Small Storm Hydrology

The Integration of Water Quality and Drainage Design Objectives

Robert Pitt, Ph.D., P.E., DEE
Department of Civil and Environmental Engineering
University of Alabama
Tuscaloosa, AL, USA 35487

Stormwater Management Steps

- Identify beneficial use impairments
- Identify causes of impairments
- Identify sources (magnitude, seasonality, flow phases, etc.) of problem constituents
- Identify, select, and design controls suitable for problem pollutants and locations
- Implement controls, conduct validation monitoring, modify controls as needed

DESIGN CONSIDERATIONS:

- TR-55 greatly underpredicts flows for small storms and SCS doesn't recommend its' use for storms less than 1" in depth.
- Most models assume all/most flows from directly connected impervious areas and very little from pervious areas.
- Most stormwater managers and model users overlook the significance of small/common storms in causing water quality problems.

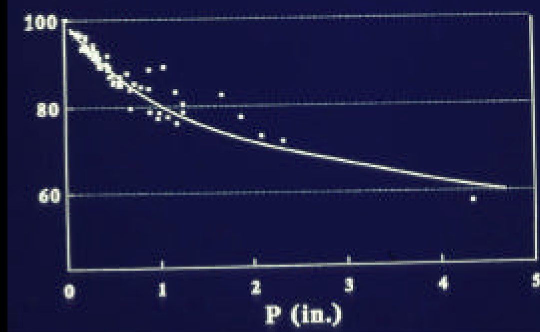
- Runoff volume key to estimate pollutant mass
- Simple relationship between rain depth and runoff total
- Changes in storm depth affects relative contributions from various sources
  - smallest storms: mostly from directly connected impervious areas
  - larger storms: "pervious" areas may dominate

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

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

Observed Curve Numbers for Residential Area (39% Imperviousness)

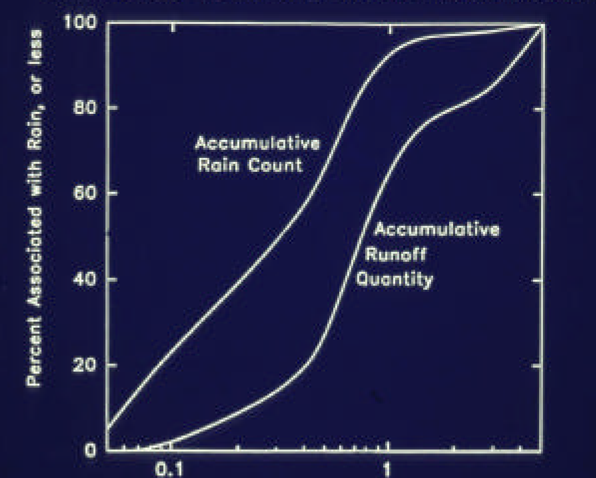
0.25 acre lots, sandy soils
(CN for A soils: 61 and CN for B soils: 75)

