Fifty Years Of Watershed Modeling - Past, Present And Future

Proceedings

2012

WinSLAMM: Integrating Stormwater Management and Green Technologies

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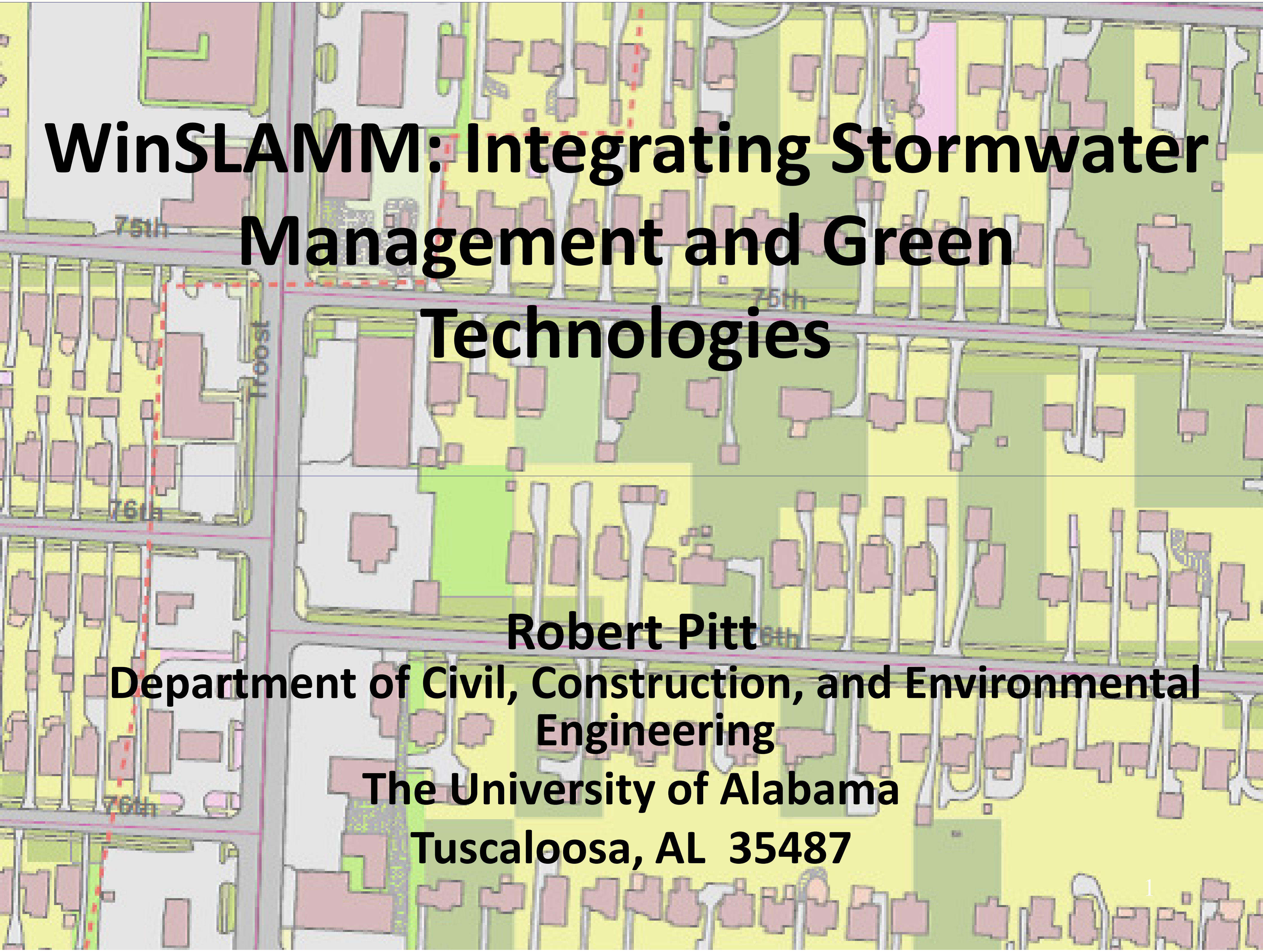

WinSLAMM: Integrating Stormwater Management and Green Technologies

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In 1977, WinSLAMM didn't start with a card deck, but with the next best thing, a Radio Shack TRS 80, model 1 ("Trash 80") with an optional tape drive (couldn't afford the $500 disk drives)

Brief History of WinSLAMM

- WinSLAMM began life as a stormwater quality model and focuses on small/intermediate storm hydrology, particulate transport, soil processes in disturbed urban soils, and stormwater quality variability.
- It is not a replacement for large system hydraulic/drainage design models, but can be integrated with many.
- WinSLAMM began as part of the data analysis efforts of EPA stormwater research projects in the 1970s.
- Extensions to the model were based on Toronto and Ottawa stormwater projects, various state projects, and the EPA’s NURP projects in the 1980s.
- Continued modifications in response to resource/regulatory agency requests and on-going research results.
- Recent efforts have focused on green infrastructure benefits in areas served by combined sewers.

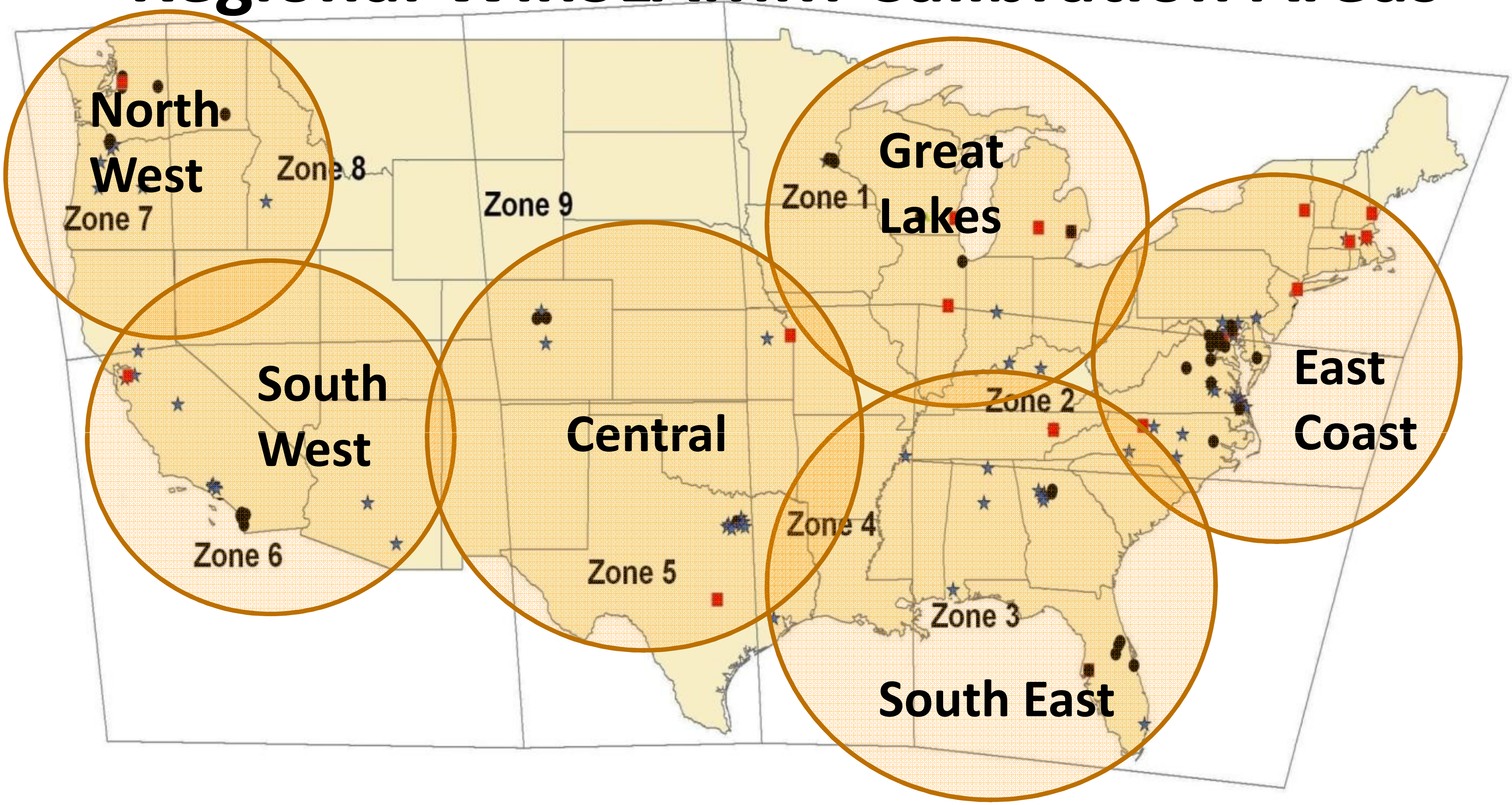
Modeling Green Infrastructure Components

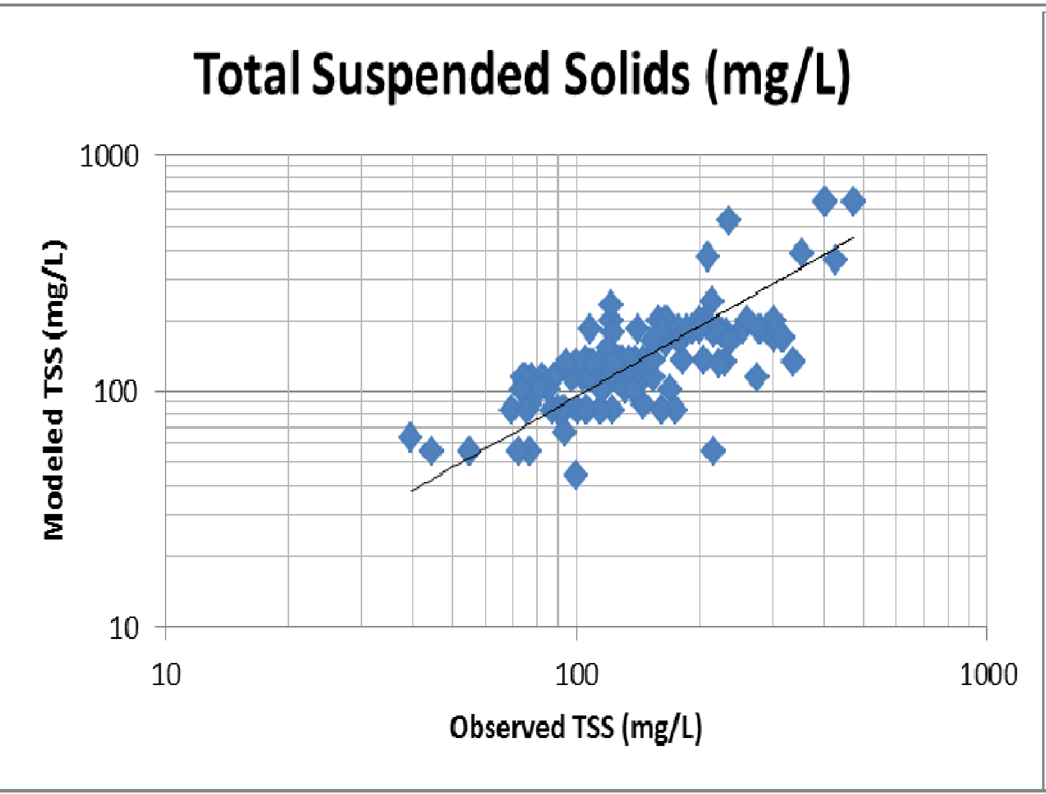
- Green infrastructure modeling typically involves a large number of infiltration and/or storage elements in the watershed, both at source areas and at consolidation locations.
- The overall effects between and within these various components are not directly additive and require complete hydraulic, particle size, and pollutant routing.
- Treatment trains at both small and large scales result in preferential removal of large particles in the initial treatment components, leaving more difficult smaller particles to be removed by subsequent treatment operations, for example.
- Detention storage (and infiltration) of runoff volumes distributed throughout the area also enhances the performance of the down-gradient stormwater controls.

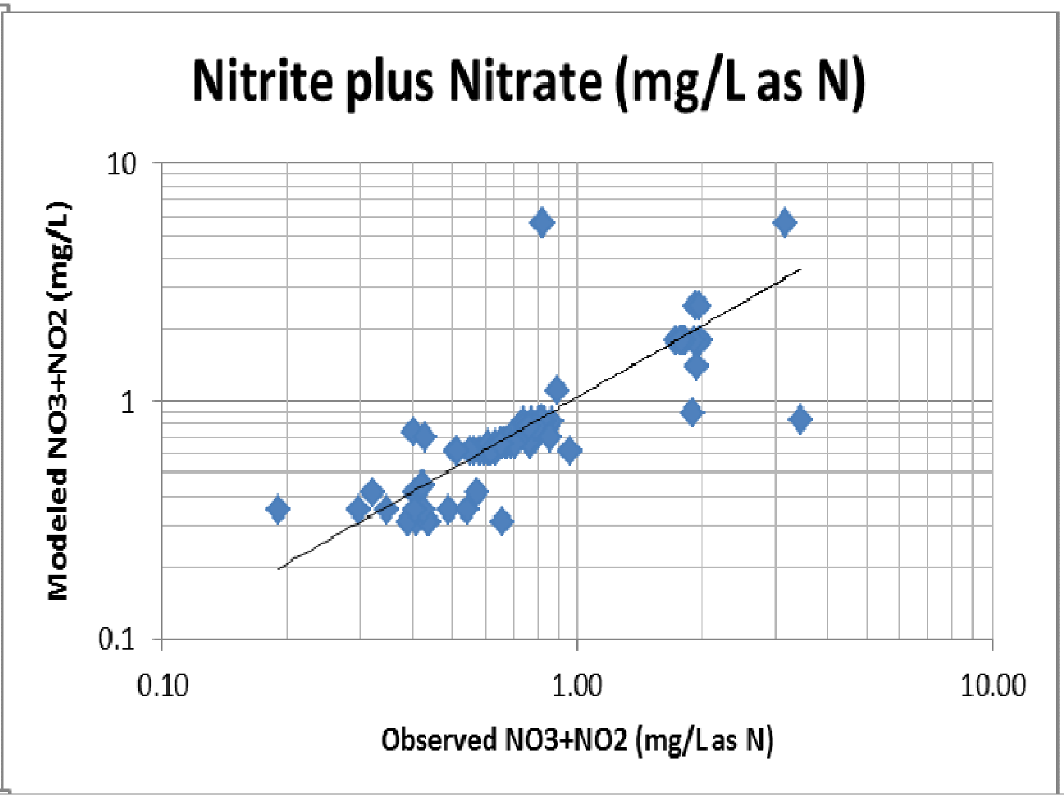
Features of WinSLAMM Benefiting Green Infrastructure Modeling

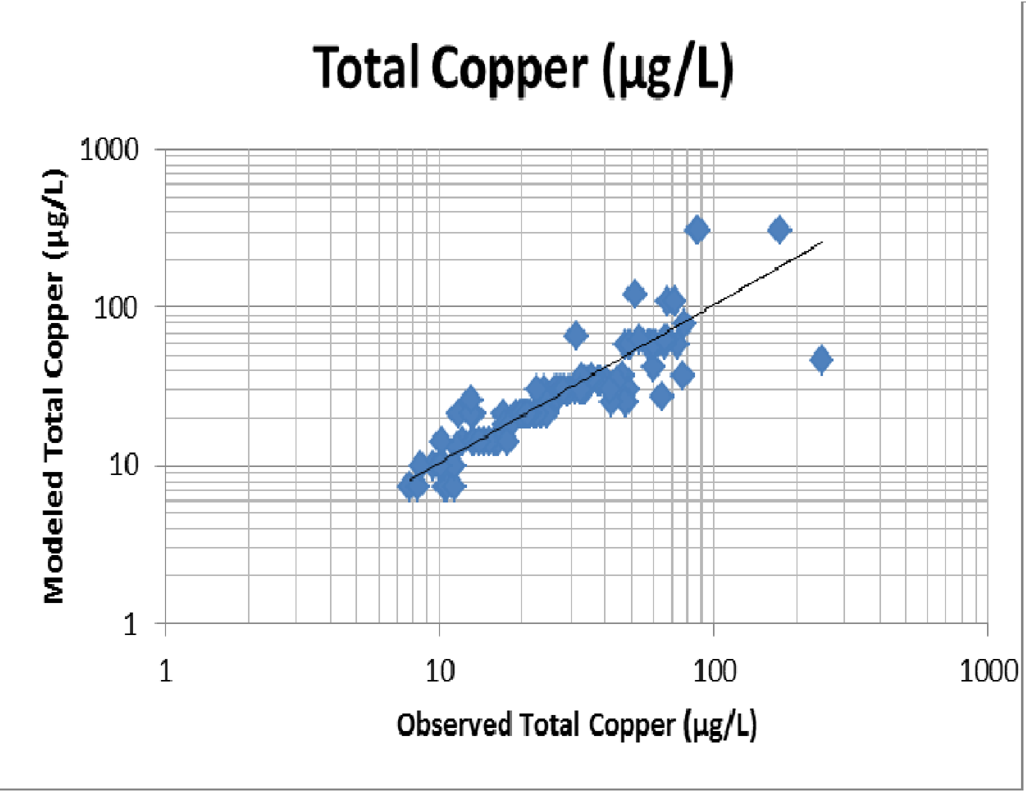
- Performance of stormwater controls are calculated based on actual sizing and other attributes that affect performance; it does not apply a generic percentage reduction.
- The calculation algorithms for the stormwater controls are based on both theory and extensive field monitoring.
- Version 10 of WinSLAMM incorporates both hydraulic and particle size routing thru and between treatment systems in complex networks.
- Regional water quality calibration files are available for many land uses and most areas of the country based on the National Stormwater Quality Database.

