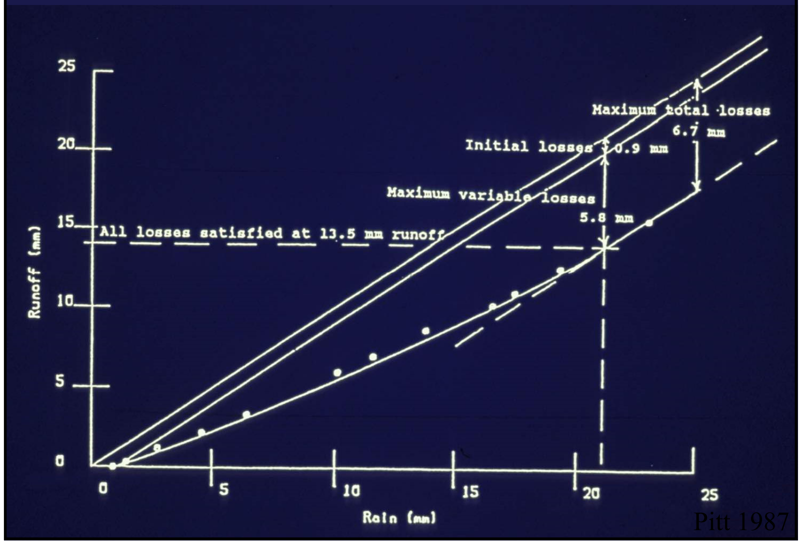
Runoff response curve for typical residential street, Toronto



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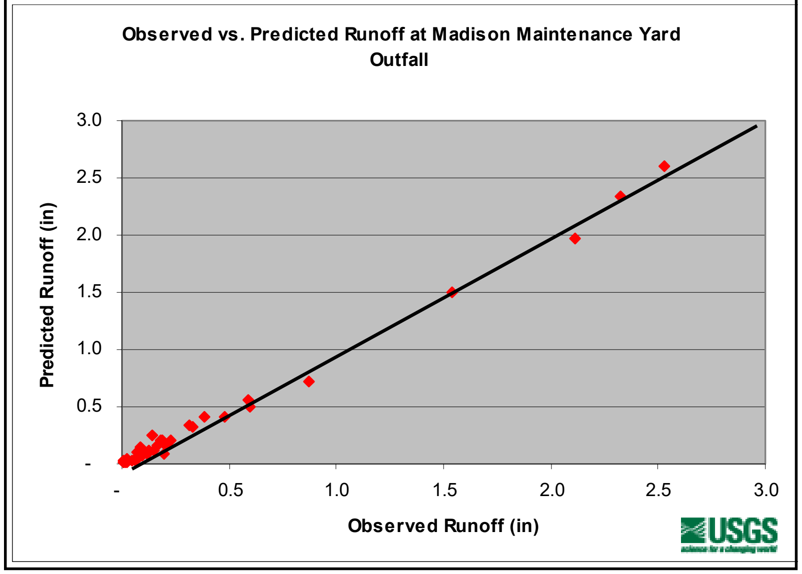

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Approach for Land Cover Investigations

- Investigated many land uses in the Birmingham, AL, area:
  - 1 large watershed, the Little Shades Creek Watershed (125 neighborhoods / 6 land uses) (original data collected in mid 1990s by USDA *Earth Team* volunteers)
  - 5 drainage areas (40 neighborhoods having 2 -6 land uses each) which are part of the Jefferson County, AL, Stormwater Permit Monitoring Program (intensive field investigations and surveys were conducted as part of this thesis research)
- Used WinSLAMM to:
  - Calculated runoff characteristics
  - Estimated the biological conditions of the receiving waters due to quantity of runoff for different land use and development characteristics

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Field Data Collection

- Delineation of the watersheds and neighborhoods using aerial photographs, topographic maps, and on-site surveys
- Single land use surveys: 6 to 12 neighborhoods studied in detail per land use in each watershed to determine the variability of the development characteristics
- Site Inventory had 2 parts:
  - Field data collection
  - Aerial photographic measurements of different land covers
- Each site had at least two photographs taken:
  - one as a general view
  - one as a close-up of the street texture