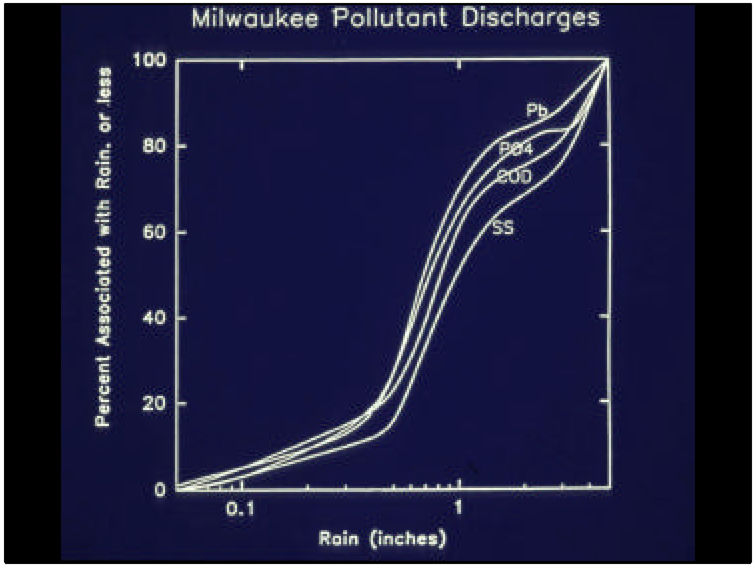


DESIGN ISSUES

- Recognize Different Objectives of Drainage
- Recognize Associated Rainfall & Runoff Conditions
- Example - Milwaukee, WI - Four Rainfall Groups:
  - < 12 mm (< 0.5 inch)
  - 12 - 40 mm (0.5 - 1.5 inches)
  - 40 - 75 mm (1.5 - 3 inches)
  - > 75 mm (>3 inches)

Milwaukee Rain and Runoff Distribution





DESIGN ISSUES (cont.)

- < 12 mm (< 0.5 inches)
  - Most of the Events (Number of Storms)
  - Little of Annual Runoff Volume
  - Little of Annual Pollutant Mass Discharge
  - Probable Little Receiving Water Effects
  - Problem: Pollutant Concentrations Likely Exceed Regulations (bacteria, total recoverable metals) for Each Event

DESIGN ISSUES (cont.)

- 12 mm - 40 mm (0.5 - 1.5 inches)
  - Majority of Annual Runoff Volume and Pollutant Discharges
  - Occurs Approximately Every Two Weeks
  - Problems:
    - Produce Moderate to High Flows
    - Produce Frequent High Pollutant Loadings

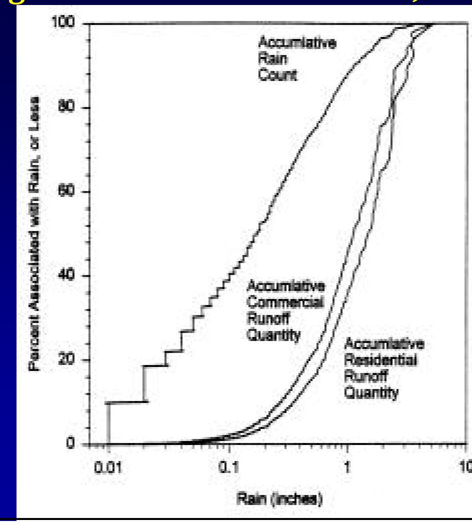
DESIGN ISSUES (cont.)

- 40 - 75 mm (1.5 - 3 inches)
  - Current Design Storms
  - Establishes Energy Gradient of Streams
  - Occurs Approximately Every Few Months (once to twice a year)
  - Problems:
    - Unstable Streambanks
    - Habitat Destruction from Damaging Flows

DESIGN ISSUES (cont.)

- > 75 mm (> 3 inches)
  - Occur Rarely (once every several years to once every several decades or centuries)
  - Produce Relatively Little of Annual Pollutant Mass Discharge
  - Produce Extremely Large Flows and Exceed Drainage System Capacity for Most Events

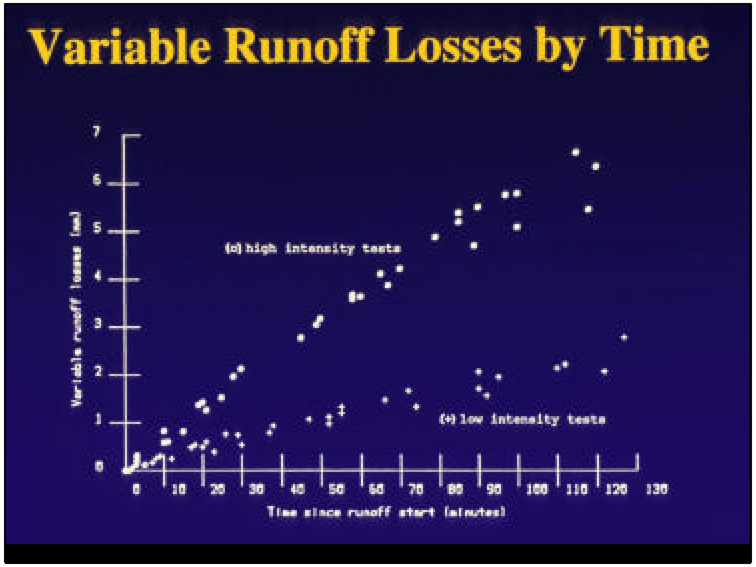
Significance of Different Rains, Los Angeles, CA



