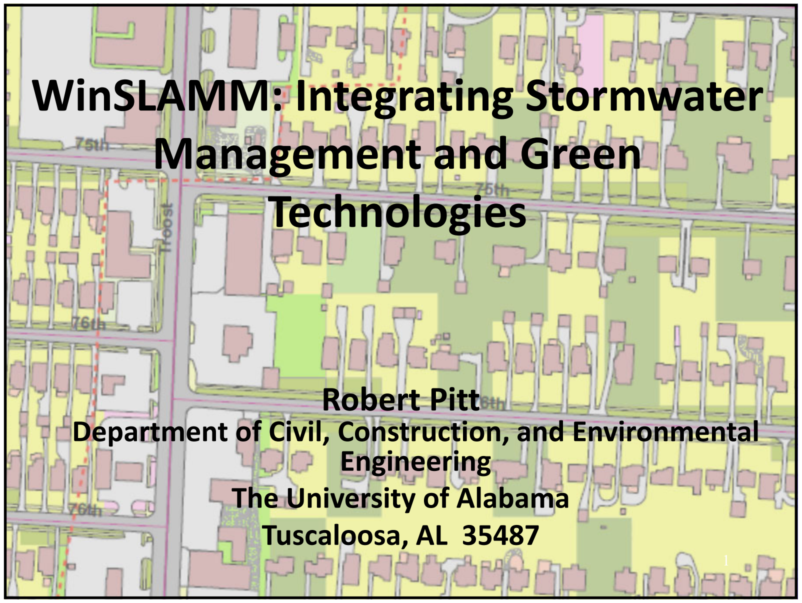

# WinSLAMM: Integrating Stormwater Management and Green Technologies

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## 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.

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## 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 early 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.

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## 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 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.

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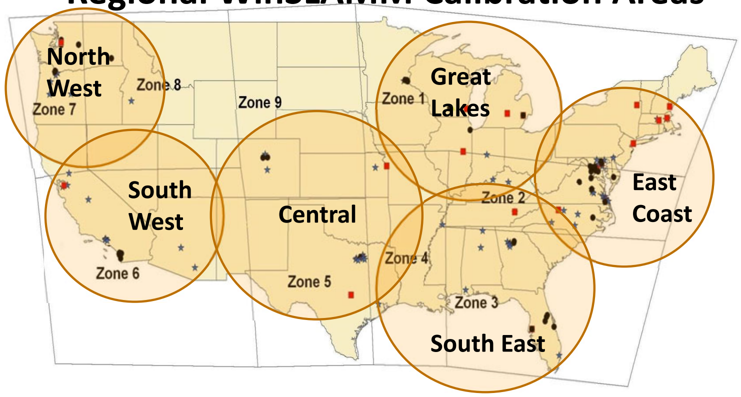
## National Stormwater Quality Database and Regional WinSLAMM Calibration Areas

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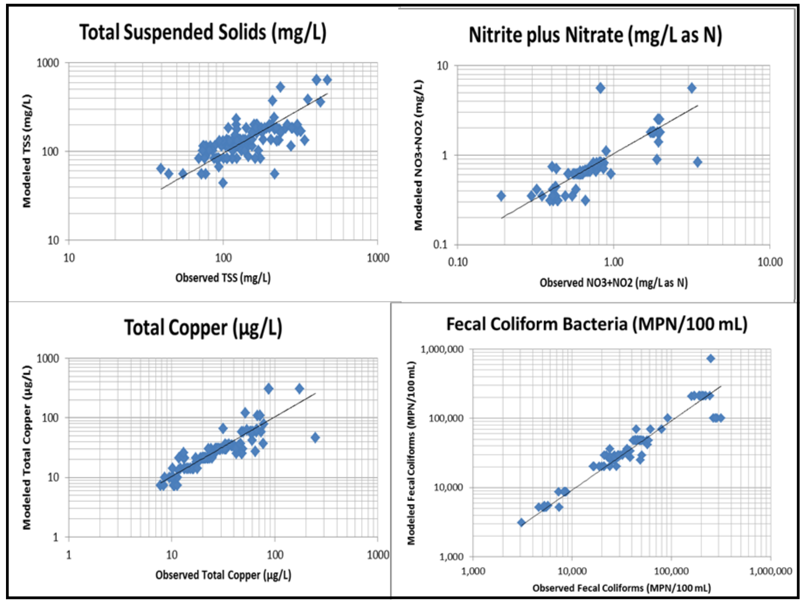


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## Stormwater Infiltration Controls Included in WinSLAMM

- 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)