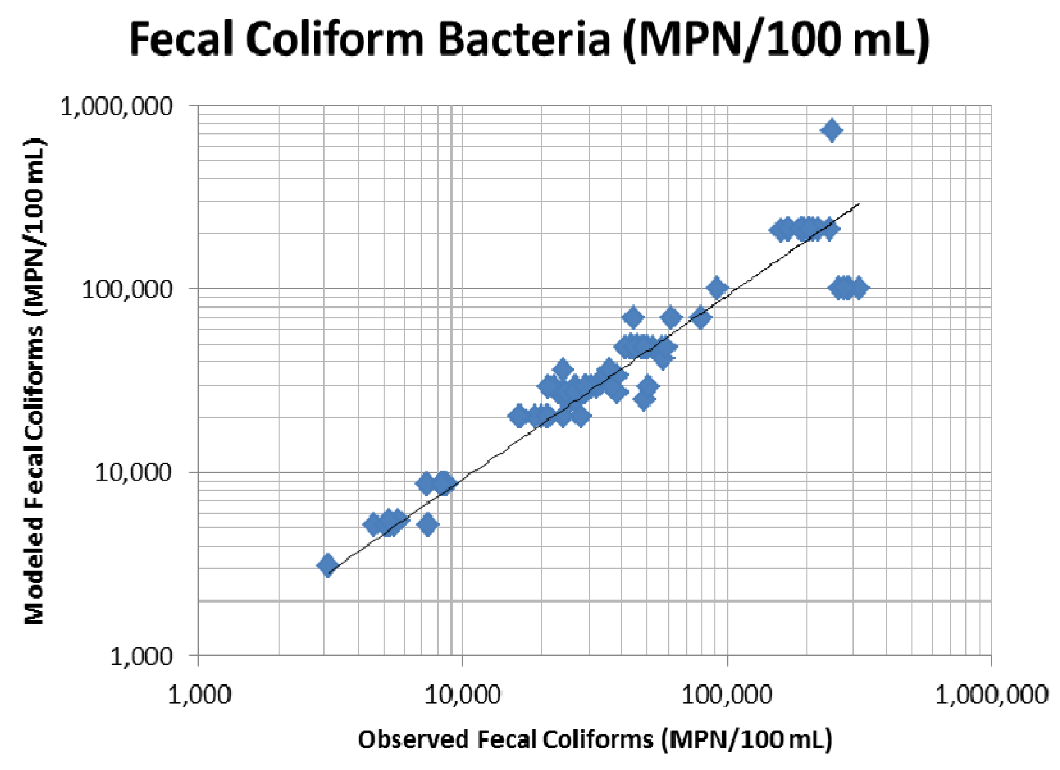
National Stormwater Quality Database and Regional WinSLAMM Calibration Areas




Total Suspended Solids (mg/L)


Nitrite plus Nitrate (mg/L as N)


Total Copper (µg/L)

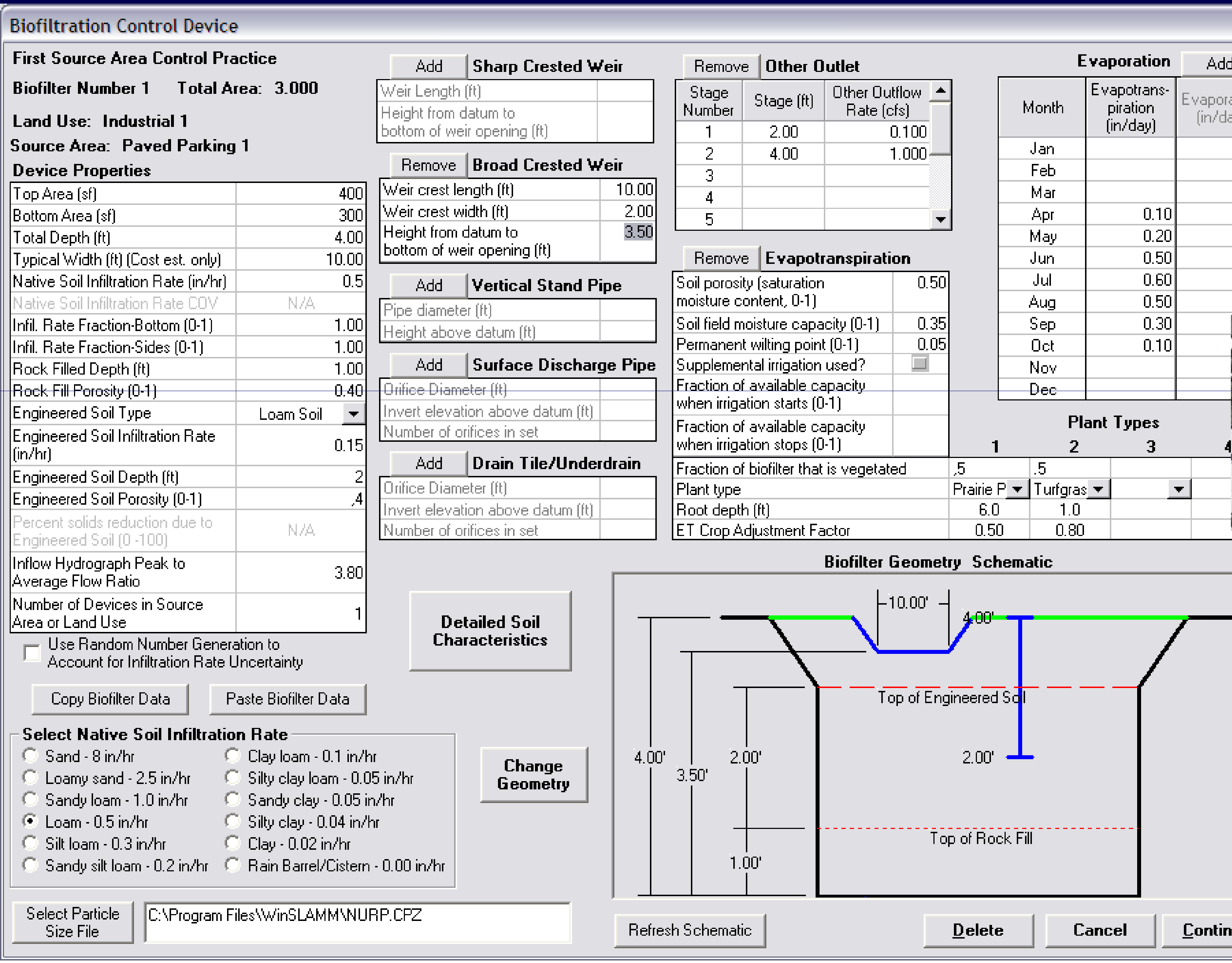

Fecal Coliform Bacteria (MPN/100 mL)

Stormwater Infiltration Controls Included in WinSLAMM

- Bioretention/biofiltration areas
- Rain gardens
- Porous pavement
- Grass swales and grass filters
- Infiltration basins
- Infiltration trenches
- Green (and blue) roofs
- Rain barrels and water tanks
- Disconnections of paved areas and roofs from the drainage system
- Evapotranspiration and stormwater beneficial use calculations are also available

Also includes: wet detention ponds, street and catchbasin cleaning, and proprietary controls (media filters and hydrodynamic devices)

Rain Garden/Biofilter Input Screen



Biofiltration Control Device

First Source Area Control Practice

Biofilter Number 1 Total Area: 3.000

Land Use: Industrial 1

Source Area: Paved Parking 1

Device Properties

Top Area (sf)	400
Bottom Area (sf)	300
Total Depth (ft)	4.00
Typical Width (ft) (Cost est. only)	10.00
Native Soil Infiltration Rate (in/hr)	0.5
Native Soil Infiltration Rate COV	N/A
Infil. Rate Fraction-Bottom (0-1)	1.00
Infil. Rate Fraction-Sides (0-1)	1.00
Rock Filled Depth (ft)	1.00
Rock Fill Porosity (0-1)	0.40
Engineered Soil Type	Loam Soil
Engineered Soil Infiltration Rate (in/hr)	0.15
Engineered Soil Depth (ft)	2
Engineered Soil Porosity (0-1)	.4
Percent solids reduction due to Engineered Soil (0 -100)	N/A
Inflow Hydrograph Peak to Average Flow Ratio	3.80
Number of Devices in Source Area or Land Use	1

☐ Use Random Number Generation to Account for Infiltration Rate Uncertainty

Select Native Soil Infiltration Rate

- ○ Sand - 8 in/hr
- ○ Loamy sand - 2.5 in/hr
- ○ Sandy loam - 1.0 in/hr
- ● Loam - 0.5 in/hr
- ○ Silt loam - 0.3 in/hr
- ○ Sandy silt loam - 0.2 in/hr
- ○ Clay loam - 0.1 in/hr
- ○ Silty clay loam - 0.05 in/hr
- ○ Sandy clay - 0.05 in/hr
- ○ Silty clay - 0.04 in/hr
- ○ Clay - 0.02 in/hr
- ○ Rain Barrel/Cistern - 0.00 in/hr

Select Particle Size File: C:\Program Files\WinSLAMM\NURP.CPZ

Sharp Crested Weir

Weir Length (ft)	
Height from datum to bottom of weir opening (ft)	

Broad Crested Weir

Weir crest length (ft)	10.00
Weir crest width (ft)	2.00
Height from datum to bottom of weir opening (ft)	3.50

Vertical Stand Pipe

Pipe diameter (ft)	
Height above datum (ft)	

Surface Discharge Pipe

Orifice Diameter (ft)	
Invert elevation above datum (ft)	
Number of orifices in set	

Drain Tile/Underdrain

Orifice Diameter (ft)	
Invert elevation above datum (ft)	
Number of orifices in set	

Other Outlet

Stage Number	Stage (ft)	Other Outflow Rate (cfs)
1	2.00	0.100
2	4.00	1.000
3		
4		
5		

Evapotranspiration

Soil porosity (saturation moisture content, 0-1)	0.50
Soil field moisture capacity (0-1)	0.35
Permanent wilting point (0-1)	0.05
Supplemental irrigation used?	☐
Fraction of available capacity when irrigation starts (0-1)	
Fraction of available capacity when irrigation stops (0-1)	

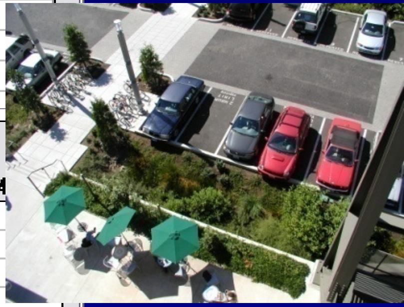
Evaporation

Month	Evapotrans-piration (in/day)	Evaporation (in/day)
Jan		
Feb		
Mar		
Apr	0.10	
May	0.20	
Jun	0.50	
Jul	0.60	
Aug	0.50	
Sep	0.30	
Oct	0.10	
Nov		
Dec		

Plant Types

	1	2	3
Fraction of biofilter that is vegetated	.5	.5	
Plant type	Prairie P	Turfgras	
Root depth (ft)	6.0	1.0	
ET Crop Adjustment Factor	0.50	0.80	

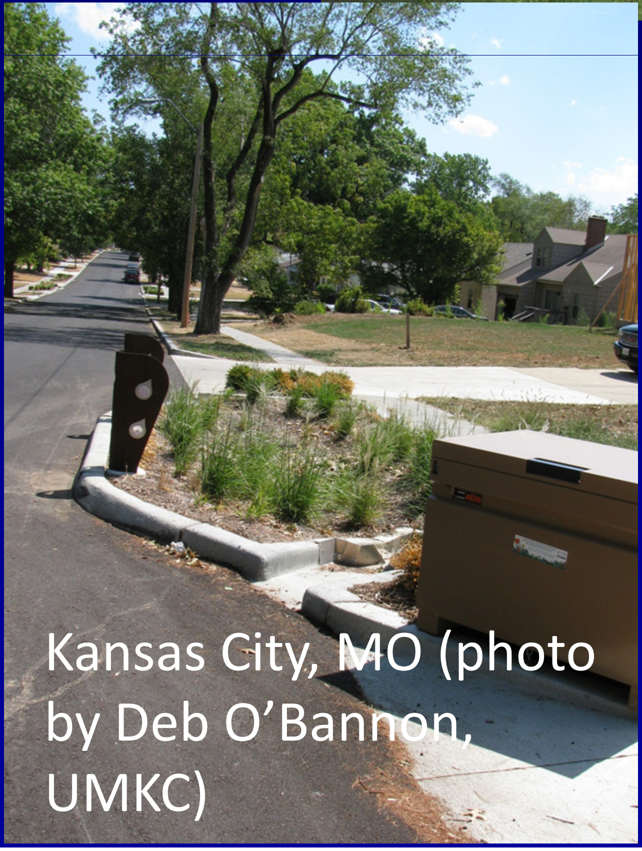
Biofilter Geometry Schematic



Different types of rain gardens/biofilters for: residential roofs, shopping center parking lots, and residential and ultra urban/downtown curb-cut biofilters.

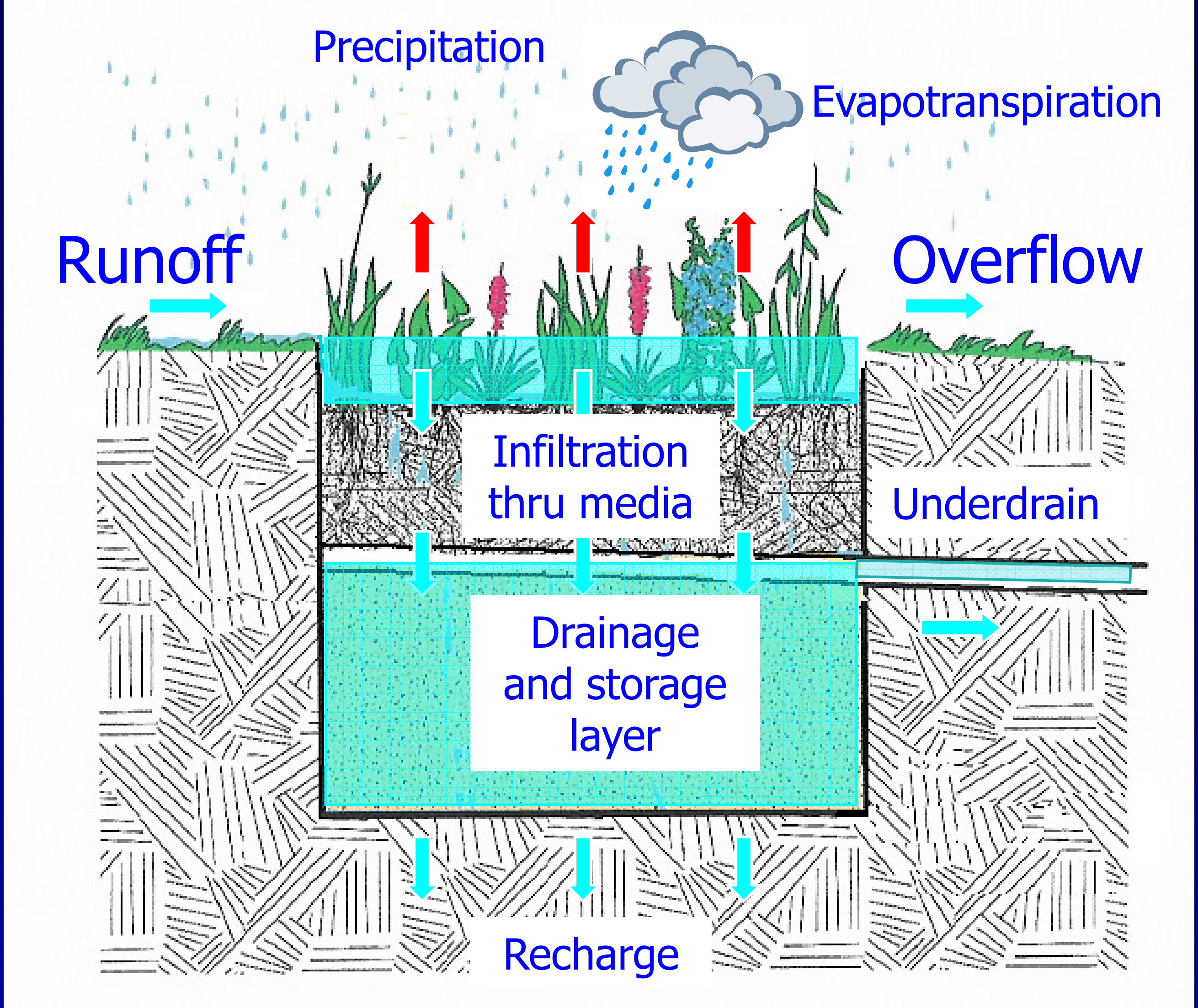

Madison, WI


Madison, WI

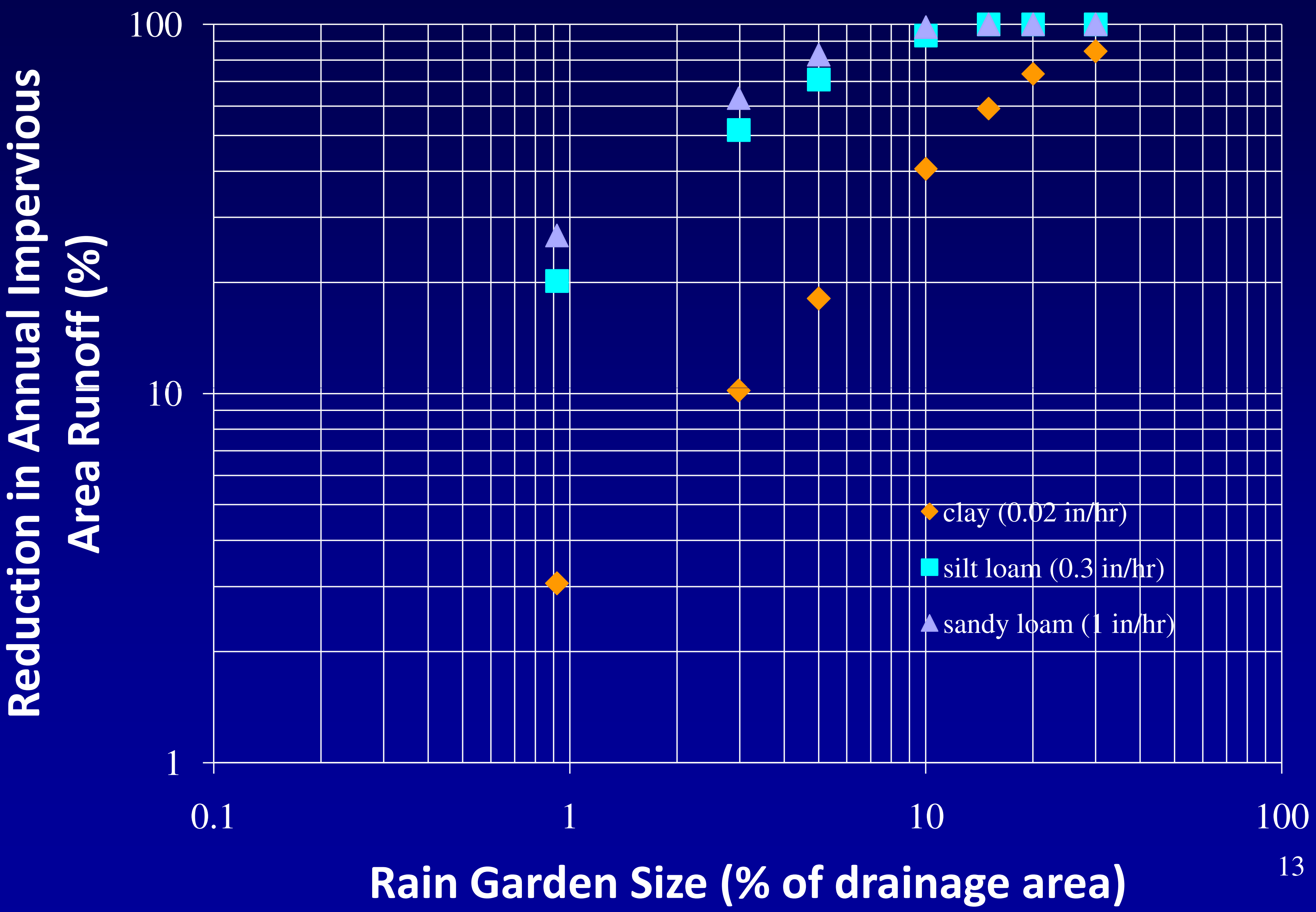

Kansas City, MO (photo by Deb O'Bannon, UMKC)