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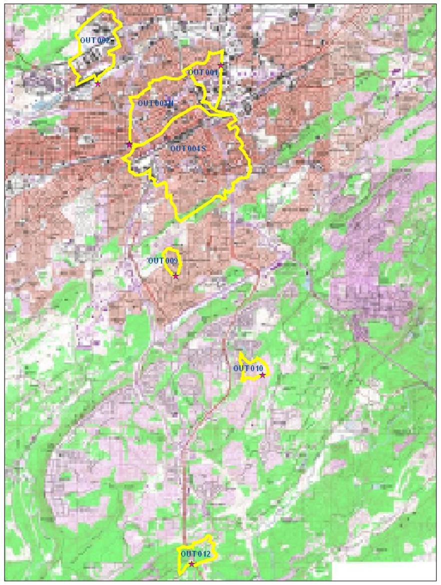

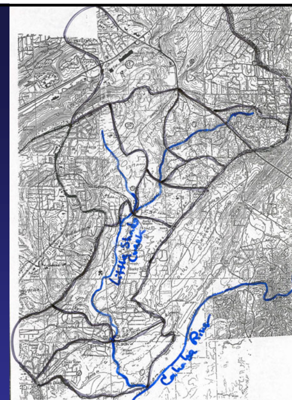

Little Shades Creek
Jefferson Co, AL

Jefferson Co. MS4
Monitoring Sites
Birmingham, AL

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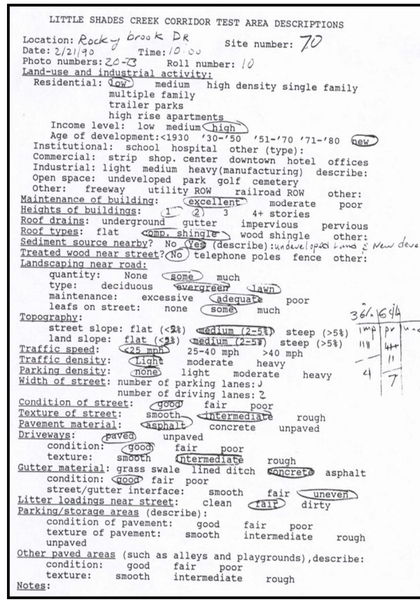

LITTLE SHADES CREEK CORRIDOR TEST AREA DESCRIPTIONS

Location: Rocky brook DR   Site number: 70
Date: 2/21/90   Time: 10.00
Photo numbers: 20-23   Roll number: 10
Land-use and industrial activity:
Residential: low medium high density single family
multiple family
trailer parks
high rise apartments
Income level: low medium high
Age of development: <1930 '30-'50 '51-'70 '71-'80 new
Institutional: school hospital other (type):
Commercial: strip shop. center downtown hotel offices
Industrial: light medium heavy(manufacturing) describe:
Open space: undeveloped park golf cemetery
Other: freeway utility ROW railroad ROW other:
Maintenance of building: excellent moderate poor
Heights of buildings: 1 2 3 4+ stories
Roof drains: underground gutter impervious pervious
Roof types: flat comp. shingle wood shingle other:
Sediment source nearby? No Yes (describe): undeveloped Land & New deve..
Treated wood near street? No telephone poles fence other:
Landscaping near road:
quantity: None some much
type: deciduous evergreen lawn
maintenance: excessive adequate poor
leafs on street: none some much
Topography:
street slope: flat (<2%) medium (2-5%) steep (>5%)
land slope: flat (<2%) medium (2-5%) steep (>5%)
Traffic speed: <25 mph 25-40 mph >40 mph
Traffic density: Light moderate heavy
Parking density: none light moderate heavy
Width of street: number of parking lanes: 0
number of driving lanes: 2
Condition of street: good fair poor
Texture of street: smooth intermediate rough
Pavement material: asphalt concrete unpaved
Driveways: paved unpaved
condition: good fair poor
texture: smooth intermediate rough
Gutter material: grass swale lined ditch concrete asphalt
condition: good fair poor
street/gutter interface: smooth fair uneven
Litter loadings near street: clean fair dirty
Parking/storage areas (describe):
condition of pavement: good fair poor
texture of pavement: smooth intermediate rough
unpaved
Other paved areas (such as alleys and playgrounds), describe:
condition: good fair poor
texture: smooth intermediate rough
Notes:

Field Inventory Sheet Prepared for Each Neighborhood

When in the field we look for:

1. Roof types *(flat or pitched)*
2. Roof connections *(connected, disconnected)*
3. Pavement conditions and texture *(smooth, interm., rough)*
4. Storm drainage type *(grass swales, curb and gutters, and roof drains)*