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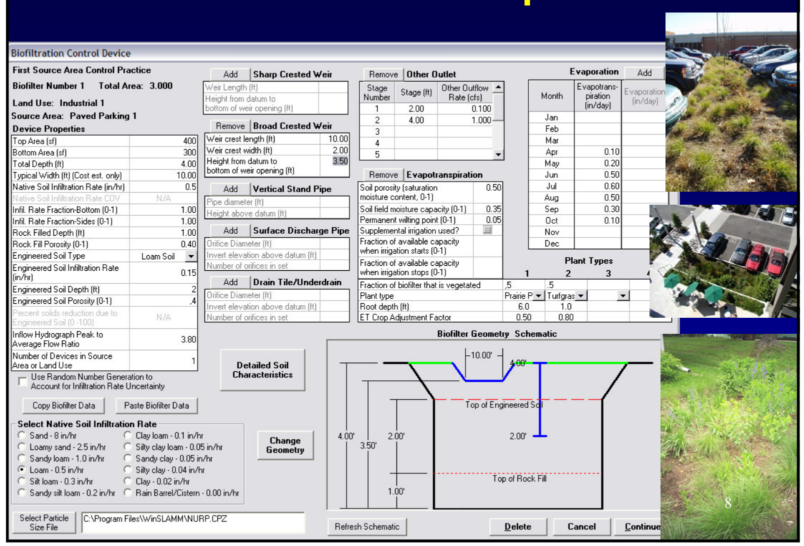
## Rain Garden/Biofilter Input Screen

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


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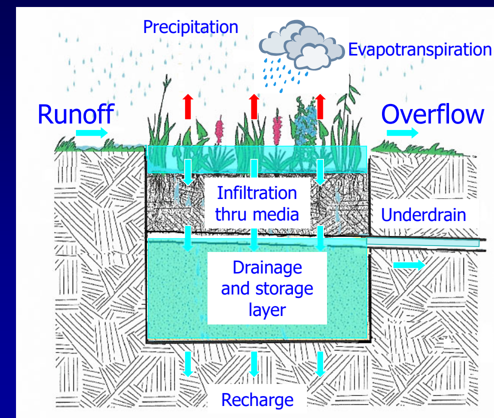
## Biofiltration/Infiltration Routing Schematic

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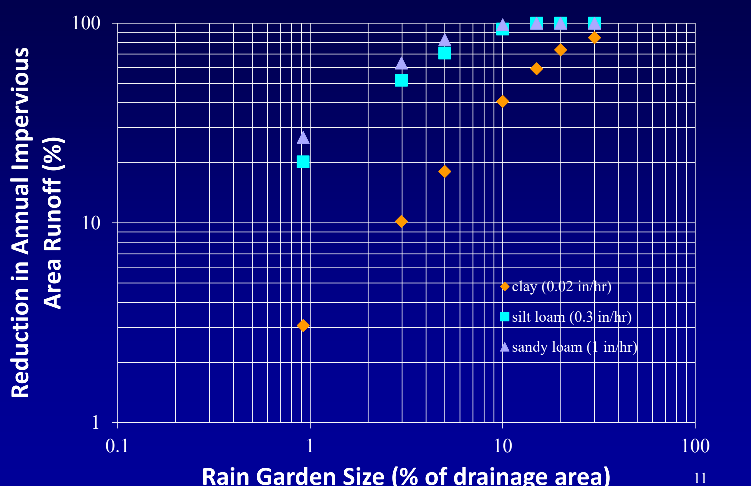
## Annual Runoff Reductions from Paved Areas or Roofs for Different Sized Rain Gardens or Biofilters

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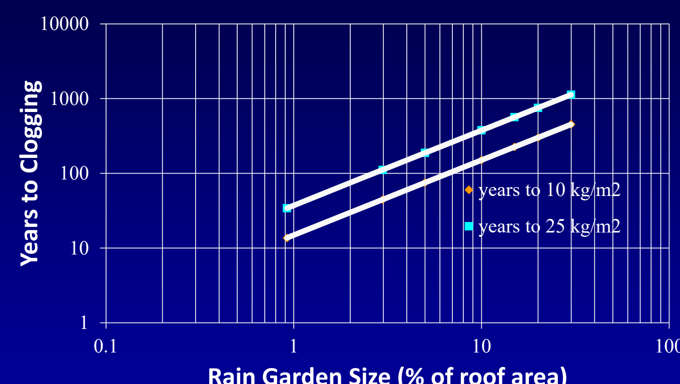
## Clogging Potential for Different Sized Rain Gardens or Biofilters Receiving Roof Runoff




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).