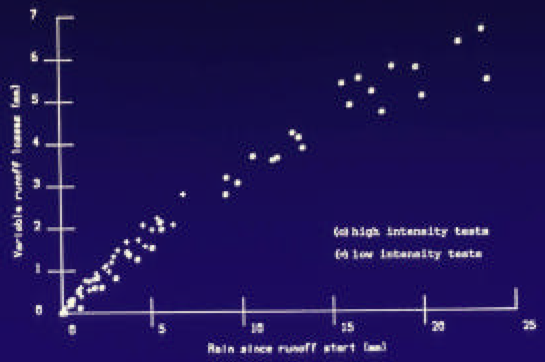
Pitt, et al. (2000)

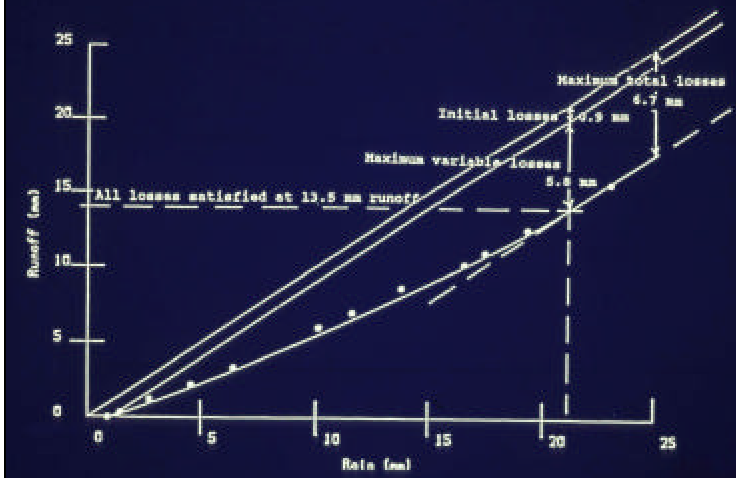
IMPORTANCE OF "SMALL" RAINS

	Birmingham	Milwaukee
% of rain <0.5" in depth	70%	66%
rain depth causing 50% of annual runoff (med. density resid. area)	<1.5"	<0.75"
100-yr, 24-hr rain causes 15% of annual runoff when it occurs, but only contributes 0.15% of runoff during typical year	8.4"	5.6"
25-yr, 24-hr rain causes 12.5% of annual runoff when it occurs, but only contributes 0.5% of runoff during typical year	6.9"	4.4"


Variable Runoff Losses by Time
Variable runoff losses (mm)
0 1 2 3 4 5 6 7
(o) high intensity tests
(+) low intensity tests
0 10 20 30 40 50 60 70 80 90 100 110 120 130
Time since runoff start (minutes)

Variable Runoff Losses by Rain Depth





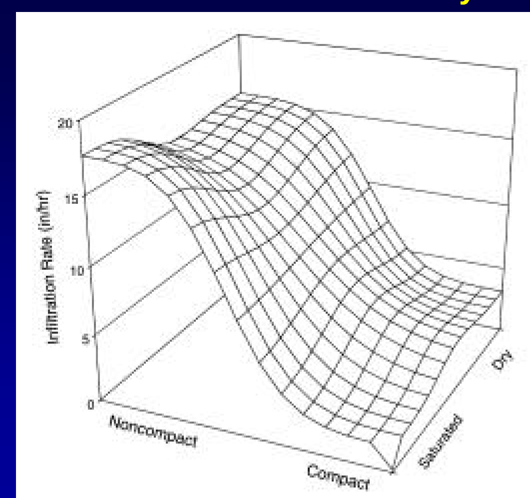
Disturbed Urban Soils during Land Development