Kansas City, MO

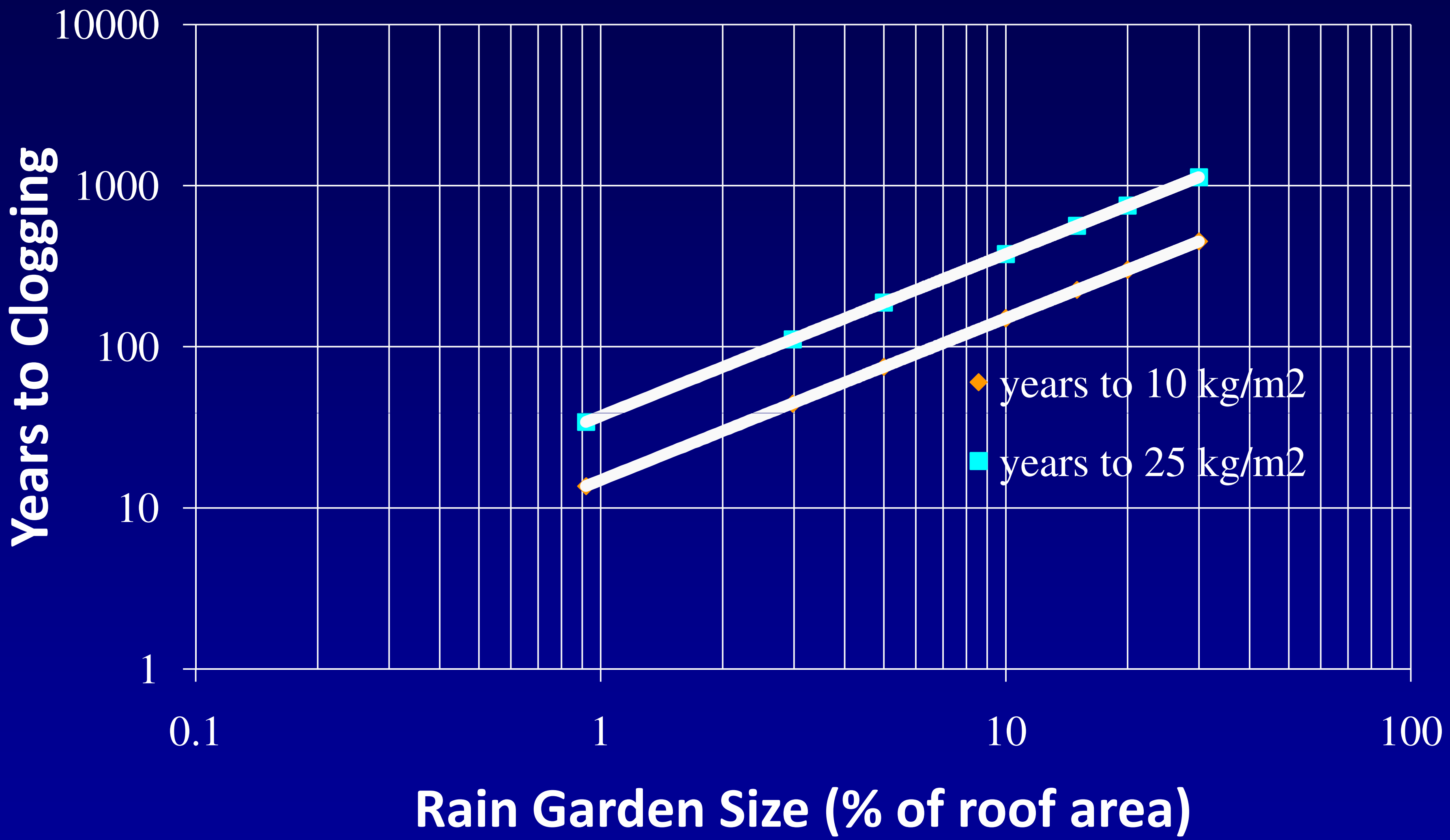
Biofiltration/Infiltration Routing Schematic



Annual Runoff Reductions from Paved Areas or Roofs for Different Sized Rain Gardens or Biofilters

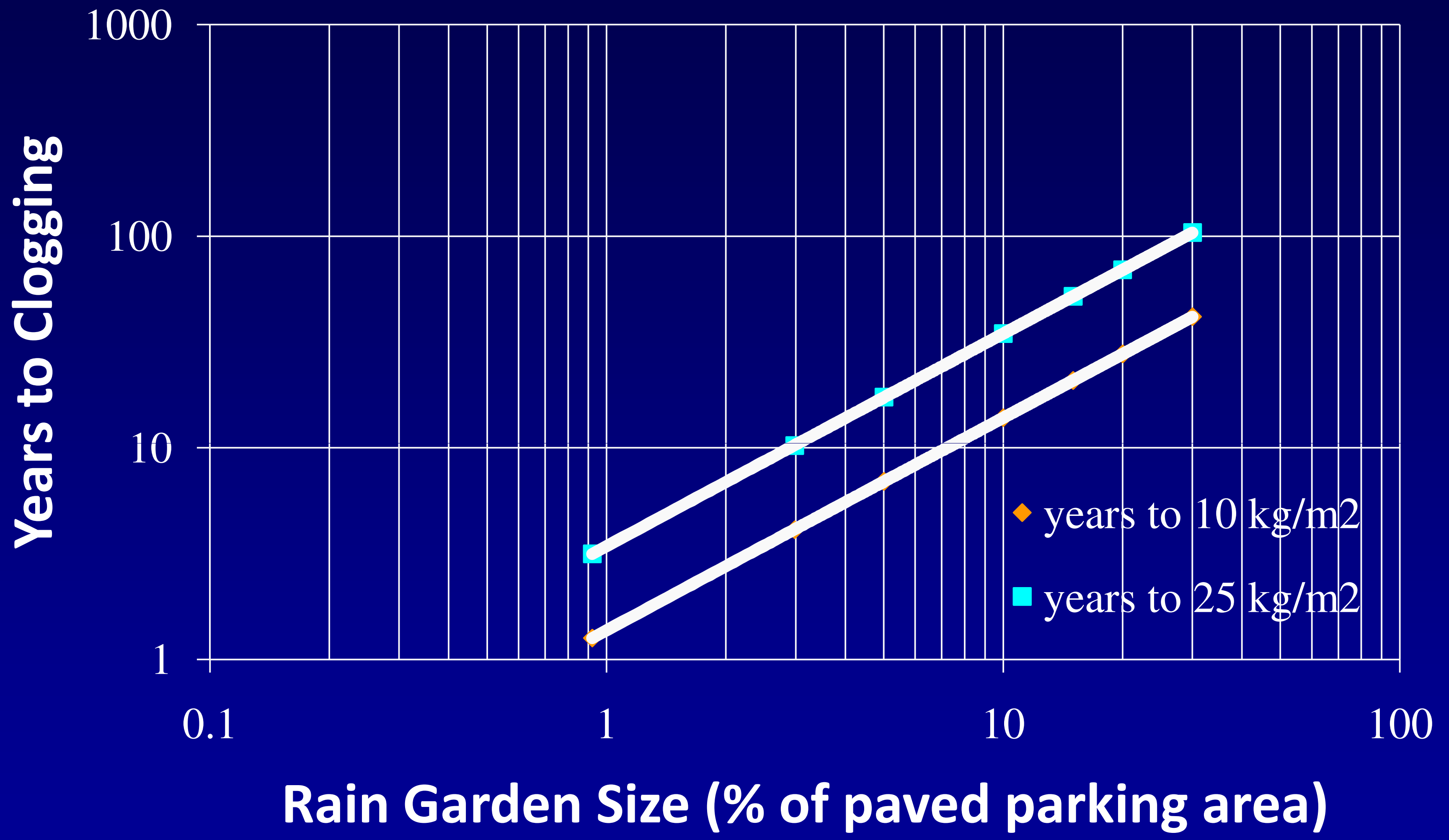


Clogging Potential for Different Sized Rain Gardens or Biofilters Receiving Roof Runoff



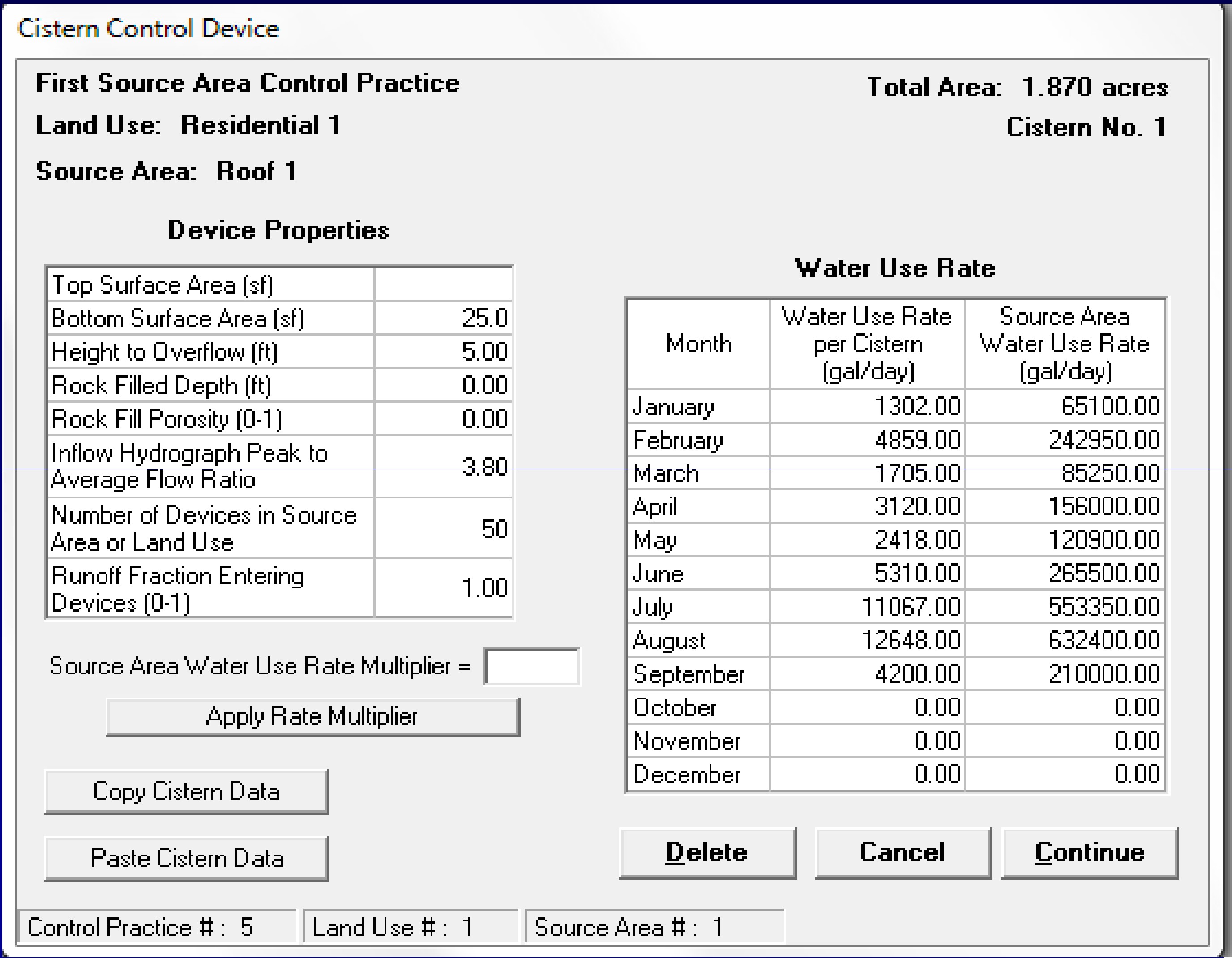
Not likely to be a problem for most roof rain gardens, as it would take several decades to approach critical sediment loading values for sizes likely necessary for significant runoff reduction (generally, want at least 10 years).

Clogging Potential for Different Sized Rain Gardens or Biofilters Receiving Paved Parking Area Runoff



Likely premature clogging potential (critical sediment loading within 10 years) for biofilters serving paved parking areas, unless at least 3 to 8% of the drainage area (most are smaller, and would therefore require suitable pre-treatment, such as grass filtering)

Water Tank/Cistern/Rain Barrel Beneficial Use of Stormwater Input Screen



Cistern Control Device

First Source Area Control Practice

Land Use: Residential 1

Source Area: Roof 1

Total Area: 1.870 acres

Cistern No. 1

Device Properties

Top Surface Area (sf)	
Bottom Surface Area (sf)	25.0
Height to Overflow (ft)	5.00
Rock Filled Depth (ft)	0.00
Rock Fill Porosity (0-1)	0.00
Inflow Hydrograph Peak to Average Flow Ratio	3.80
Number of Devices in Source Area or Land Use	50
Runoff Fraction Entering Devices (0-1)	1.00

Source Area Water Use Rate Multiplier =

Water Use Rate

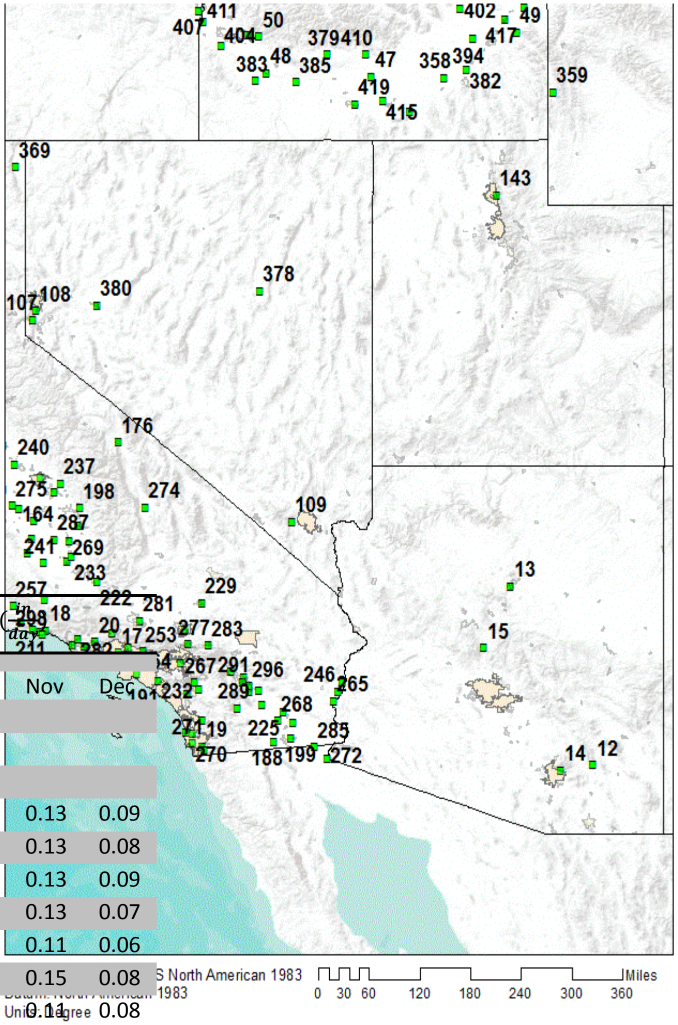
Month	Water Use Rate per Cistern (gal/day)	Source Area Water Use Rate (gal/day)
January	1302.00	65100.00
February	4859.00	242950.00
March	1705.00	85250.00
April	3120.00	156000.00
May	2418.00	120900.00
June	5310.00	265500.00
July	11067.00	553350.00
August	12648.00	632400.00
September	4200.00	210000.00
October	0.00	0.00
November	0.00	0.00
December	0.00	0.00

Control Practice # : 5
Land Use # : 1
Source Area # : 1

ET Rates can Vary Greatly Over Small Distances, Especially in the West

Our recent WERF report has compilations of various ET databases showing monthly ET values for many regions in the US that can be used to estimate the irrigation needs for stormwater beneficial uses. Some areas have large amounts of ET data (such as CA and FL), while the data are more sparse for other areas.