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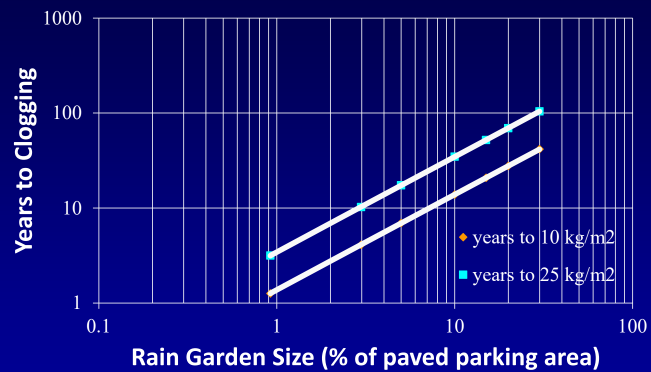
## Clogging Potential for Different Sized Rain Gardens or Biofilters Receiving Paved Parking Area Runoff




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)

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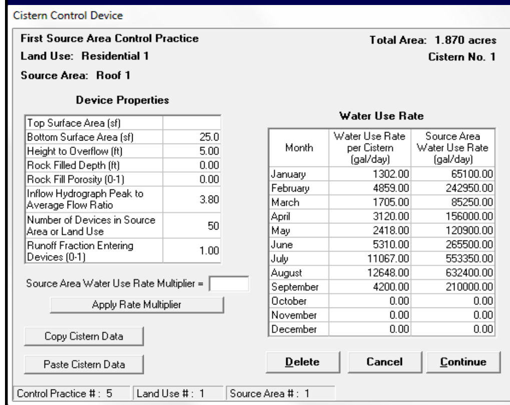
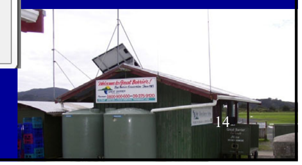
## Water Tank/Cistern/Rain Barrel Beneficial Use of Stormwater Input Screen



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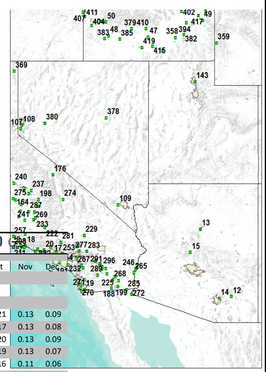
## ET Rates can Vary Greatly Over Small Distances, Especially in the West

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.



Kimberly Penman Equation (1982) ($ET_r$)

| Lat | Long | Elev | Station Name | Years of Data | 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 |

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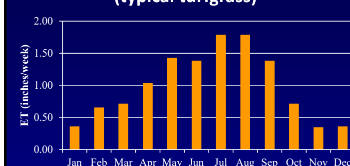
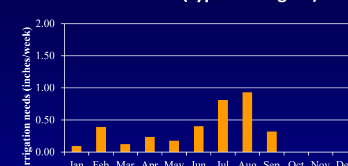
## Kansas City Water Harvesting Potential of Roof Runoff

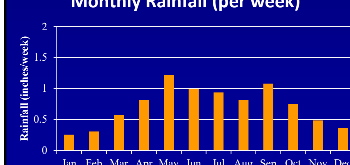
Evapotranspiration per Week (typical turfgrass)




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.

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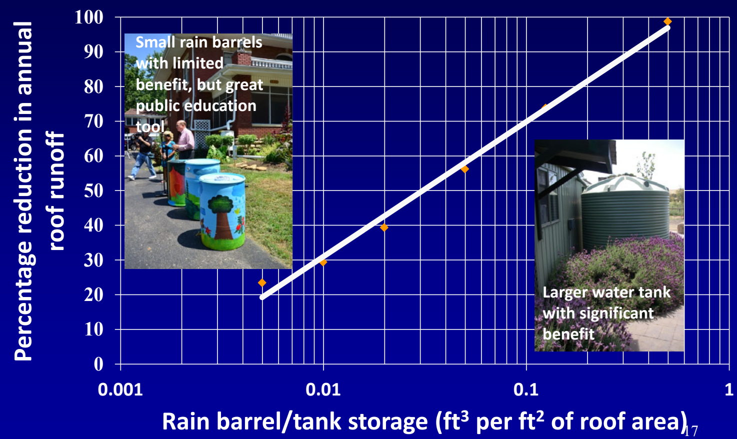
## Reductions in Annual Runoff Quantity from Directly Connected Roofs with the use of Rain Barrels and Water Tanks (Kansas City CSO Study Area)

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0.125 ft of storage is needed for use of 75% of the total annual runoff from these roofs for irrigation. With 945 ft² roofs, the total storage is therefore 118 ft³, 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 (ft³) | 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 |

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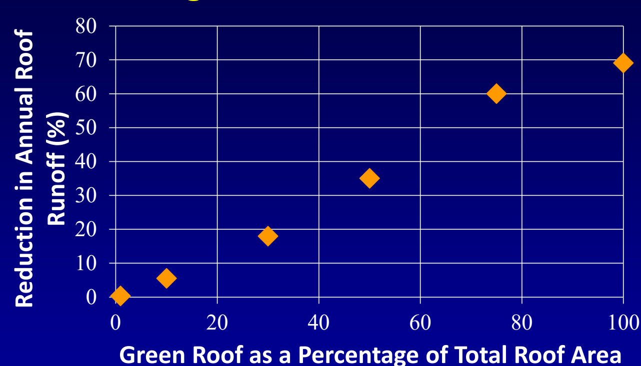
## Annual Roof Runoff Reductions for Birmingham, AL, Green Roofs




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.