OCONOMOWOC, WI, URBAN SOIL DOUBLE RING INFILTRATION TESTS (IN/HR) (MOSTLY A/B/ SOILS)

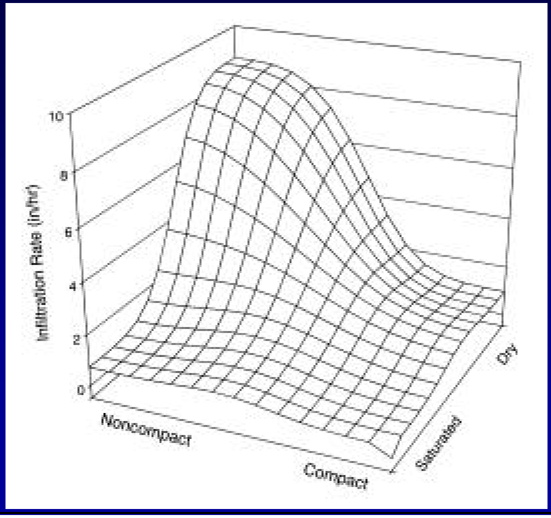
Initial Rate	Final Rate	Range of Rates Observed
25	15	11 to 25
22	17	17 to 24
14.7	9.4	9.4 to 17
5.8	9.4	0.2 to 9.4
5.7	9.4	5.1 to 9.6
4.7	3.6	3.1 to 6.3
4.1	6.8	2.9 to 6.8
3.1	3.3	2.4 to 3.8
2.6	2.5	1.6 to 2.6
0.3	0.1	0 to 0.3
0.3	1.7	0.3 to 3.2
0.2	0	0 to 0.2
0	0.6	0 to 0.6
0	0	all 0
0	0	all 0
0	0	all 0

Site #	Land Use	Age (years)	Texture	Compaction (psi)
1a	Recreational	>40	Clayey	100-200
1b				>300
2a	Residential	<1	Clayey	150
2b			Clayey	>300
3a	Commercial	>25	Sandy	>300
3b			Sandy	225
3c			Clayey	280
4a	Residential	>30	Clayey	200
4b			Clayey	>300
4c			Sandy	200-250
5a	Residential	>30	Clayey	150-200
5b			Sandy	>300
6	Agricultural	>10	Sandy	>300
7a	Residential	<1	Clayey	>300
7b				<150
8	Residential	>30	Clayey	>300
9a	Recreational	<5	Sandy	150-175
9b		<5	Sandy	>300
9c		>10	Sandy	100
10	Residential	>20	Sandy	100

Infiltration Rates in Disturbed Sandy Urban Soils



Infiltration Rates in Disturbed Clayey Urban Soils



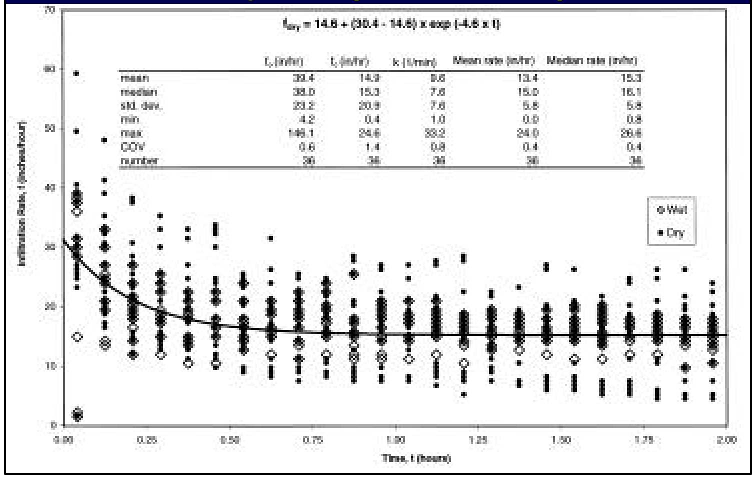
Results of Infiltration Tests in Disturbed Urban Soils