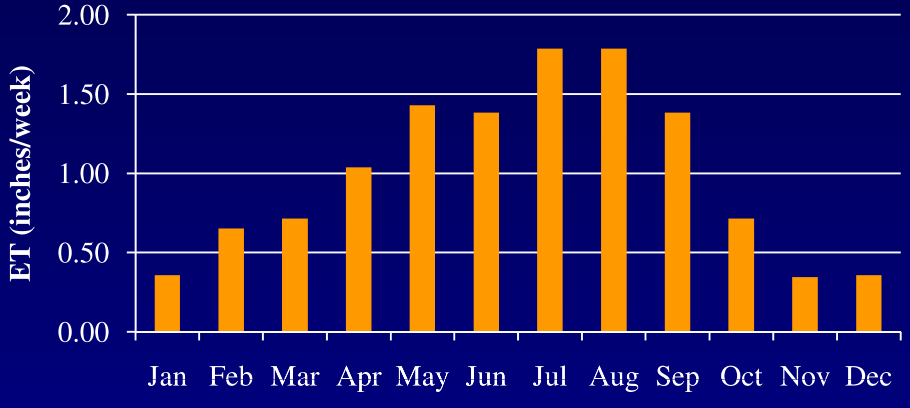
Urban ET values need to be modified based on microclimate factors that differ from typical agricultural areas where ET rates are usually measured.



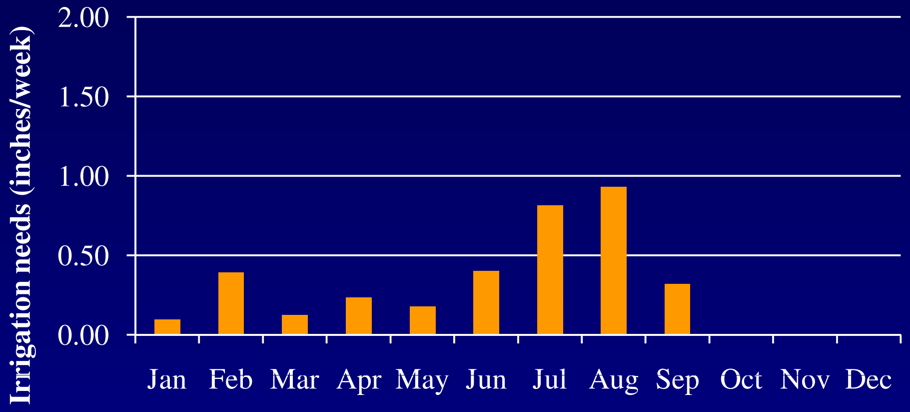
Lat	Long	Elev	Station Name	Years of Data	Kimberly Penman Equation (1982) (ET_r)											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
64.84	-147.62	454	Fairbanks Alaska		Unavailable at this time											
61.08	-149.73	1480	Rabbit Creek Alaska		Unavailable at this time											
57.8	-135.13	450	Hoonah Alaska		Unavailable at this time											
33.44	-86.081	600	Talladega Alabama	5	0.07	0.13	0.18	0.24	0.26	0.26	0.25	0.24	0.23	0.21	0.13	0.09
32.96	-87.171	363	Oakmulgee Alabama	7	0.08	0.09	0.13	0.20	0.22	0.25	0.24	0.22	0.21	0.17	0.13	0.08
34.14	-87.362	804	Bankhead Alabama	7	0.06	0.12	0.17	0.24	0.25	0.26	0.25	0.25	0.23	0.20	0.13	0.09
32.45	-85.641	283	Tuskegee Alabama	5	0.08	0.13	0.17	0.24	0.26	0.27	0.27	0.25	0.23	0.19	0.13	0.07
34.76	-90.722	253	Marianna Arkansas	3	0.06	0.07	0.13	0.18	0.21	0.27	0.26	0.25	0.20	0.16	0.11	0.06
34.27	-92.393	270	Sheridan Arkansas	6	0.07	0.12	0.19	0.08	0.32	0.31	0.20	0.30	0.28	0.21	0.15	0.08
36.07	-93.357	2365	Compton Arkansas	2	0.06	0.10	0.15	0.21	0.32	0.38	0.35	0.30	0.24	0.22	0.11	0.08
35.87	-94.297	1633	Strickler Arkansas	6	0.06	0.07	0.12	0.16	0.19	0.23	0.24	0.24	0.20	0.15	0.11	0.07
32.4	-110.27	4175	Muleshoe Ranch AZ	13	0.09	0.15	0.22	0.29	0.35	0.37	0.29	0.29	0.31	0.25	0.16	0.11
35.15	-111.68	7000	Flagstaff Arizona	10	0.06	0.10	0.14	0.18	0.24	0.28	0.28	0.24	0.23	0.18	0.10	0.06
32.32	-110.81	3100	Saguaro Arizona	8	0.12	0.18	0.21	0.29	0.35	0.36	0.30	0.29	0.31	0.26	0.17	0.11

Kansas City Water Harvesting Potential of Roof Runoff

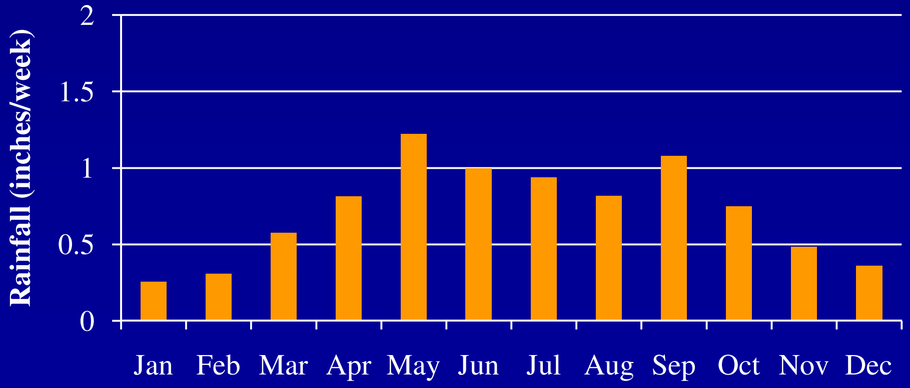
Evapotranspiration per Week (typical turfgrass)



Supplemental Irrigation Needs per Week (typical turfgass)

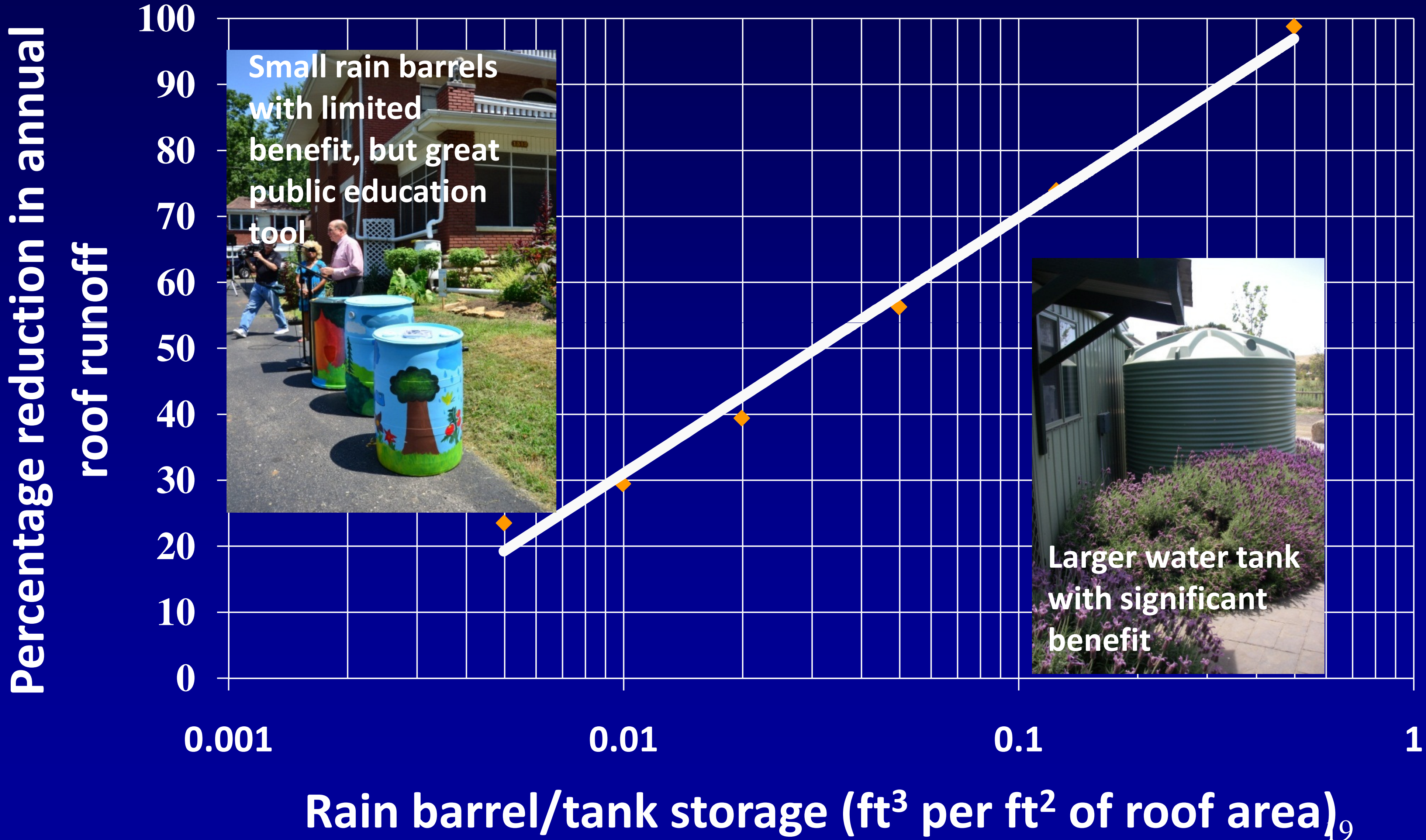


Monthly Rainfall (per week)



Irrigation needs for the landscaped areas surrounding the homes were calculated by subtracting long-term infiltrating rainfall amounts from the regional evapotranspiration demands for turf grass. However, can “over-irrigate” as water conservation is not a primary stormwater management goal, and want to infiltrate as much roof runoff as possible into the landscaped areas without harming the plants.

Reductions in Annual Runoff Quantity from Directly Connected Roofs with the use of Rain Barrels and Water Tanks (Kansas City CSO Study Area)



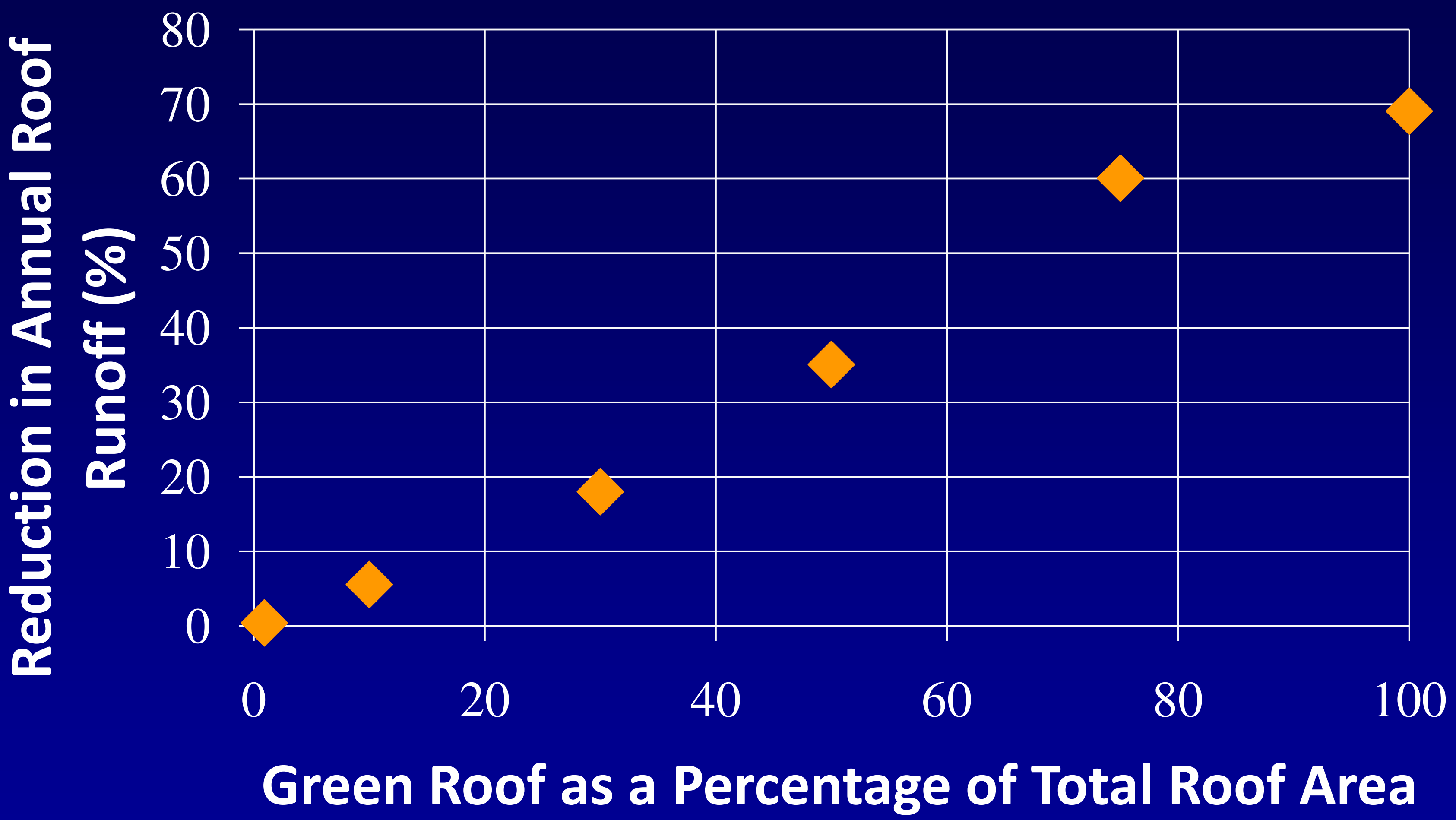
Small rain barrels with limited benefit, but great public education tool

Larger water tank with significant benefit

0.125 ft of storage is needed for use of 75% of the total annual runoff from these roofs for irrigation. With 945 ft^2 roofs, the total storage is therefore 118 ft^3, which would require 25 typical rain barrels per house, way too many! However, a relatively small water tank (5 ft D and 6 ft H) can be used instead.

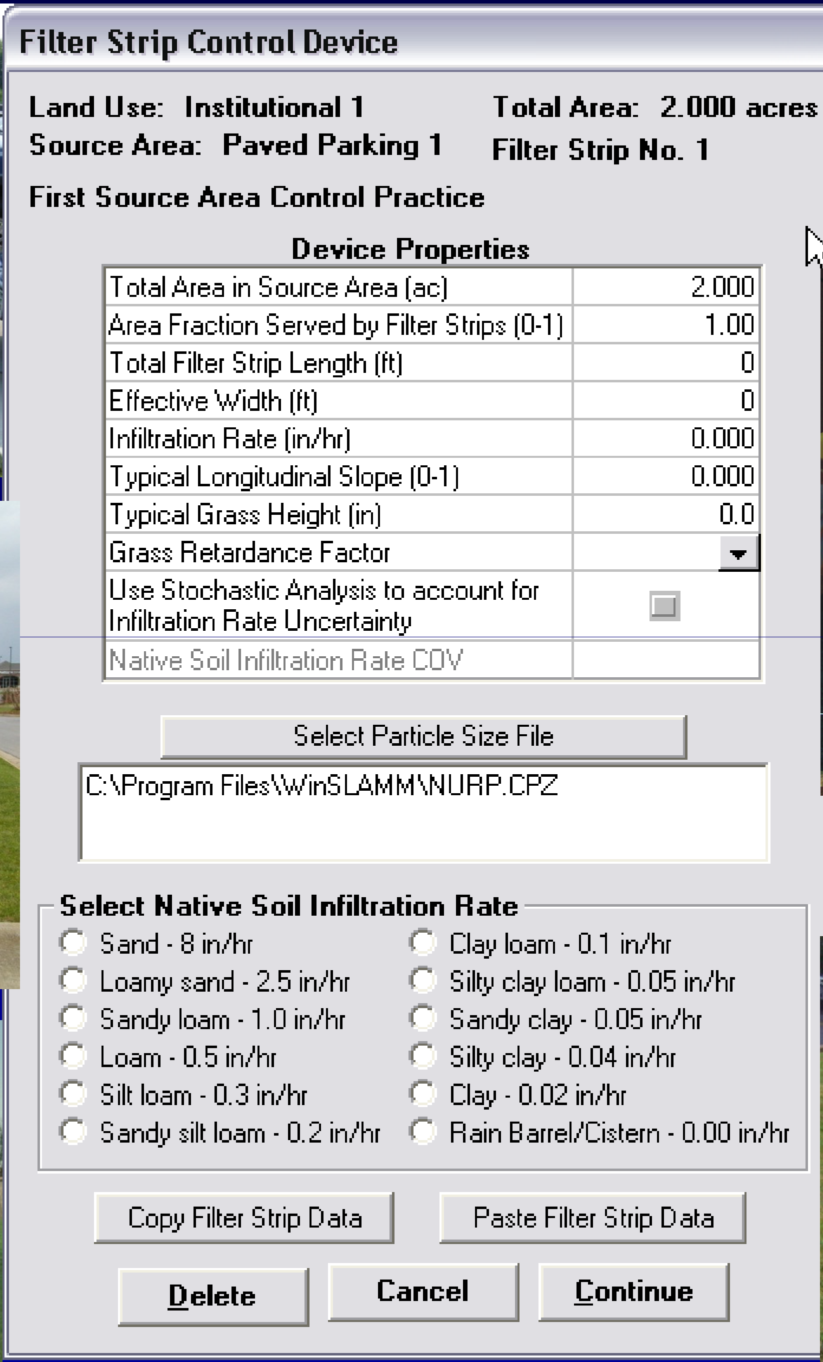
rain barrel/tank storage per house (ft^3)	percentage reduction in annual roof runoff	# of 35 gallon rain barrels	tank height size required if 5 ft D (ft)	tank height size required if 10 ft D (ft)
0	0	0	0	0
4.7	20	1	0.24	0.060
9.4	31	2	0.45	0.12
19	43	4	0.96	0.24
47	58	10	2.4	0.60
118	75	25	6.0	1.5
470	98	100	24	6.0

Annual Roof Runoff Reductions for Birmingham, AL, Green Roofs



Green roof performance calculations are similar to the biofilter calculations (but no infiltration!) and rely on ET as the major water reduction process. Excess roof runoff can be directed to rain gardens or water tanks for further runoff volume reductions.