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## Grass Filter Strips Input Screen


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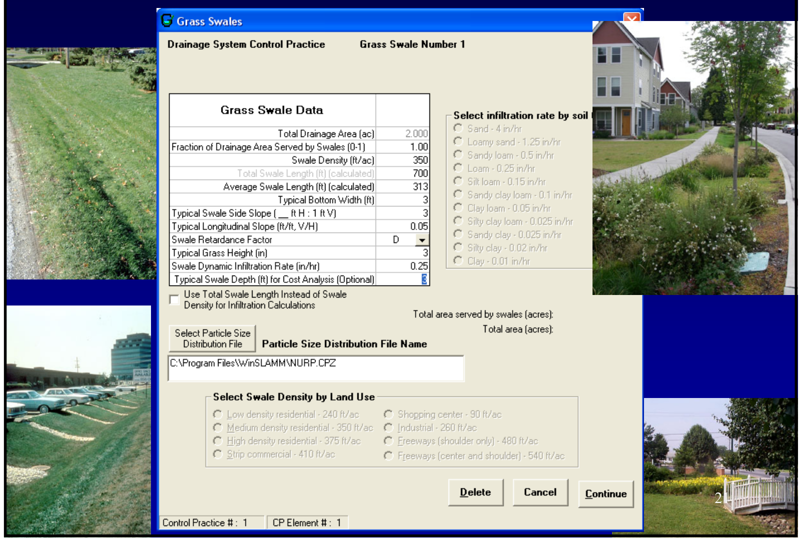
## Grass Swales Input Screen

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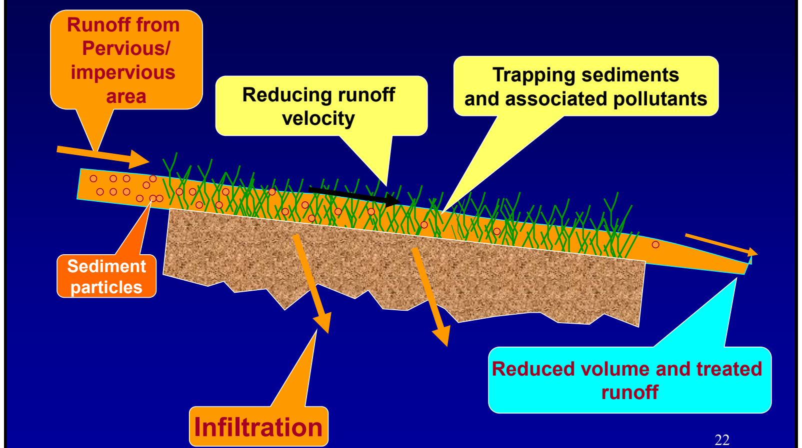
## Pollutant Control in Grass Swales and Grass Filters

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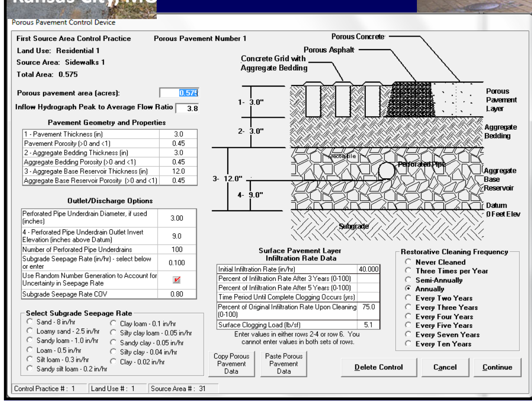
## Porous Pavement Input Screen







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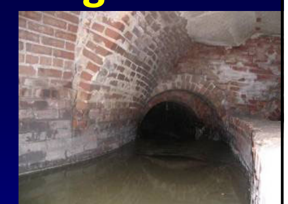
## Kansas City's CSO Challenge