- Four general categories were observed to be unique:
  - Noncompacted-sandy soils
  - Compacted-sandy soils
  - Dry-noncompacted-clayey soils
  - All other clayey soils (compacted and dry, plus all saturated conditions)

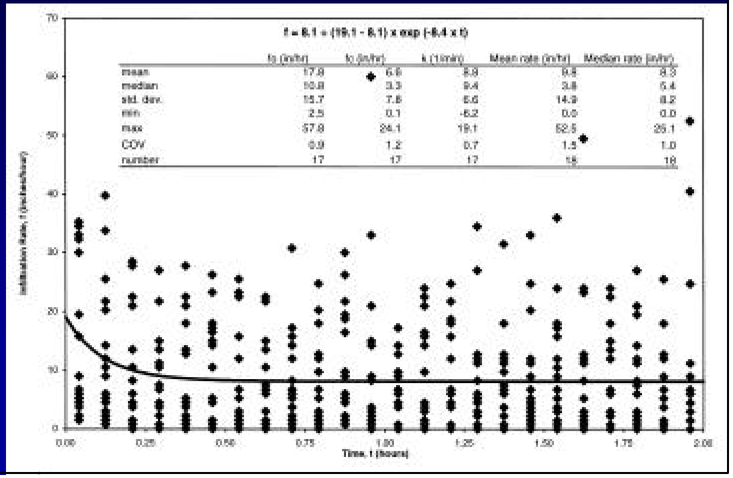
Infiltration Rates during Prior Tests of Disturbed Urban Soils

	Number of tests	Average infiltration rate (in/hr)	COV
Noncompacted sandy soils	36	13	0.4
Compacted sandy soils	39	1.4	1.3
Noncompacted and dry clayey soils	18	9.8	1.5
All other clayey soils (compacted and dry, plus all wetter conditions)	60	0.2	2.4

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



Infiltration Measurements for Dry-Noncompacted, Clayey Soils (Pitt, *et al.* 1999)



Effects of Compost-Amended Soils on Runoff Properties

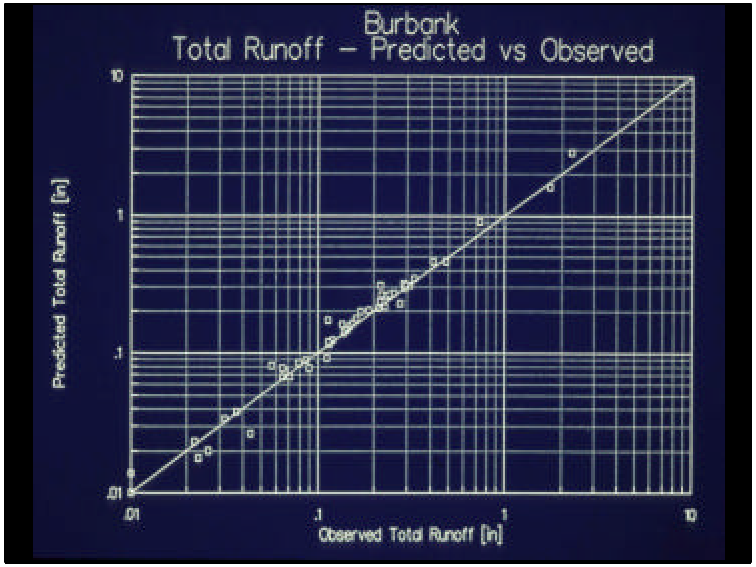
- Another portion of the research was conducted in Seattle, Washington, area by Rob Harrison of the University of Washington.
- They examined the benefits of adding large amounts of compost to a glacial till soil at the time of development.