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Village Creek Site (SWMA 002) Birmingham, AL

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Example of high resolution color satellite image (Google)

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Land Use Categories Examined

- Residential
  - High, medium, low density
  - Apartments, Multi- family units
- Commercial
  - Strip commercial, shopping centers
  - Office parks, downtown business district
- Industrial
  - Manufacturing (power plants, steel mills, cement plants)
  - Non-manufacturing (warehouses)
  - Medium Industrial (lumber yards, junk and auto salvage yards, storage areas)
- Institutional
  - Schools, churches, hospitals, nursing homes
- Open Space
  - Parks, cemeteries, golf courses
  - Vacant spaces, undeveloped areas
- Freeways – drained by swales

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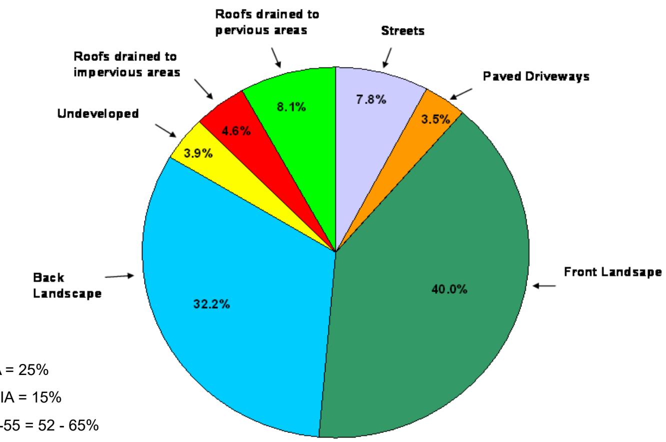
Little Shades Creek Watershed

Average Land Cover Distribution

High Density Residential (6 houses/acre)



TIA = 25%

DCIA = 15%

TR-55 = 52 - 65%

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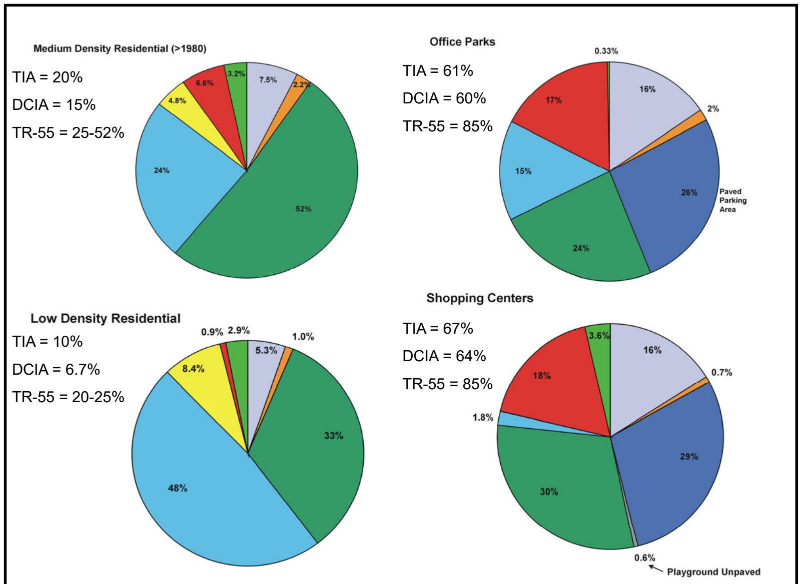

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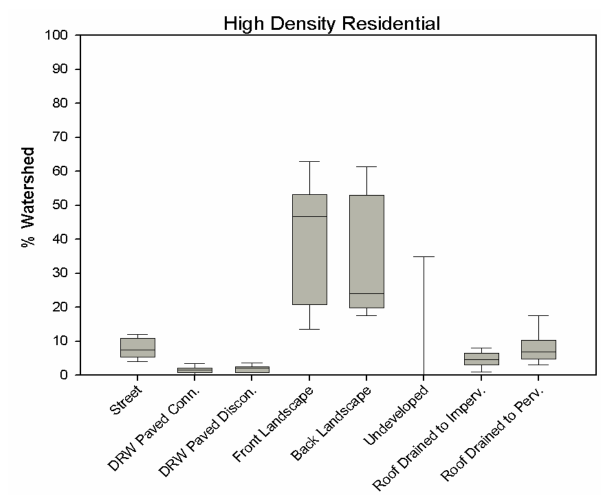
Little Shades Creek Watershed