- 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

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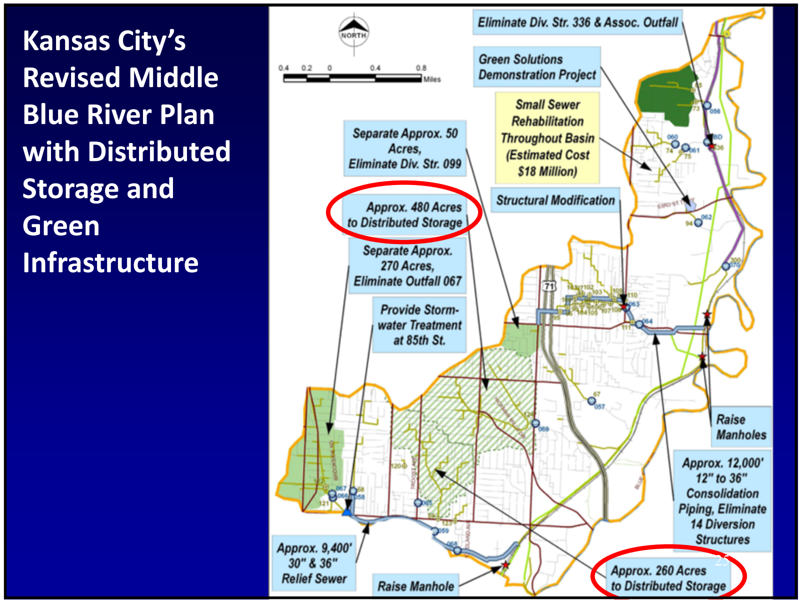
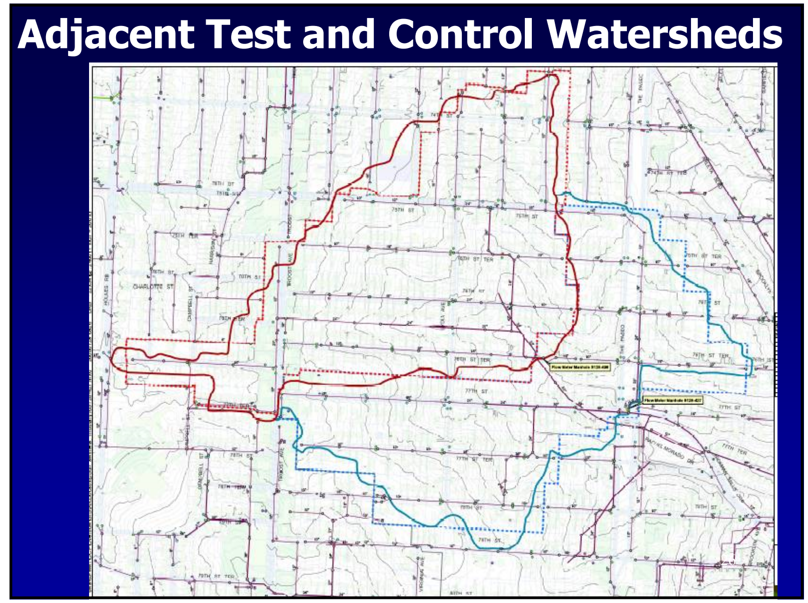
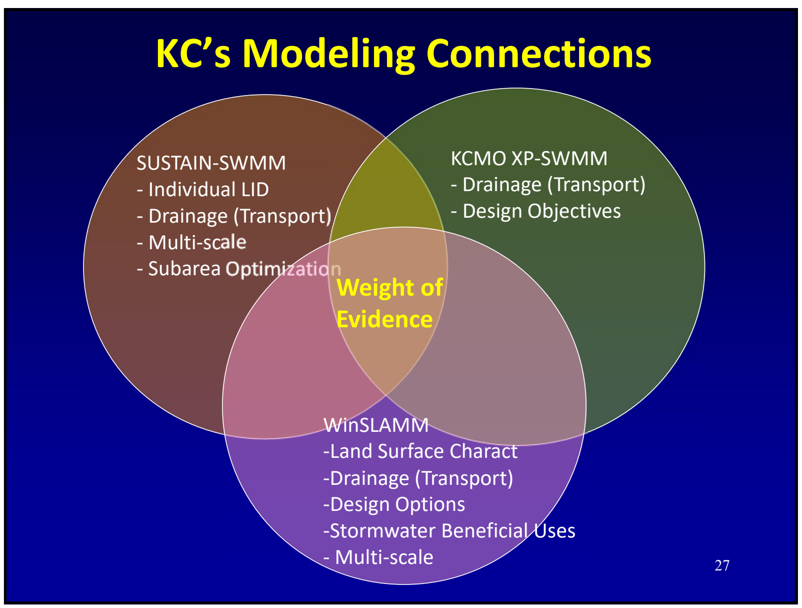