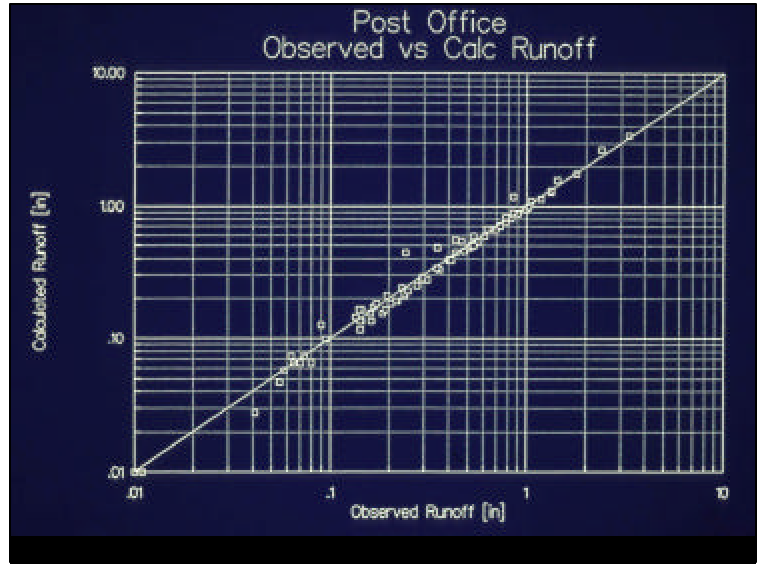
Water Quality and Quantity Effects of Amending Soils with Compost

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

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
Ammonium-nitrogen	0.56	4.4
Nitrate-nitrogen	0.28	1.5
Copper	0.33	1.2
Zinc	0.061	0.18

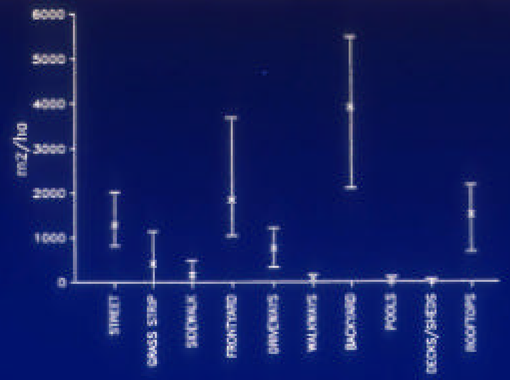




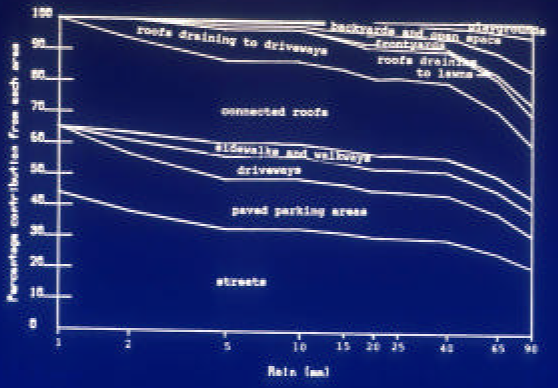
The Source Loading and Management Model (SLAMM)

- Developed during past 25 years during EPA, state, and Canadian funded research.
- Identifies pollutant sources during different rain and climatic conditions.
- Prioritizes subwatersheds and critical source areas.
- Evaluates alternative development scenarios, pollution prevention, and combinations of source area and outfall control options.