Variation in Land Cover Distribution



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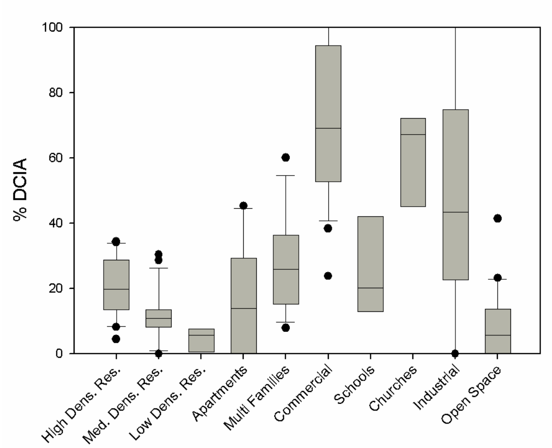
Little Shades Creek and Jefferson Co. Drainage Areas: DCIA by Land Use



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Average Percent Directly Connected Impervious Area

Land Use	Local Conditions	TR – 55 (using interpolation)
HDR (> 6 units/ac)	21	52
MDR (2-6 units/ac)	11	39
LDR (< 2 units/ac)	5	23
APARTMENTS	23	65
COM	71	85
IND	50	72

- TR- 55 assumes all impervious areas to be directly connected to the drainage system
- Overestimation of impervious cover for local conditions

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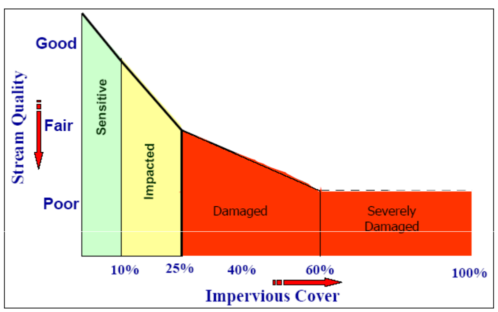
Figure and Table from Center for Watershed Protection



Urban Steam Classification	Sensitive 0 – 10% Imperviousness	Impacted 11– 25% Imperviousness	Damaged 26–100% Imperviousness
Channel Stability	Stable	Unstable	Highly Unstable
Aquatic Life Biodiversity	Good/Excellent	Fair/Good	Poor

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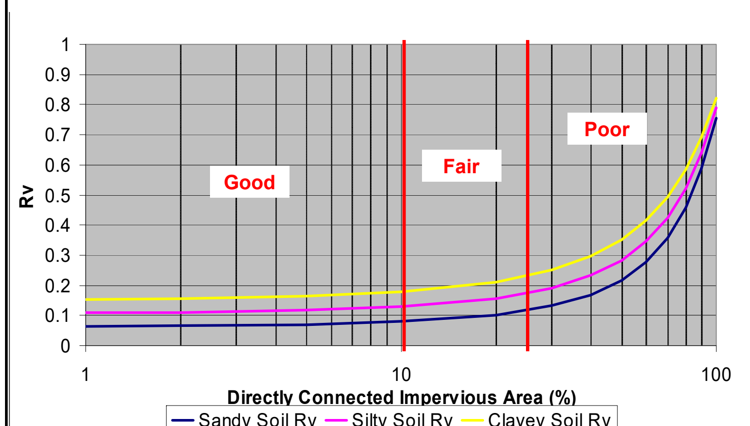
Relationship between Directly Connected Impervious Areas, Volumetric Runoff Coefficient, and Expected Biological Conditions



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Watershed ID	Major Land Use	Area (ac)	Pervious Areas (%)	Directly Connected Impervious Areas (%)	Disconnected Impervious Areas (%)	Vol. Runoff Coeff. (Rv)	Expected Biological Conditions of Receiving Waters
ALJC 001	IND	341	25	72	2.8	0.67	Poor
ALJC 002	IND	721	40	53	7.3	0.51	Poor
ALJC 009	Resid. High Dens.	102	54	34	12	0.37	Poor
ALJC 010	Resid. Med. Dens.	133	64	28	7.9	0.30	Poor
ALJC 012	COM	228	36	61	3.4	0.61	Poor
Little Shades Creek	RES	5120	67	21	12	0.29	Poor