Grass Filter Strips Input Screen



Filter Strip Control Device

Land Use: Institutional 1
Total Area: 2.000 acres
Source Area: Paved Parking 1
Filter Strip No. 1

First Source Area Control Practice

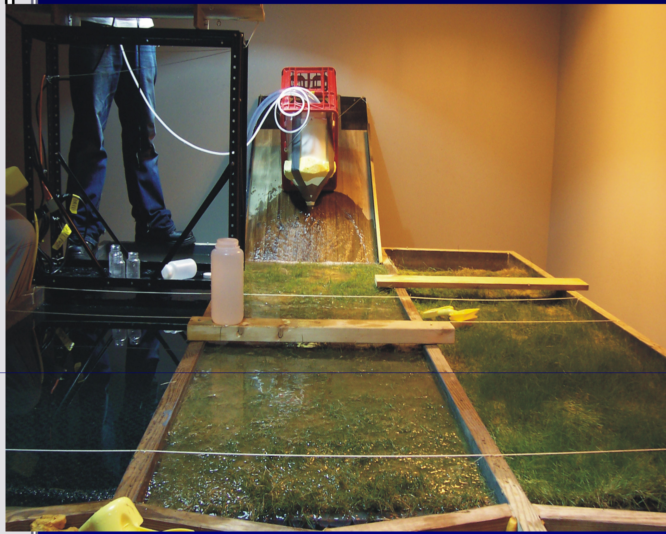
Device Properties

Total Area in Source Area (ac)	2.000
Area Fraction Served by Filter Strips (0-1)	1.00
Total Filter Strip Length (ft)	0
Effective Width (ft)	0
Infiltration Rate (in/hr)	0.000
Typical Longitudinal Slope (0-1)	0.000
Typical Grass Height (in)	0.0
Grass Retardance Factor	
Use Stochastic Analysis to account for Infiltration Rate Uncertainty	☐
Native Soil Infiltration Rate COV	

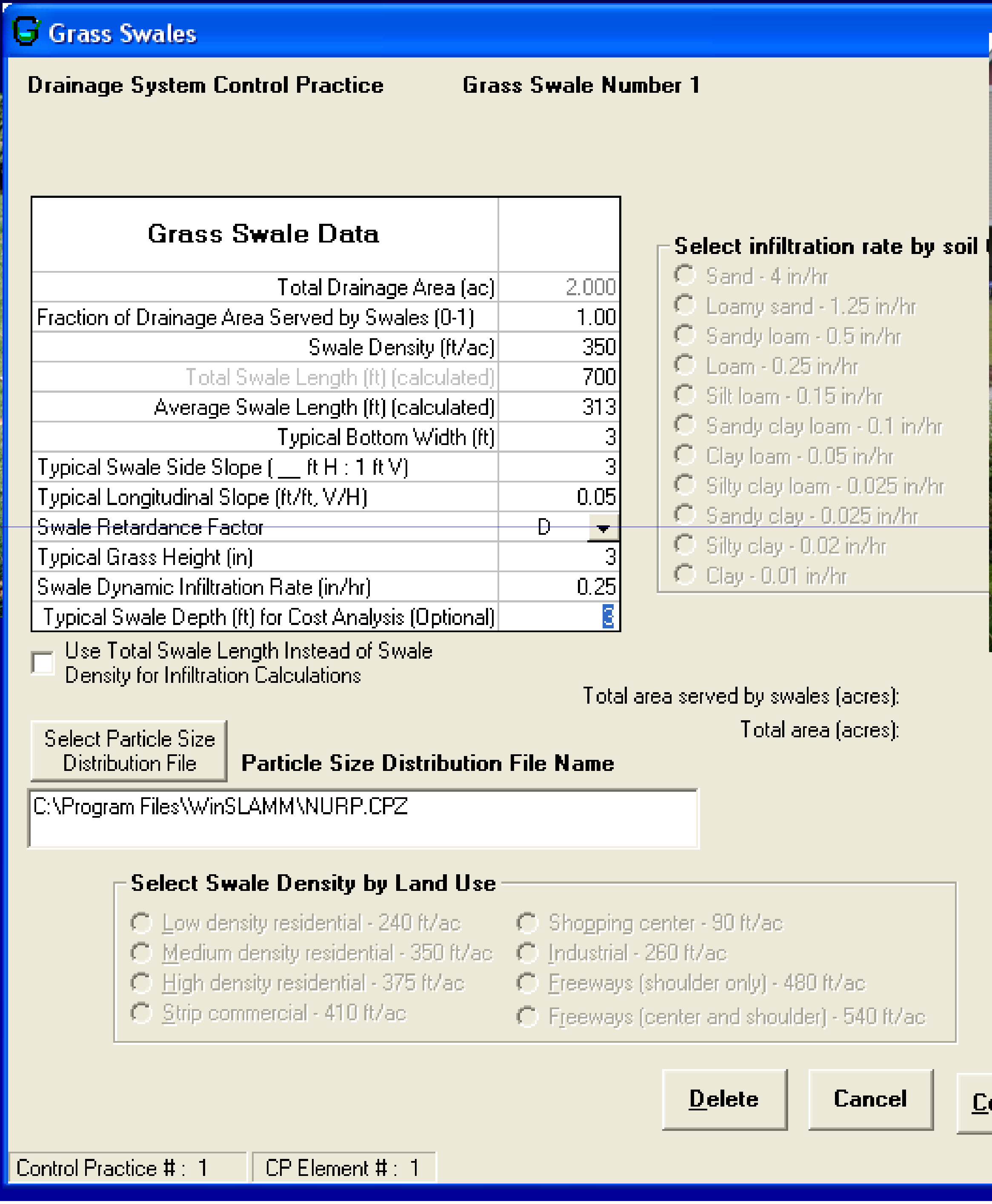
C:\Program Files\WinSLAMM\NURP.CPZ

Select Native Soil Infiltration Rate

○ Sand - 8 in/hr
○ Loamy sand - 2.5 in/hr
○ Sandy loam - 1.0 in/hr
○ Loam - 0.5 in/hr
○ Silt loam - 0.3 in/hr
○ Sandy silt loam - 0.2 in/hr
○ Clay loam - 0.1 in/hr
○ Silty clay loam - 0.05 in/hr
○ Sandy clay - 0.05 in/hr
○ Silty clay - 0.04 in/hr
○ Clay - 0.02 in/hr
○ Rain Barrel/Cistern - 0.00 in/hr



Grass Swales Input Screen



Drainage System Control Practice **Grass Swale Number 1**

Grass Swale Data	
Total Drainage Area (ac)	2.000
Fraction of Drainage Area Served by Swales (0-1)	1.00
Swale Density (ft/ac)	350
Total Swale Length (ft) (calculated)	700
Average Swale Length (ft) (calculated)	313
Typical Bottom Width (ft)	3
Typical Swale Side Slope (__ ft H : 1 ft V)	3
Typical Longitudinal Slope (ft/ft, V/H)	0.05
Swale Retardance Factor	D
Typical Grass Height (in)	3
Swale Dynamic Infiltration Rate (in/hr)	0.25
Typical Swale Depth (ft) for Cost Analysis (Optional)	3

Select infiltration rate by soil

- ○ Sand - 4 in/hr
- ○ Loamy sand - 1.25 in/hr
- ○ Sandy loam - 0.5 in/hr
- ○ Loam - 0.25 in/hr
- ○ Silt loam - 0.15 in/hr
- ○ Sandy clay loam - 0.1 in/hr
- ○ Clay loam - 0.05 in/hr
- ○ Silty clay loam - 0.025 in/hr
- ○ Sandy clay - 0.025 in/hr
- ○ Silty clay - 0.02 in/hr
- ○ Clay - 0.01 in/hr

☐ Use Total Swale Length Instead of Swale Density for Infiltration Calculations

Total area served by swales (acres):

Total area (acres):

Particle Size Distribution File Name

C:\Program Files\WinSLAMM\NURP.CPZ

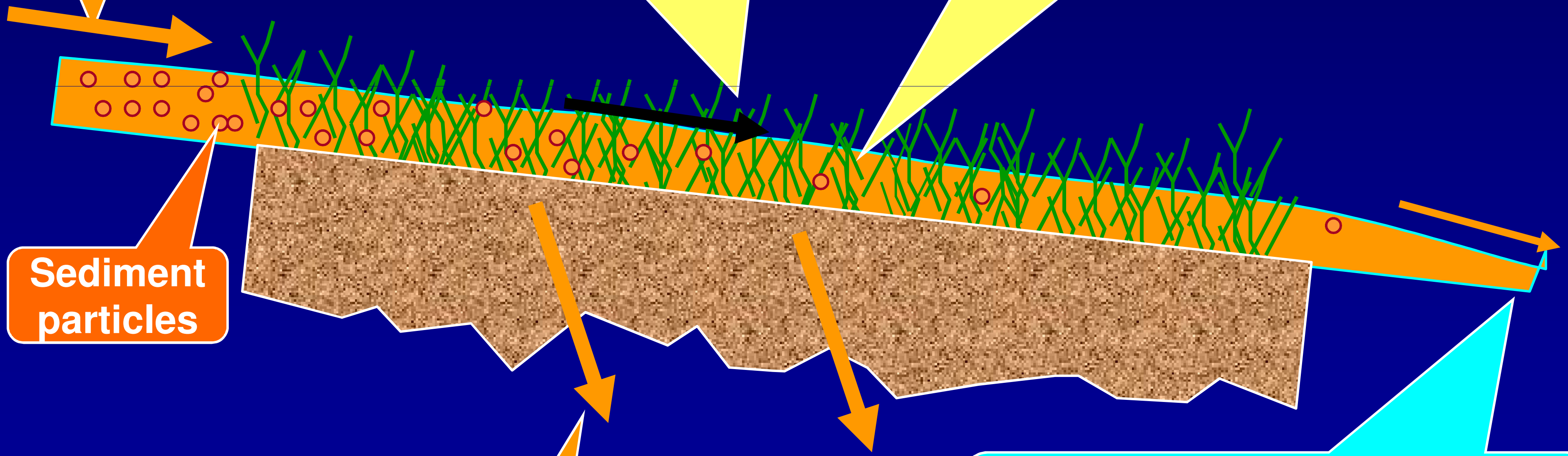
Select Swale Density by Land Use

- ○ Low density residential - 240 ft/ac
- ○ Medium density residential - 350 ft/ac
- ○ High density residential - 375 ft/ac
- ○ Strip commercial - 410 ft/ac
- ○ Shopping center - 90 ft/ac
- ○ Industrial - 260 ft/ac
- ○ Freeways (shoulder only) - 480 ft/ac
- ○ Freeways (center and shoulder) - 540 ft/ac

Control Practice # : 1

CP Element # : 1

Pollutant Control in Grass Swales and Grass Filters



Runoff from Pervious/ impervious area

Reducing runoff velocity

Trapping sediments and associated pollutants

Sediment particles

Infiltration

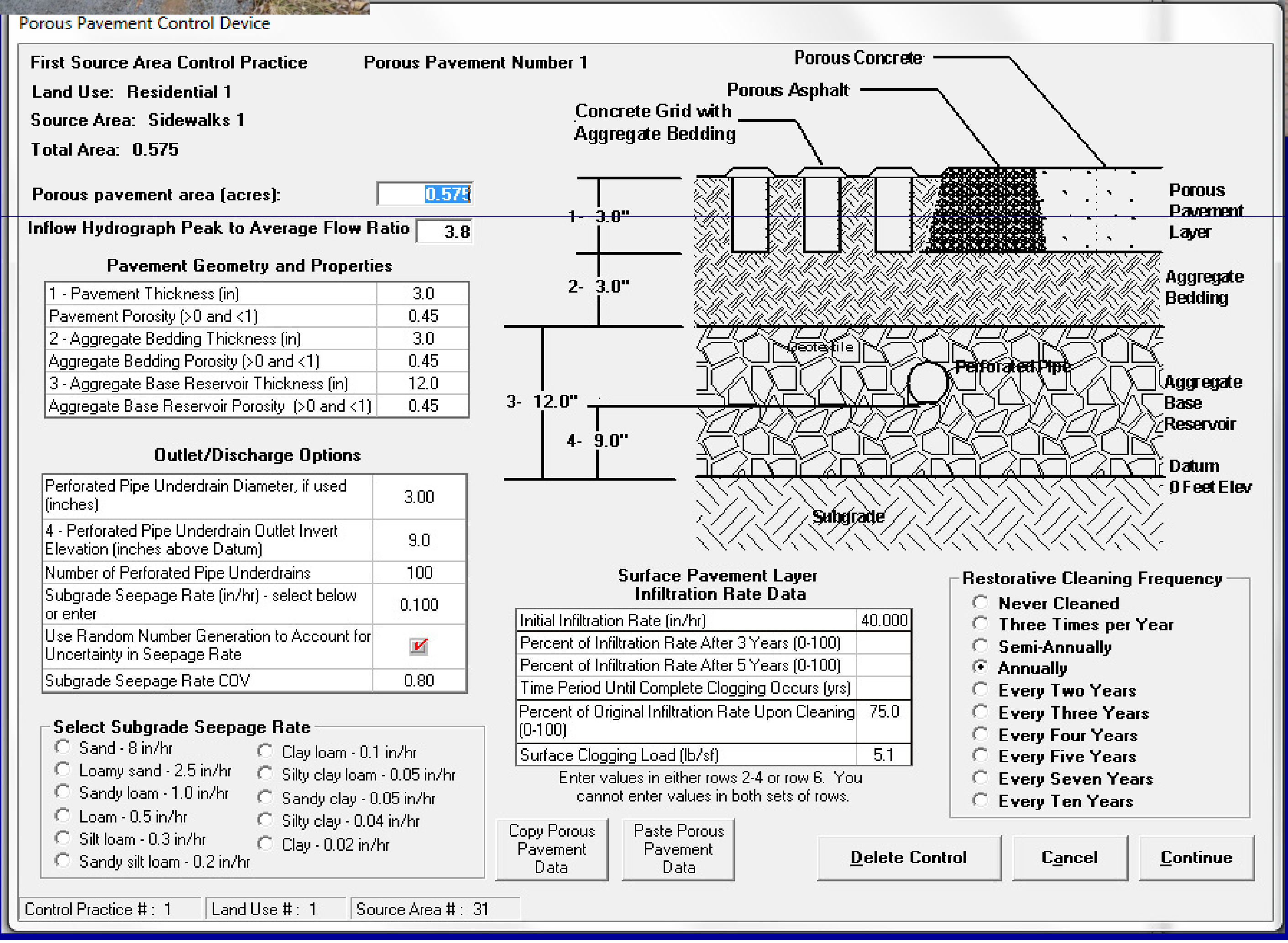
Reduced volume and treated runoff

Porous Pavement Input Screen


Kansas City, MO


Malmo, Sweden


Madison, WI


Porous Pavement Control Device

First Source Area Control Practice **Porous Pavement Number 1**

Land Use: Residential 1

Source Area: Sidewalks 1

Total Area: 0.575

Porous pavement area (acres): 0.575

Inflow Hydrograph Peak to Average Flow Ratio 3.8

Pavement Geometry and Properties

1 - Pavement Thickness (in)	3.0
Pavement Porosity (>0 and <1)	0.45
2 - Aggregate Bedding Thickness (in)	3.0
Aggregate Bedding Porosity (>0 and <1)	0.45
3 - Aggregate Base Reservoir Thickness (in)	12.0
Aggregate Base Reservoir Porosity (>0 and <1)	0.45

Outlet/Discharge Options

Perforated Pipe Underdrain Diameter, if used (inches)	3.00
4 - Perforated Pipe Underdrain Outlet Invert Elevation (inches above Datum)	9.0
Number of Perforated Pipe Underdrains	100
Subgrade Seepage Rate (in/hr) - select below or enter	0.100
Use Random Number Generation to Account for Uncertainty in Seepage Rate	☑
Subgrade Seepage Rate COV	0.80

Select Subgrade Seepage Rate

○ Sand - 8 in/hr
○ Loamy sand - 2.5 in/hr
○ Sandy loam - 1.0 in/hr
○ Loam - 0.5 in/hr
○ Silt loam - 0.3 in/hr
○ Sandy silt loam - 0.2 in/hr
○ Clay loam - 0.1 in/hr
○ Silty clay loam - 0.05 in/hr
○ Sandy clay - 0.05 in/hr
○ Silty clay - 0.04 in/hr
○ Clay - 0.02 in/hr

Surface Pavement Layer Infiltration Rate Data

Initial Infiltration Rate (in/hr)	40.000
Percent of Infiltration Rate After 3 Years (0-100)	
Percent of Infiltration Rate After 5 Years (0-100)	
Time Period Until Complete Clogging Occurs (yrs)	
Percent of Original Infiltration Rate Upon Cleaning (0-100)	75.0
Surface Clogging Load (lb/sf)	5.1

Enter values in either rows 2-4 or row 6. You cannot enter values in both sets of rows.