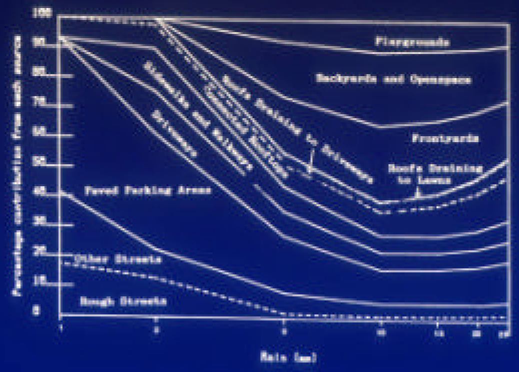
Source Areas - Milwaukee Medium Density Residential (without alleys)

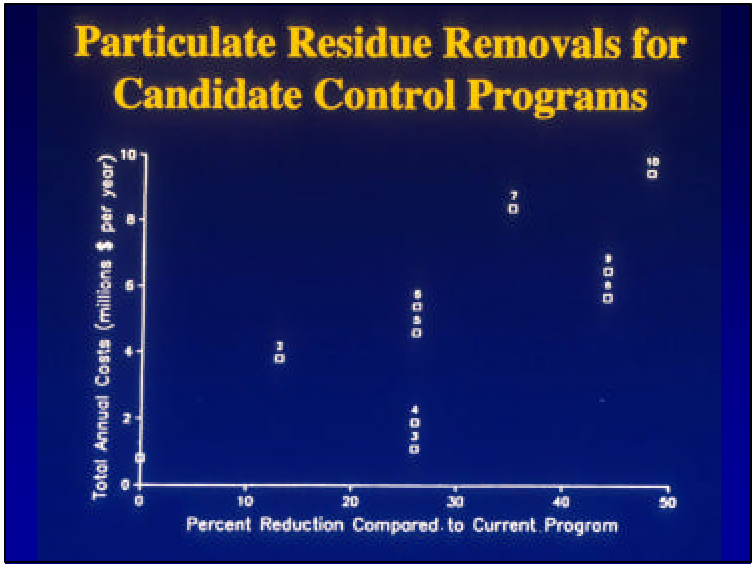


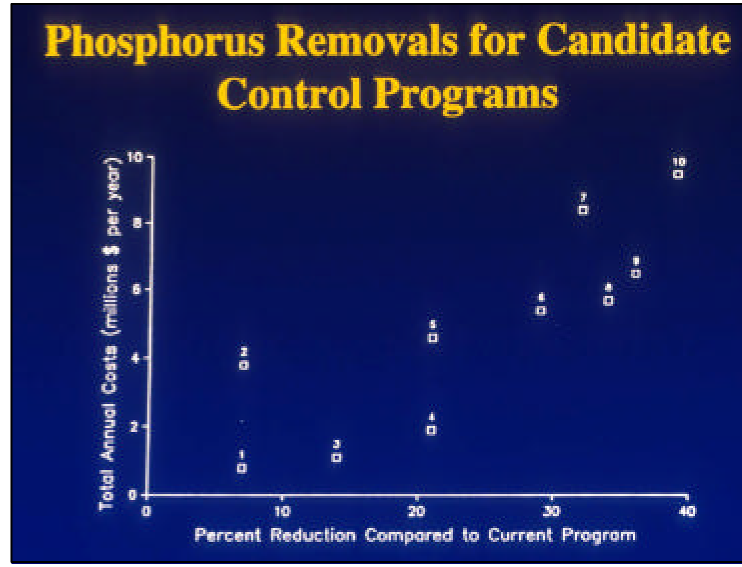
Thistledowns Urban Runoff Flow Sources



Total Residue Source Area Contributions - Thistledowns




Particulate Residue Removals for Candidate Control Programs
Total Annual Costs (millions $ per year)
0
2
4
6
8
10
0
10
20
30
40
50
Percent Reduction Compared to Current Program


Phosphorus Removals for Candidate Control Programs
Total Annual Costs (millions $ per year)
0
2
4
6
8
10
0
10
20
30
40
Percent Reduction Compared to Current Program