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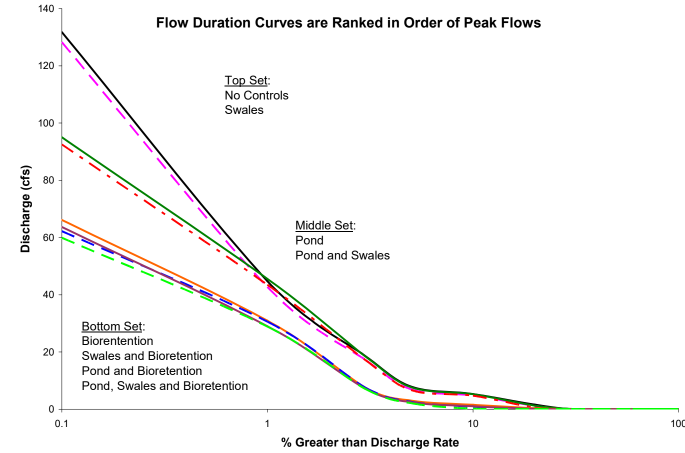
Flow-Duration Curves for Different Stormwater Conservation Design Practices



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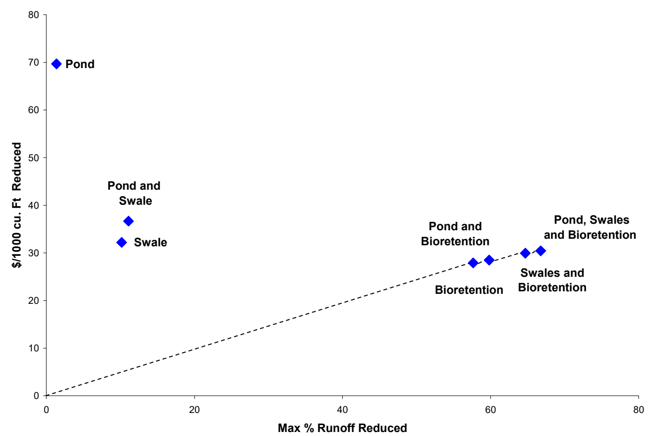
Cost Effectiveness of Stormwater Control Practices for Runoff Volume Reductions



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Example of Stormwater Control Implementation

	No controls	Pond Only	Swales Only	Bioretention Only	Pond, Swales and Bioretention
Annualized Total Costs ($/year/ac)	0	118	404	1974	2456
Runoff Coefficient (Rv)	0.61	0.60	0.54	0.26	0.20
% Reduction of Total Runoff Volume Discharges	n/a	1.4%	10%	58%	67%
Unit Removal Costs for Runoff Volume ($/ft^3)	n/a	0.07	0.03	0.03	0.03
Expected biological conditions in receiving waters (based on Rv)	poor	poor	poor	poor	fair

- Site ALJC 012
- Area 228 acres = 92.3 ha
- Bioretention devices give the greatest reduction in runoff volume discharged
- The biological conditions improved from “poor” to “fair” due to stormwater controls

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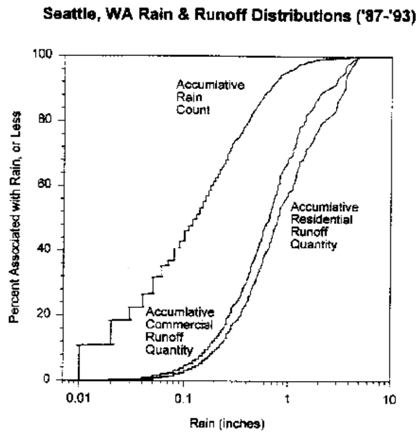
Combinations of Controls Needed to Meet Many Stormwater Management Objectives

- Smallest storms should be captured on-site for reuse, or infiltrated
- Design controls to treat runoff that cannot be infiltrated on site
- Provide controls to reduce energy of large events that would otherwise affect habitat
- Provide conventional flood and drainage controls



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Conclusions

- Literature assumptions on impervious cover are not very accurate when applied to SE US conditions
- Almost all impervious surfaces are directly connected in the Jefferson County study areas examined
- Impervious cover variability within land uses need to be considered when modeling runoff conditions
- WinSLAMM showed that stream quality in the receiving waters is in poor condition, a fact confirmed by in-stream investigations by the SWMA biologists,
- Substantial applications of complimentary stormwater controls are needed to improve these conditions.

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Acknowledgments

- **Storm Water Management Authority at Birmingham, AL who provided the data**
- **SWMA employees who helped in this research**
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- **Many UA-CE graduate students who helped in the field data collection**

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