Restorative Cleaning Frequency

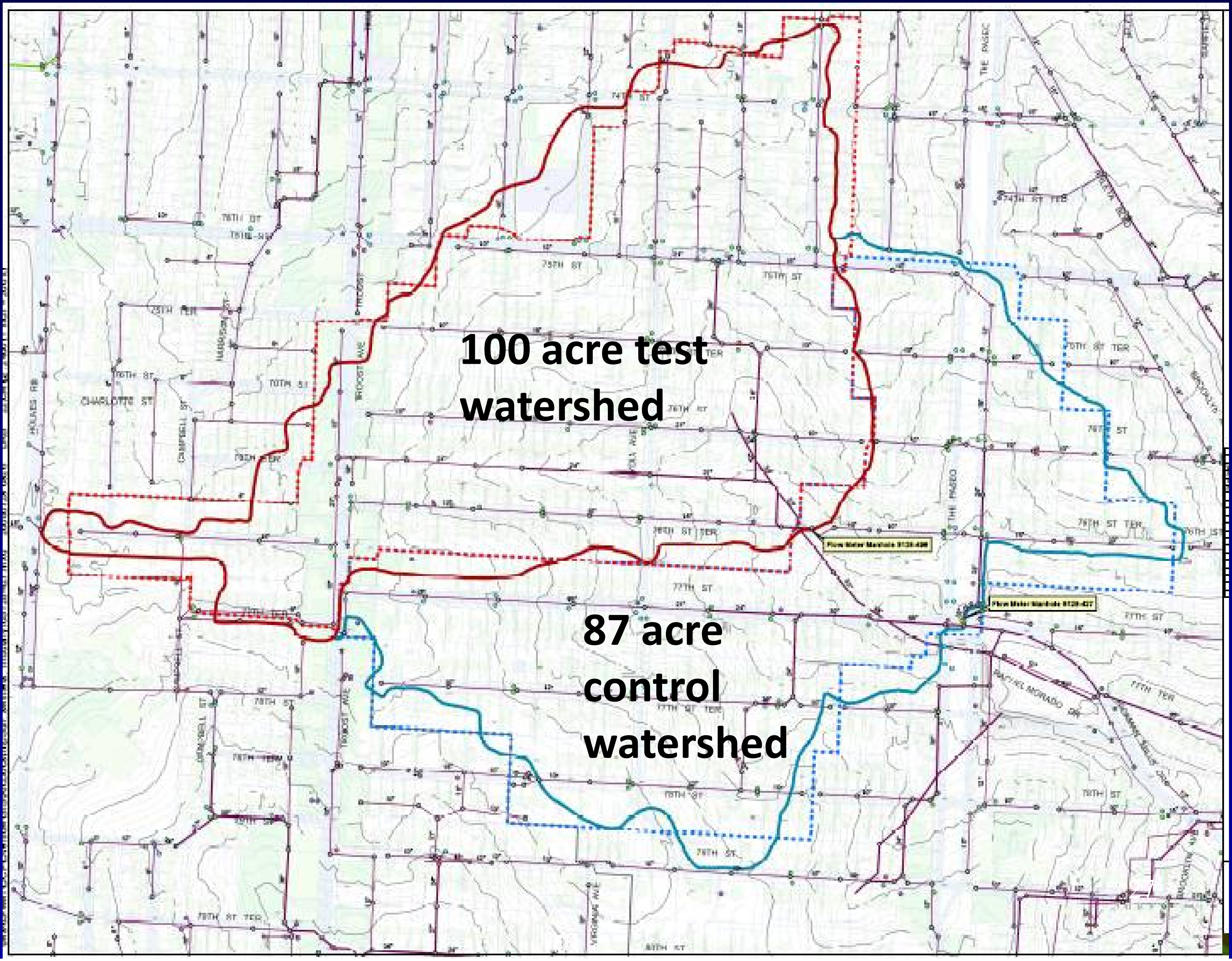
○ Never Cleaned
○ Three Times per Year
○ Semi-Annually
● Annually
○ Every Two Years
○ Every Three Years
○ Every Four Years
○ Every Five Years
○ Every Seven Years
○ Every Ten Years

Control Practice # : 1 | Land Use # : 1 | Source Area # : 31

Kansas City's CSO Challenge

- Combined sewer area: 58 mi^2
- Fully developed
- Rainfall: 37 in./yr
- 36 sewer overflows/yr by rain > 0.6 in; reduce frequency by 65%.
- 6.4 billion gal overflow/yr, reduce to 1.4 billion gal/yr
- Aging wastewater infrastructure
- Sewer backups
- Poor receiving-water quality

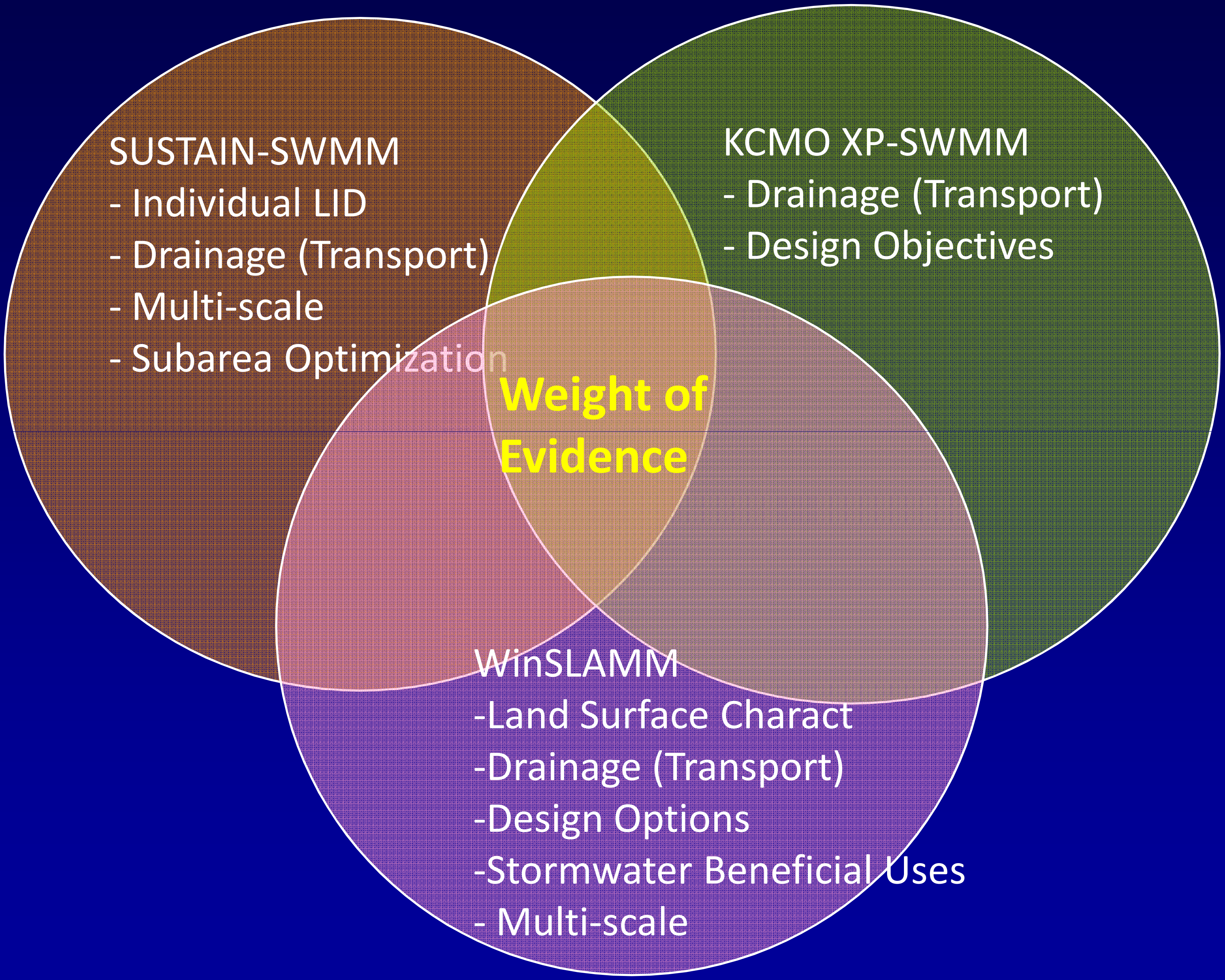
Adjacent Test and Control Watersheds



100 acre test watershed

87 acre control watershed

KC’s Modeling Connections

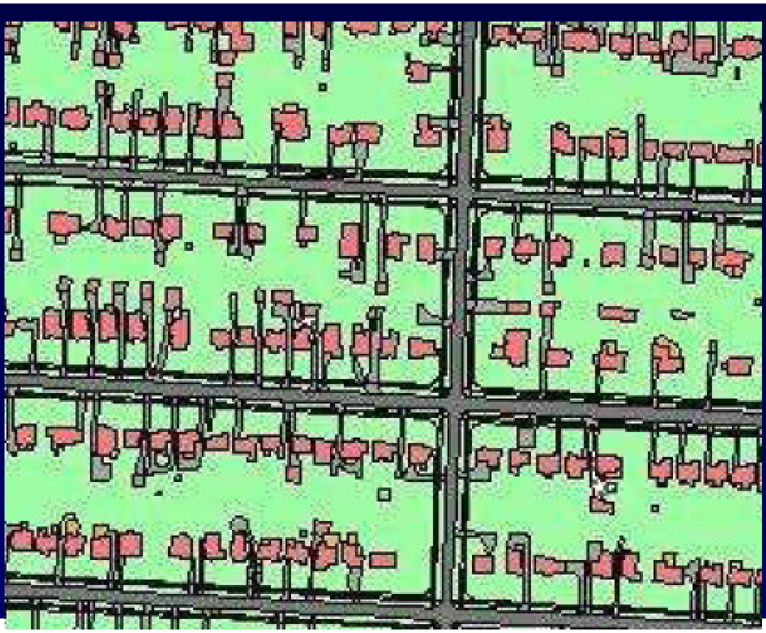


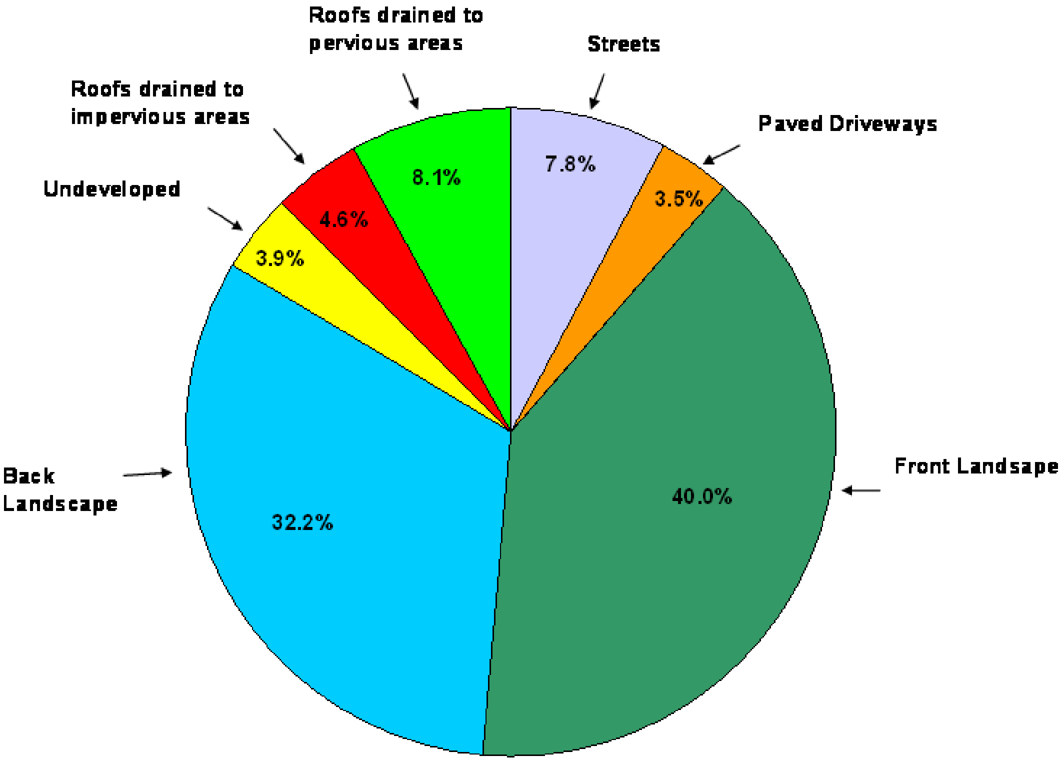
SUSTAIN-SWMM
- Individual LID
- Drainage (Transport)
- Multi-scale
- Subarea Optimization

KCMO XP-SWMM
- Drainage (Transport)
- Design Objectives

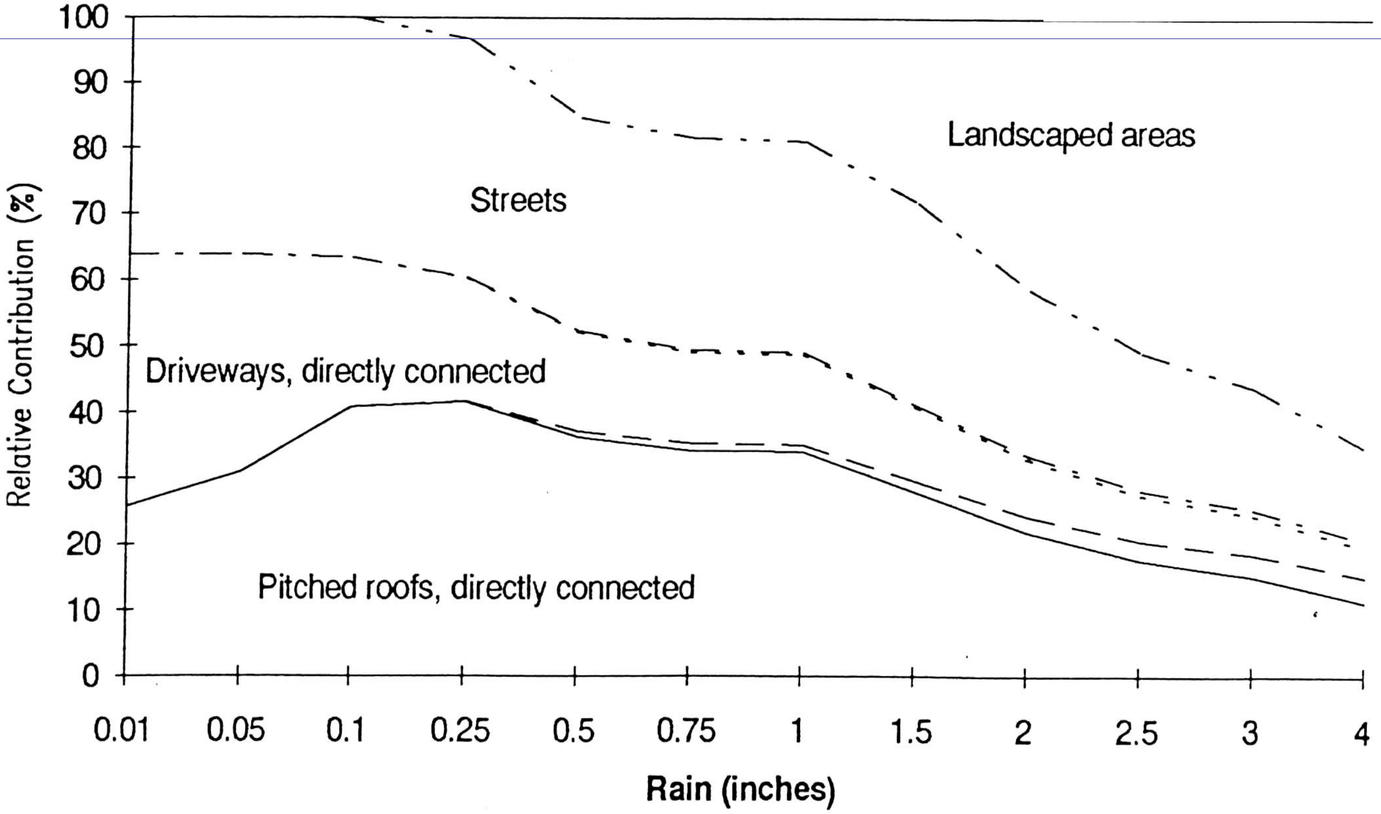
Weight of Evidence

WinSLAMM
- Land Surface Charact
- Drainage (Transport)
- Design Options
- Stormwater Beneficial Uses
- Multi-scale