Kansas City's Revised Middle Blue River Plan with Distributed Storage and Green Infrastructure
NORTH
Miles
Eliminate Div. Str. 336 & Assoc. Outfall
Green Solutions Demonstration Project
Small Sewer Rehabilitation Throughout Basin (Estimated Cost $18 Million)
Separate Approx. 50 Acres, Eliminate Div. Str. 099
Approx. 480 Acres to Distributed Storage
Structural Modification
Separate Approx. 270 Acres, Eliminate Outfall 067
Provide Storm-water Treatment at 85th St.
Raise Manholes
Approx. 12,000' 12" to 36" Consolidation Piping, Eliminate 14 Diversion Structures
Approx. 9,400' 30" & 36" Relief Sewer
Raise Manhole
Approx. 260 Acres to Distributed Storage

25


Adjacent Test and Control Watersheds

26


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
27

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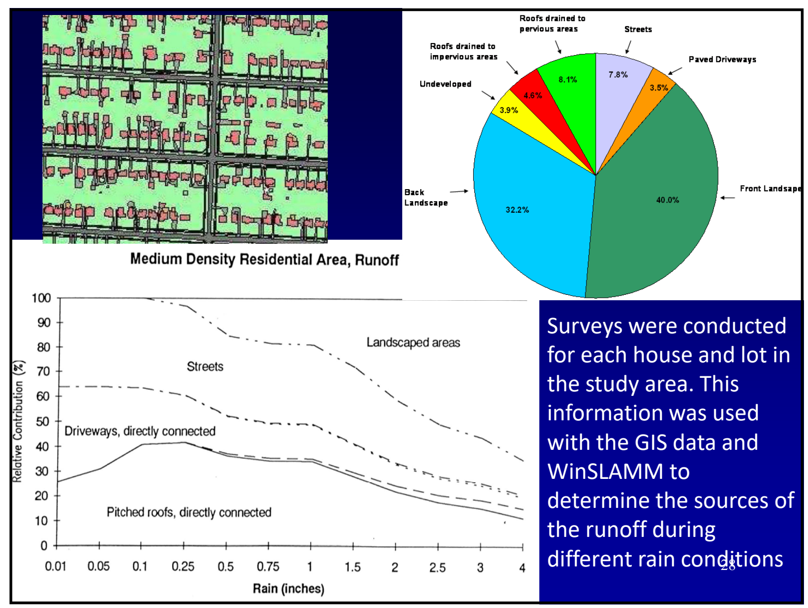
Roofs drained to pervious areas
Streets
Roofs drained to impervious areas
Paved Driveways
Undeveloped
Back Landscape
Front Landscape
8.1%
7.8%
4.6%
3.5%
3.9%
32.2%
40.0%
Medium Density Residential Area, Runoff
Landscaped areas
Streets
Driveways, directly connected
Pitched roofs, directly connected
Relative Contribution (%)
Rain (inches)
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

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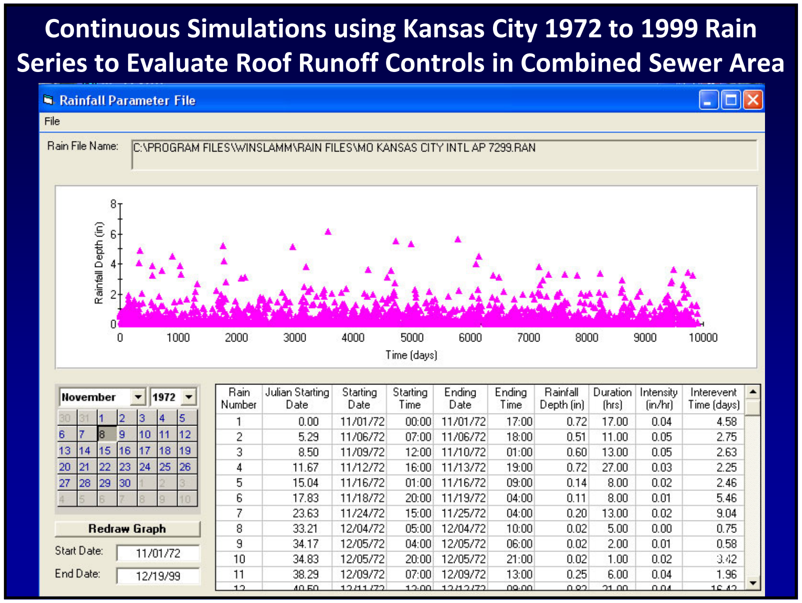


| Rain Number | Julian Starting Date | Starting Date | Starting Time | Ending Date | Ending Time | Rainfall Depth (in) | Duration (hrs) | Intensity (in/hr) | Interevent Time (days) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 11/01/72 | 00:00 | 11/01/72 | 17:00 | 0.72 | 17.00 | 0.04 | 4.58 |
| 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 |