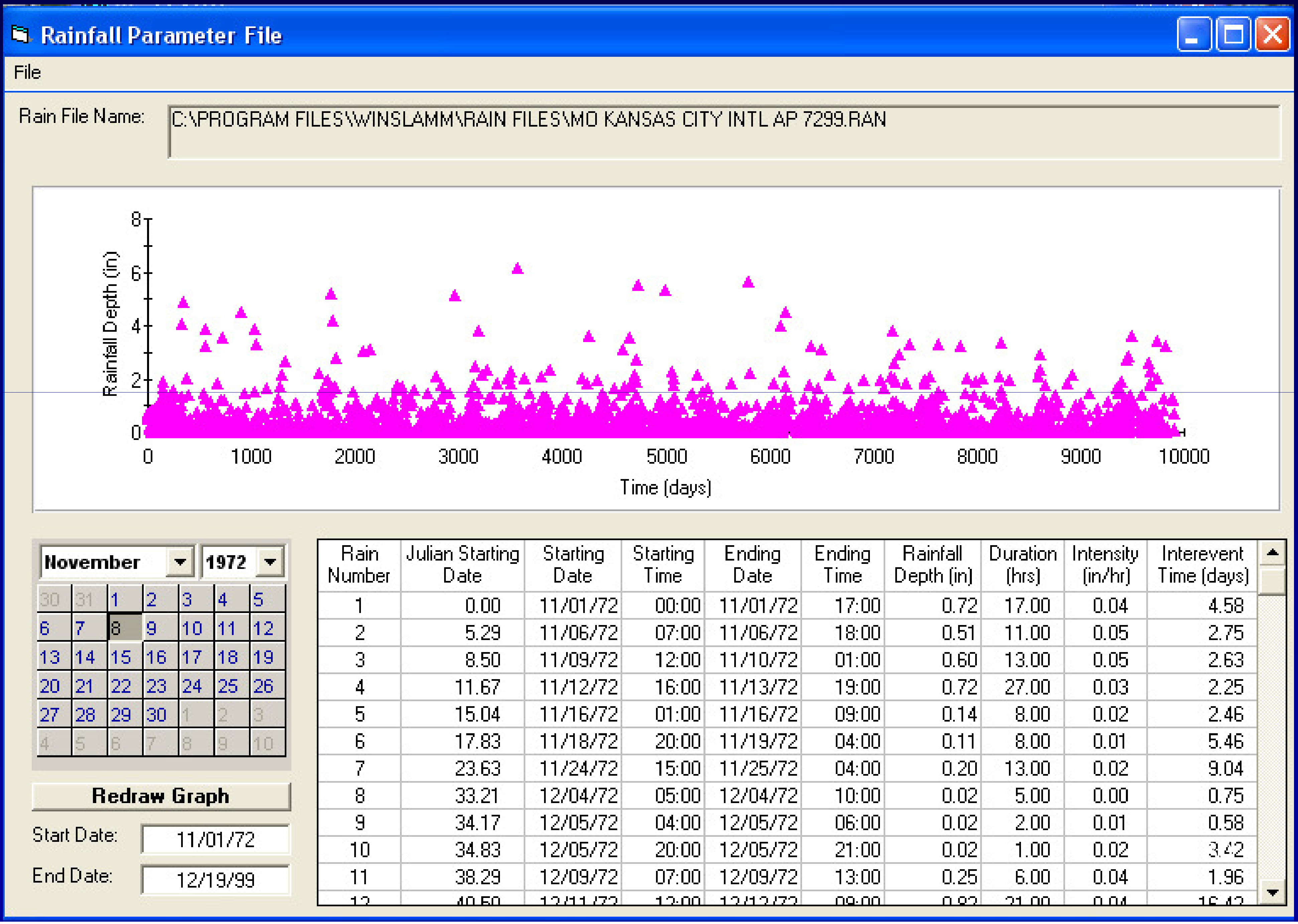


Medium Density Residential Area, Runoff



Surveys were conducted for each house and lot in the study area. This information was used with the GIS data and WinSLAMM to determine the sources of the runoff during different rain conditions

Continuous Simulations using Kansas City 1972 to 1999 Rain Series to Evaluate Roof Runoff Controls in Combined Sewer Area



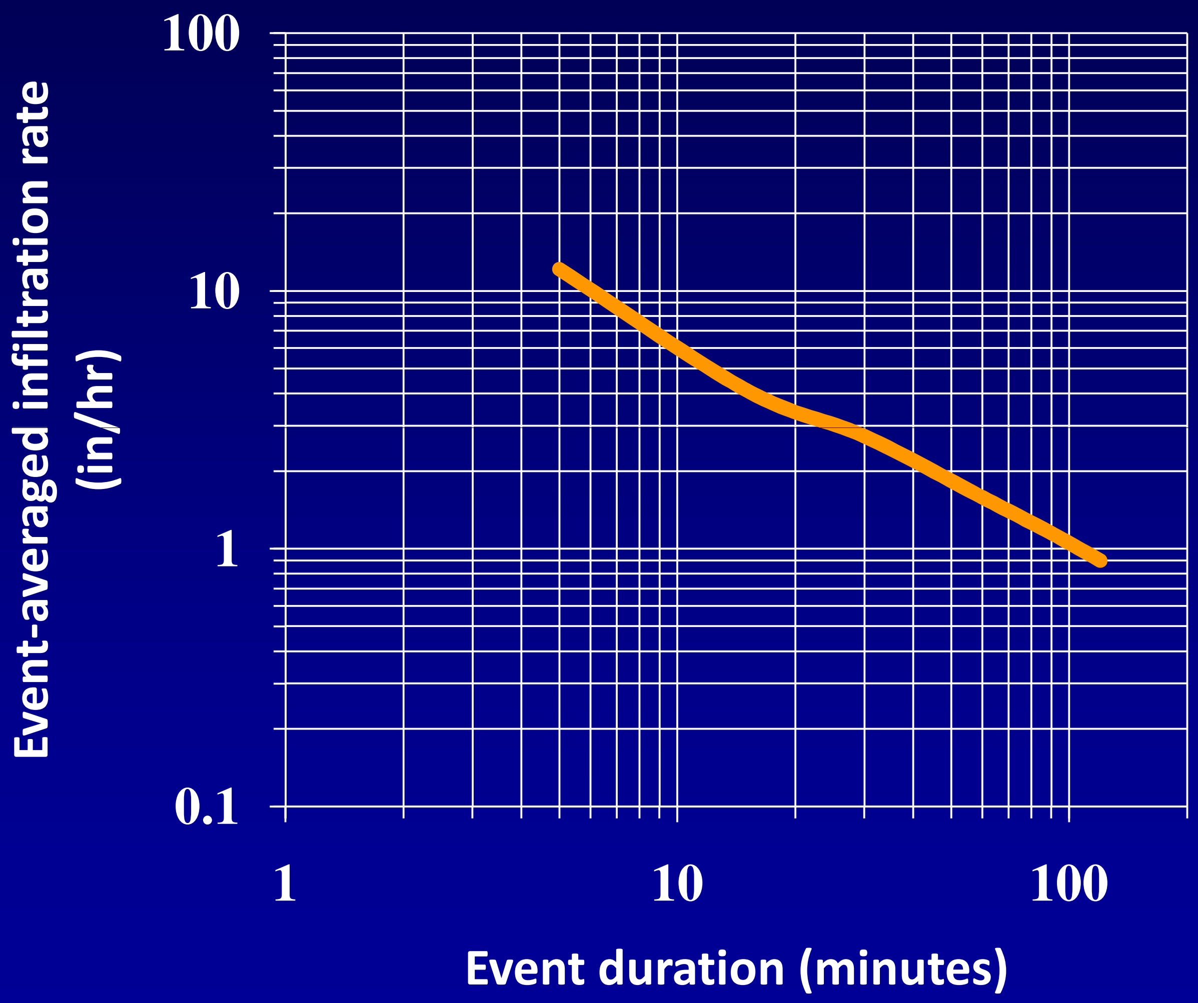
Rain File Name: C:\PROGRAM FILES\WINSLAMM\RAIN FILES\MO KANSAS CITY INTL AP 7299.RAN

Start Date: 11/01/72

End Date: 12/19/99

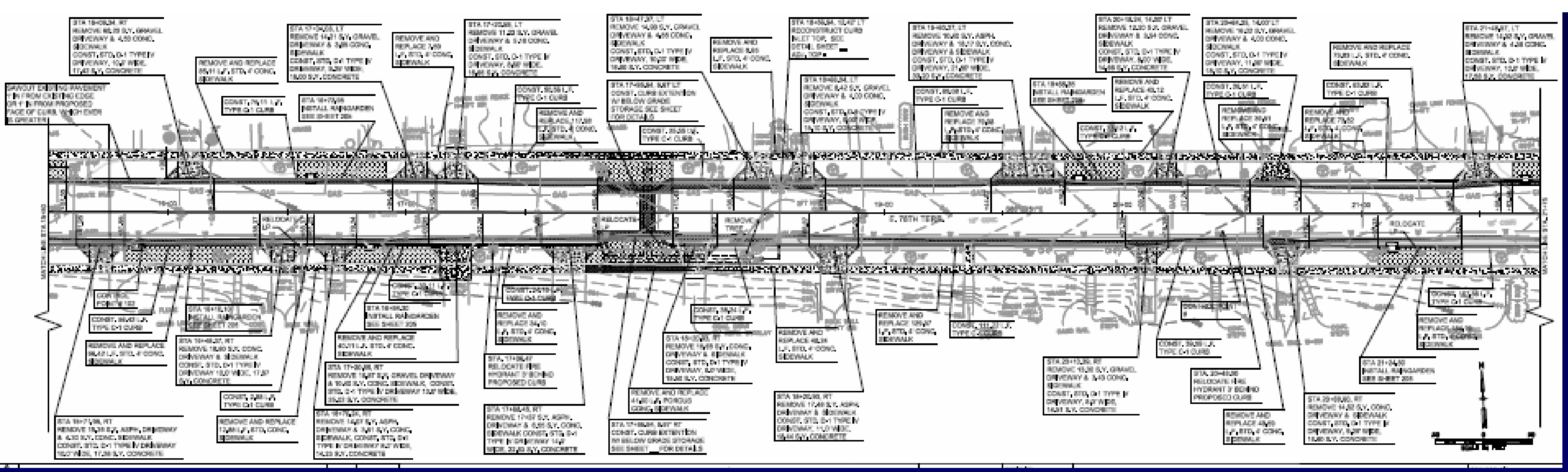
Rain Number	Julian Starting Date	Starting Date	Starting Time	Ending Date	Ending Time	Rainfall Depth (in)	Duration (hrs)	Intensity (in/hr)	Interevent Time (days)
1	0.00	11/01/72	00:00	11/01/72	17:00	0.72	17.00	0.04	4.58
2	5.29	11/06/72	07:00	11/06/72	18:00	0.51	11.00	0.05	2.75
3	8.50	11/09/72	12:00	11/10/72	01:00	0.60	13.00	0.05	2.63
4	11.67	11/12/72	16:00	11/13/72	19:00	0.72	27.00	0.03	2.25
5	15.04	11/16/72	01:00	11/16/72	09:00	0.14	8.00	0.02	2.46
6	17.83	11/18/72	20:00	11/19/72	04:00	0.11	8.00	0.01	5.46
7	23.63	11/24/72	15:00	11/25/72	04:00	0.20	13.00	0.02	9.04
8	33.21	12/04/72	05:00	12/04/72	10:00	0.02	5.00	0.00	0.75
9	34.17	12/05/72	04:00	12/05/72	06:00	0.02	2.00	0.01	0.58
10	34.83	12/05/72	20:00	12/05/72	21:00	0.02	1.00	0.02	3.42
11	38.29	12/09/72	07:00	12/09/72	13:00	0.25	6.00	0.04	1.96

Varying-duration Site Infiltration Rates

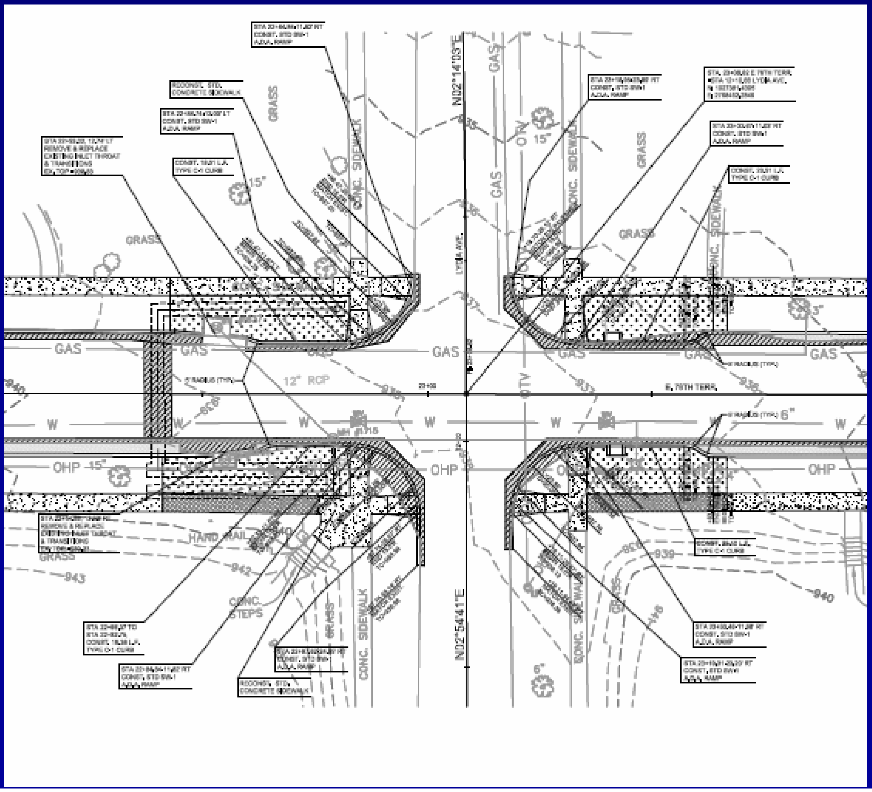


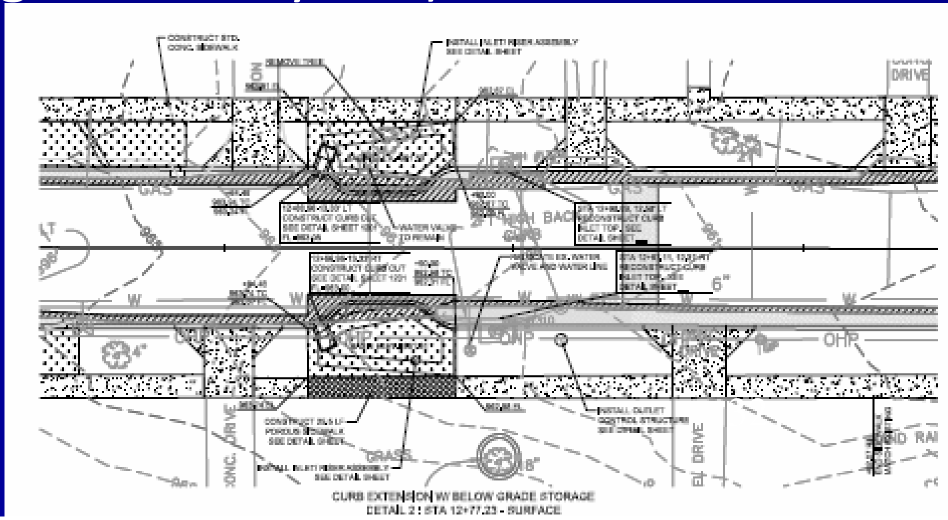
This plot shows the time-averaged infiltration rates based on the individual incremental values. The surface infiltration rates are less than 1 in/hr for rain durations about 2 hrs, and longer.

Additional site measurements and deep soil profiles have indicated that infiltration rates are quite low for most of the area during the large and long-duration critical events for overflows.

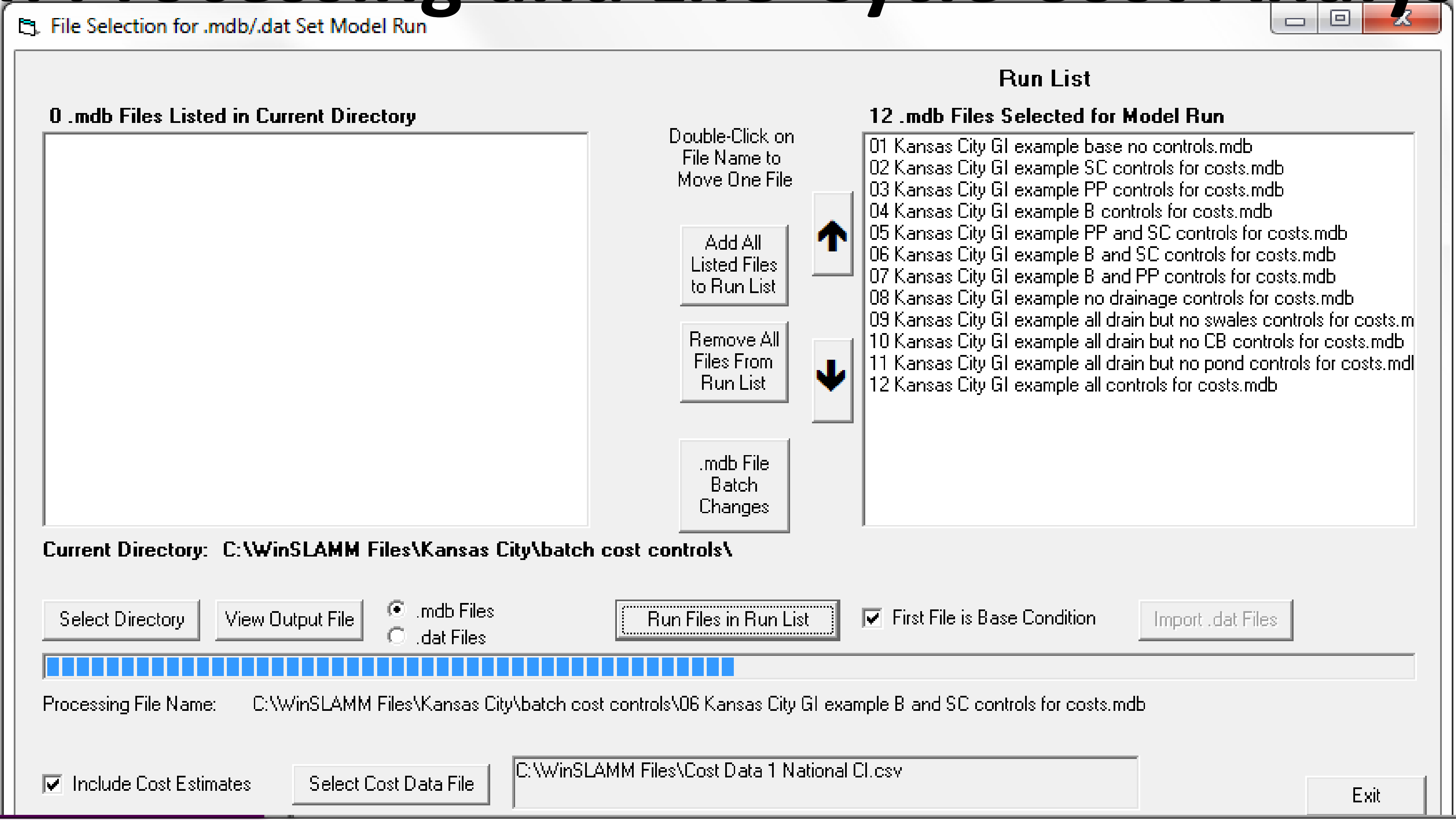


Examples from “95%” plans prepared by URS for project streets. Plans reviewed and modeled by project team, and construction completed in Summer 2012. Initial site monitoring until end of year (large scale monitoring for last 3 years).