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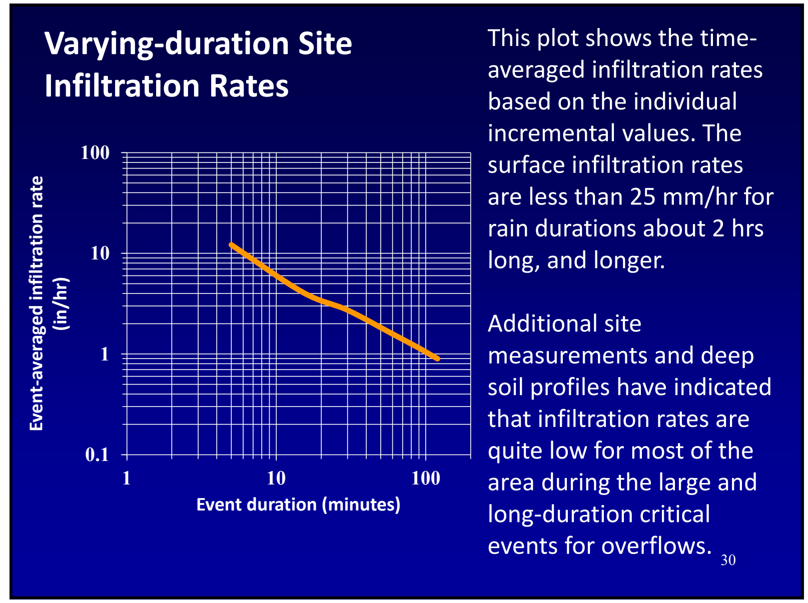


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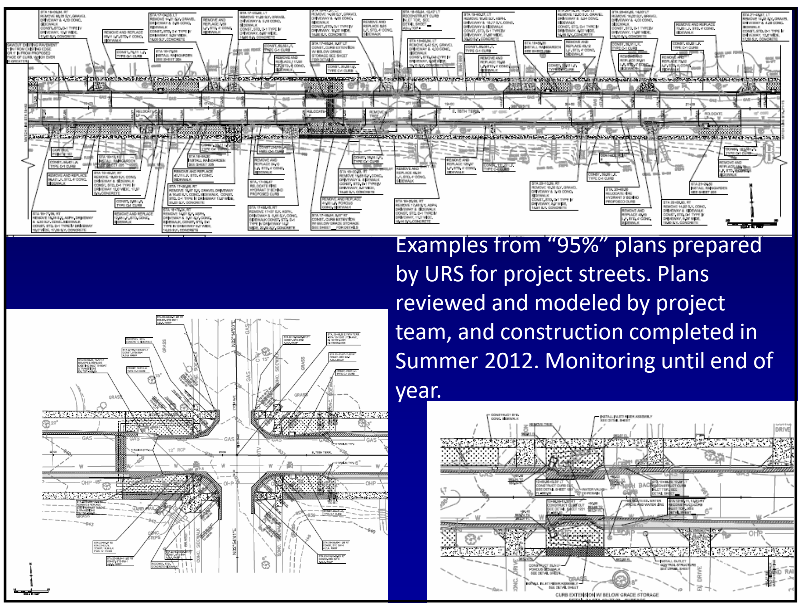


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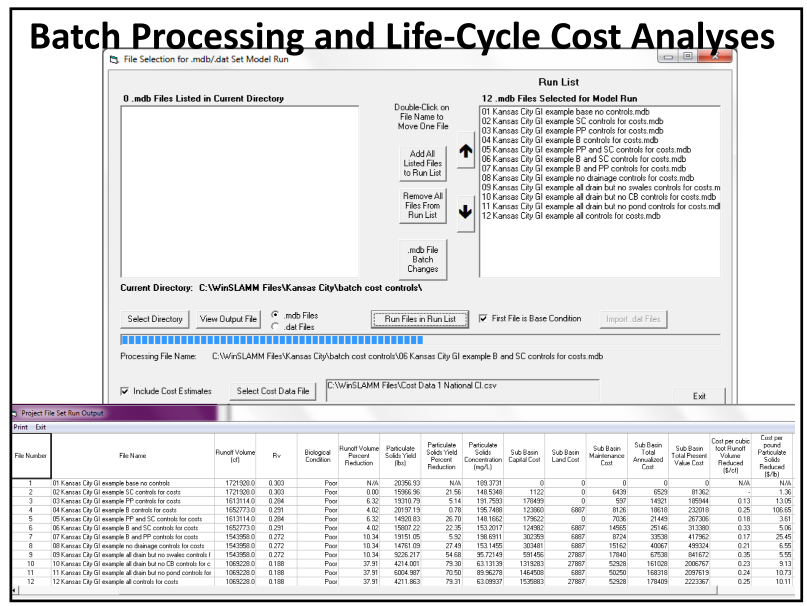


| File Number | File Name | Runoff Volume (cf) | Rv | Biological Condition | Runoff Volume Percent Reduction | Particulate Solids Yield (lbs) | Particulate Solids Yield Percent Reduction | Particulate Solids Concentration (mg/L) | Sub Basin Capital Cost | Sub Basin Land Cost | Sub Basin Maintenance Cost | 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 |