Batch Processing and Life-Cycle Cost Analyses



Run List

0 .mdb Files Listed in Current Directory

12 .mdb Files Selected for Model Run

01 Kansas City GI example base no controls.mdb
02 Kansas City GI example SC controls for costs.mdb
03 Kansas City GI example PP controls for costs.mdb
04 Kansas City GI example B controls for costs.mdb
05 Kansas City GI example PP and SC controls for costs.mdb
06 Kansas City GI example B and SC controls for costs.mdb
07 Kansas City GI example B and PP controls for costs.mdb
08 Kansas City GI example no drainage controls for costs.mdb
09 Kansas City GI example all drain but no swales controls for costs.m
10 Kansas City GI example all drain but no CB controls for costs.mdb
11 Kansas City GI example all drain but no pond controls for costs.mdl
12 Kansas City GI example all controls for costs.mdb

Current Directory: C:\WinSLAMM Files\Kansas City\batch cost controls

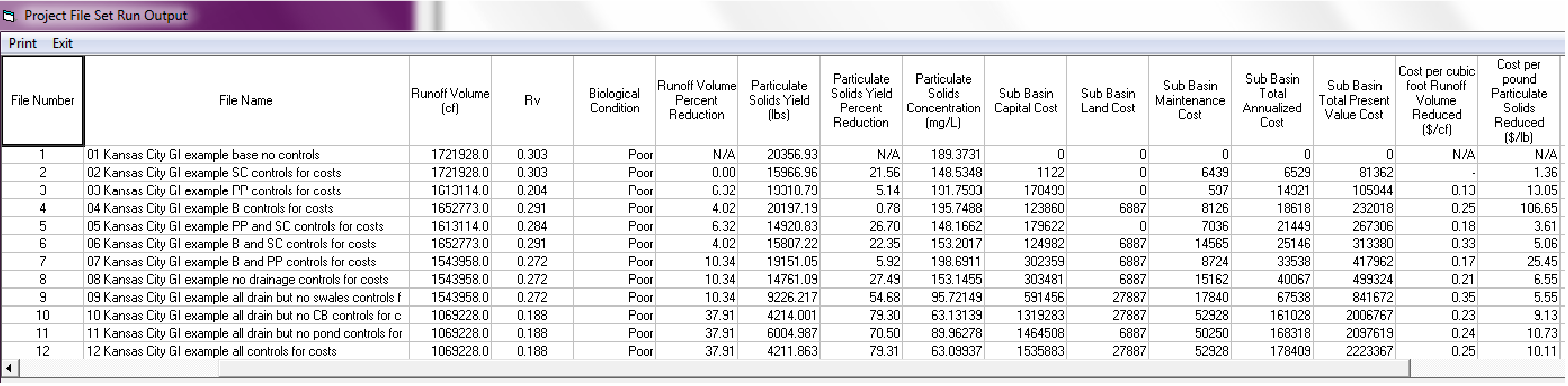
● .mdb Files
○ .dat Files

☑ First File is Base Condition

Processing File Name: C:\WinSLAMM Files\Kansas City\batch cost controls\06 Kansas City GI example B and SC controls for costs.mdb

☑ Include Cost Estimates

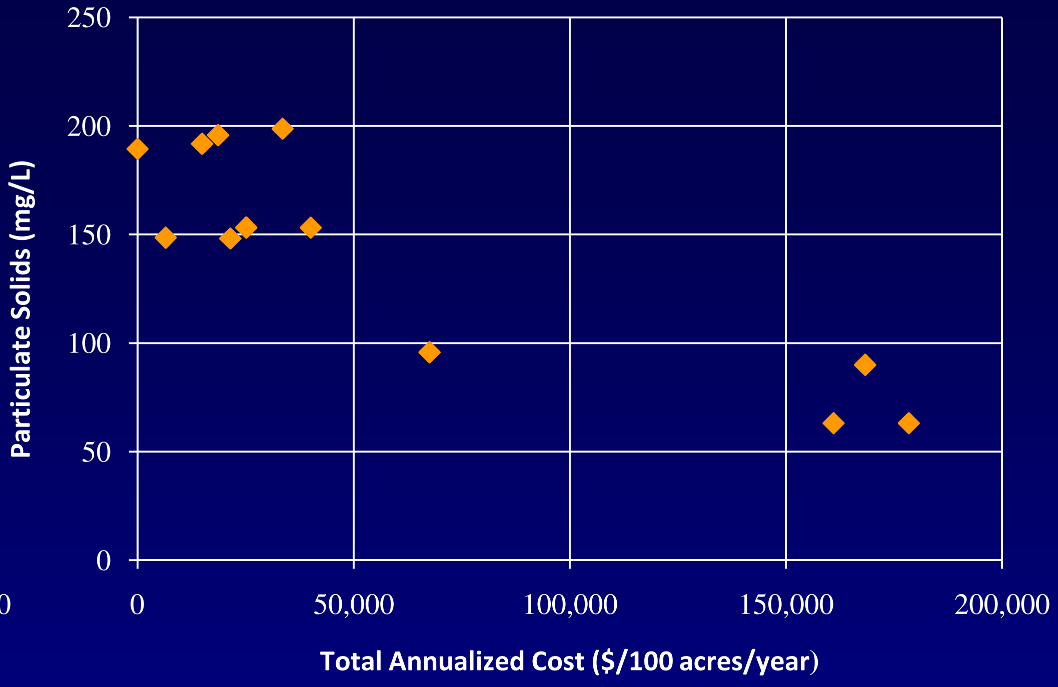
C:\WinSLAMM Files\Cost Data 1 National CI.csv



File Number	File Name	Runoff Volume (cf)	Rv	Biological Condition	Runoff Volume Percent Reduction	Particulate Solids Yield (lbs)	Particulate Solids Yield Percent Reduction	Particulate Solids Concentration (mg/L)	Sub Basin Capital Cost	Sub Basin Land Cost	Sub Basin Maintenance Cost	Sub Basin Total Annualized Cost	Sub Basin Total Present Value Cost	Cost per cubic foot Runoff Volume Reduced ($/cf)	Cost per pound Particulate Solids Reduced ($/lb)
1	01 Kansas City GI example base no controls	1721928.0	0.303	Poor	N/A	20356.93	N/A	189.3731	0	0	0	0	0	N/A	N/A
2	02 Kansas City GI example SC controls for costs	1721928.0	0.303	Poor	0.00	15966.96	21.56	148.5348	1122	0	6439	6529	81362	-	1.36
3	03 Kansas City GI example PP controls for costs	1613114.0	0.284	Poor	6.32	19310.79	5.14	191.7593	178499	0	597	14921	185944	0.13	13.05
4	04 Kansas City GI example B controls for costs	1652773.0	0.291	Poor	4.02	20197.19	0.78	195.7488	123860	6887	8126	18618	232018	0.25	106.65
5	05 Kansas City GI example PP and SC controls for costs	1613114.0	0.284	Poor	6.32	14920.83	26.70	148.1662	179622	0	7036	21449	267306	0.18	3.61
6	06 Kansas City GI example B and SC controls for costs	1652773.0	0.291	Poor	4.02	15807.22	22.35	153.2017	124982	6887	14565	25146	313380	0.33	5.06
7	07 Kansas City GI example B and PP controls for costs	1543958.0	0.272	Poor	10.34	19151.05	5.92	198.6911	302359	6887	8724	33538	417962	0.17	25.45
8	08 Kansas City GI example no drainage controls for costs	1543958.0	0.272	Poor	10.34	14761.09	27.49	153.1455	303481	6887	15162	40067	499324	0.21	6.55
9	09 Kansas City GI example all drain but no swales controls f	1543958.0	0.272	Poor	10.34	9226.217	54.68	95.72149	591456	27887	17840	67538	841672	0.35	5.55
10	10 Kansas City GI example all drain but no CB controls for c	1069228.0	0.188	Poor	37.91	4214.001	79.30	63.13139	1319283	27887	52928	161028	2006767	0.23	9.13
11	11 Kansas City GI example all drain but no pond controls for	1069228.0	0.188	Poor	37.91	6004.987	70.50	89.96278	1464508	6887	50250	168318	2097619	0.24	10.73
12	12 Kansas City GI example all controls for costs	1069228.0	0.188	Poor	37.91	4211.863	79.31	63.09937	1535883	27887	52928	178409	2223367	0.25	10.11

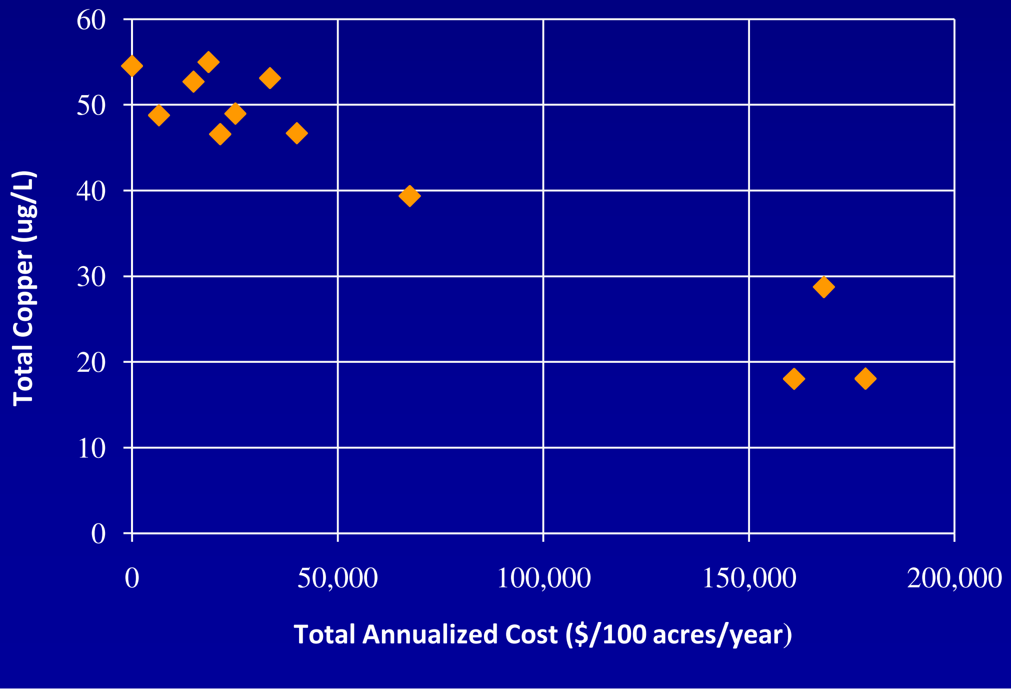
Costs for Rv Goals

Costs for SSC Concentration Goals



Costs for TP Concentration Goals

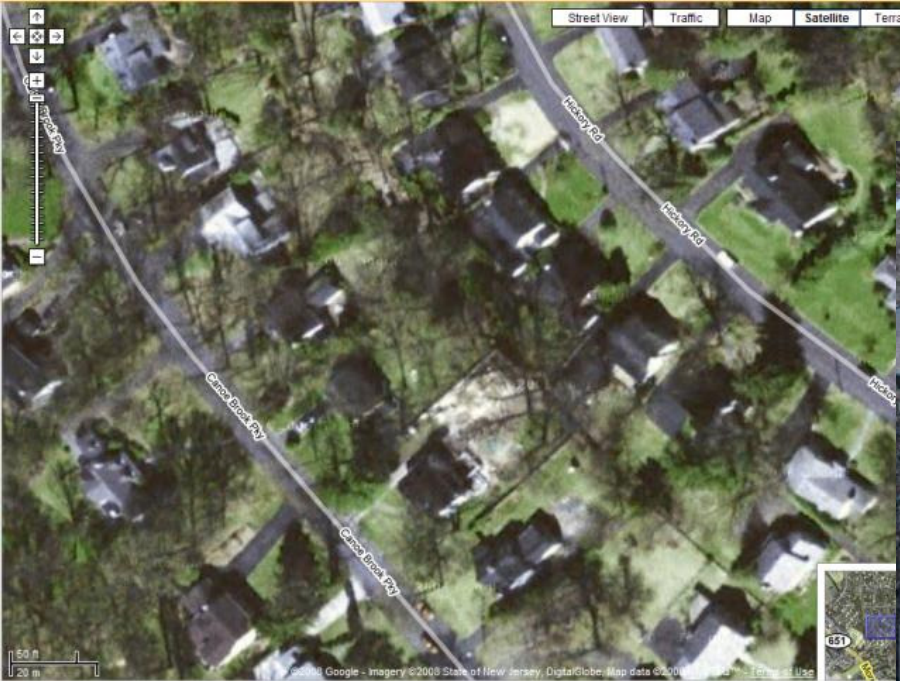
Costs for Cu Concentration Goals

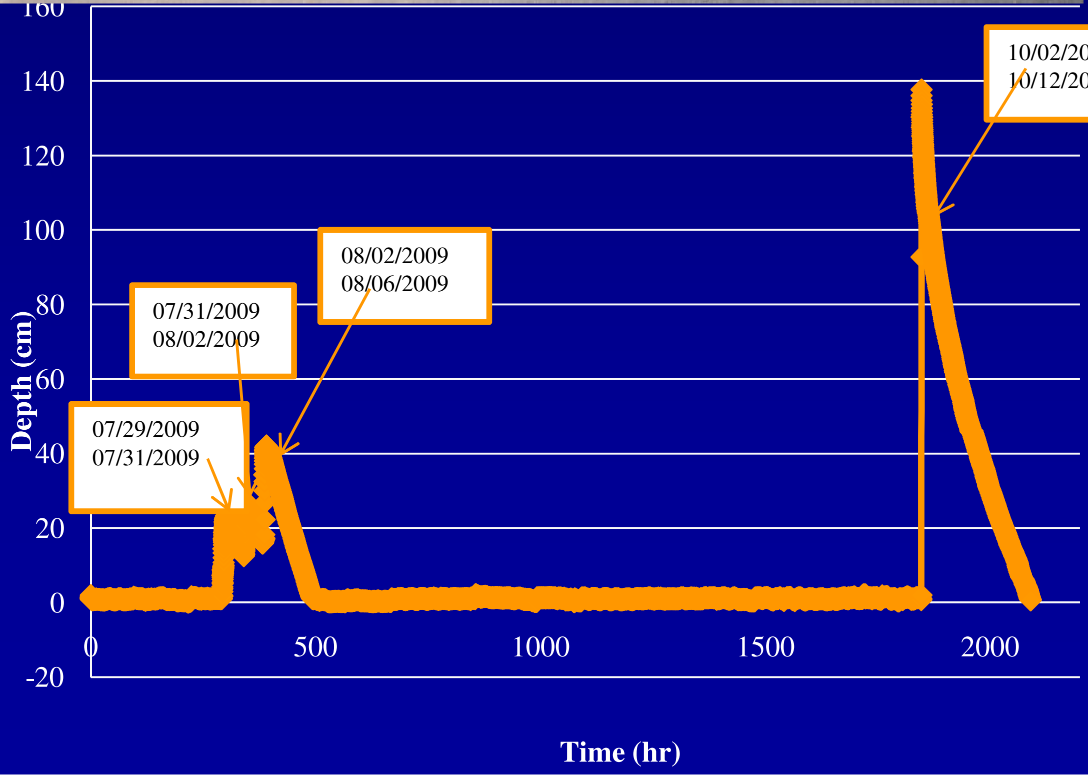


Millburn, NJ

Dry well disposal of stormwater for groundwater recharge in conjunction with irrigation beneficial uses

- For the past several years, the city of Millburn has required dry wells to infiltrate increased flows from newly developed areas.
- There are some underground water storage tanks now being installed to use stormwater for irrigation.
- Our recent project, supported by the Wet Weather Flow Research Program of the US EPA, is investigating the performance of this shallow groundwater recharge (including groundwater contamination potential) in conjunction with irrigation beneficial uses of the stormwater.





Nine dry wells were monitored in Millburn, NJ as part of EPA project for long-term hydraulic performance, and six were monitored to examine surface and subsurface water quality conditions.

This major home restoration project included the installation of underground water storage tanks instead of dry wells. Homes in this neighborhood have summer water bills approaching $1k/month for landscape irrigation, so the economic benefits of irrigation using stormwater are very good.

Dry Well Drainage Observations

- Most of the dry wells were dry most of the time during the monitoring period (75 to 98% of the time)
- Standing water was observed at a few sites when sufficient time occurred to allow the water to reach an equilibrium minimum water level (about 5 ft below the ground surface).
- Several sites experienced periodic slowly draining conditions, mainly in the early spring.
- These problems could be due to poor soils (with the clays resulting in SAR problems), compacted soils, saturated soil conditions, or high groundwater.

Monitored Water Quality below Dry Wells

- Ten rains (0.1 to 9 inches in depth, including Hurricane Irene); median depth 0.15 inches.
- Three dry wells were monitored (along with one cistern).
- TN, NO_3, TP, COD, Cu, Pb, Zn, enterococci, *E. coli* for all events and pesticides/herbicides for one event.
- No significant differences in the paired sample concentrations for the dry wells.
- Bacteria and lead may exceed New Jersey groundwater disposal guidelines.

Parting Thought (delivered by way of a Chinese fortune cookie at dinner last night in Boulder):

“Be careful! Straight trees often have crooked roots.”

If you don’t like that commentary on poor model documentation or faulty fundamental processes, how about Lucky Numbers:
34, 4, 12, 37, 32, 33 (a new process for selecting random seed numbers for Monte Carlo analyses

Acknowledgements

- This summary presentation includes information from many sources. The examples from Kansas City and Millburn were part of EPA ORD sponsored research projects that used WinSLAMM as part of the data analyses. Some of the beneficial use material was from a recent WERF sponsored research project, and the Huntsville material was from a project sponsored by that Alabama city. Their support for these research projects is gratefully acknowledged, but the use of this material in this presentation does not imply endorsement by these agencies.
- WinSLAMM has benefited from many research project results over the years. However, the time and costs associated with the development of the WinSLAMM code has been mostly a private effort conducted by PV & Assoc. (Robert Pitt, John Voorhees, and Caroline Burger). Additional support provided by government and industry is gratefully acknowledged.