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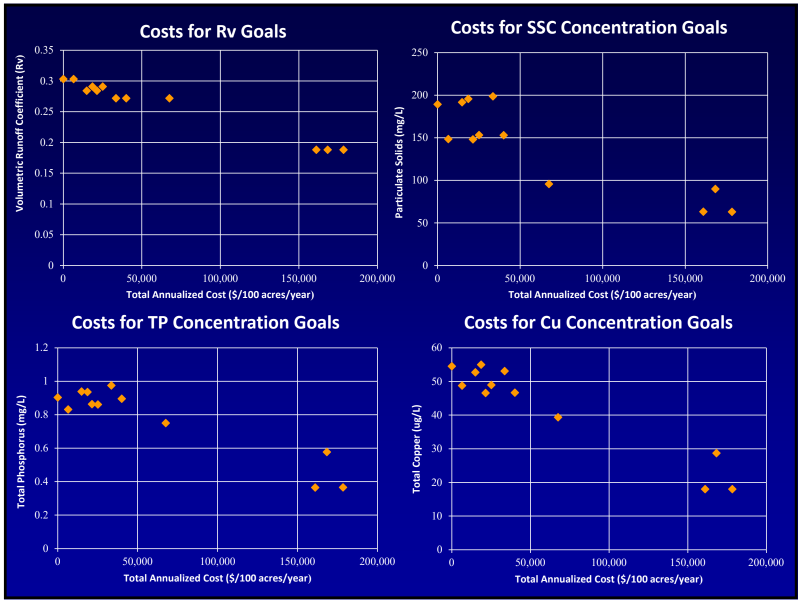


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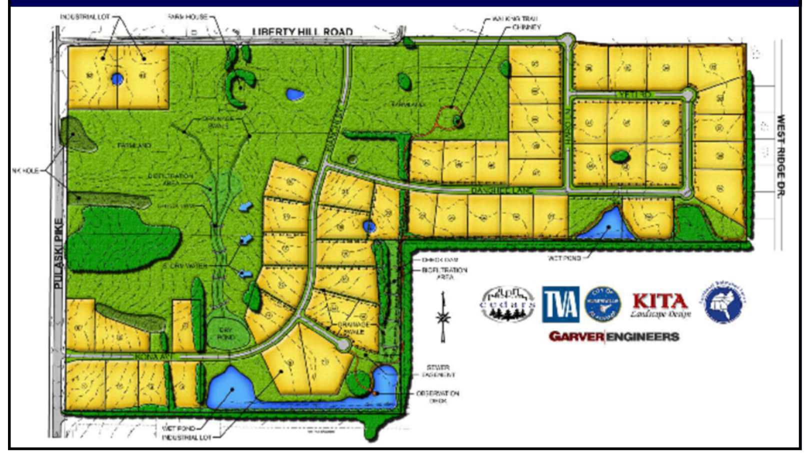
## North Huntsville Conservation Design Industrial Park

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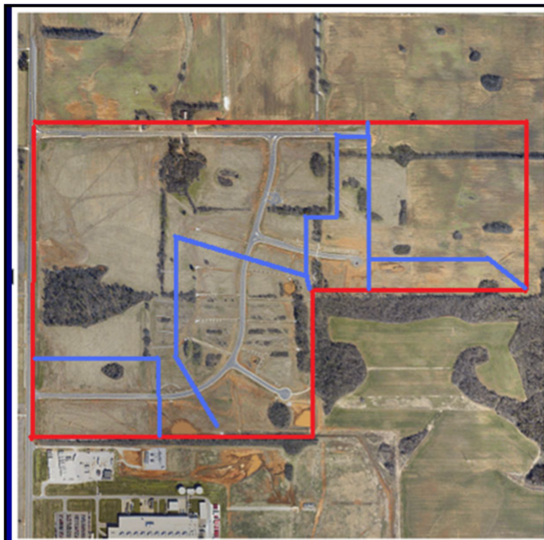

### Aerial Photo of Site under Construction (Google Earth)

- On-site bioretention swales
- Level spreaders
- Large regional swales
- Wet detention ponds
- Critical source area controls
- Pollution prevention (no Zn!)
- Buffers around sinkholes
- Extensive trail system linking water features and open space

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## Conservation Design Elements for North Huntsville, AL, Industrial Park

- Grass filtering and swale drainages
- Modified soils to protect groundwater
- Wet detention ponds
- Bioretention and site infiltration devices
- Critical source area controls at loading docks, etc.
- Pollution prevention through material selection (no exposed galvanized metal, for example) and no exposure of materials and products.
- Trail system throughout area.

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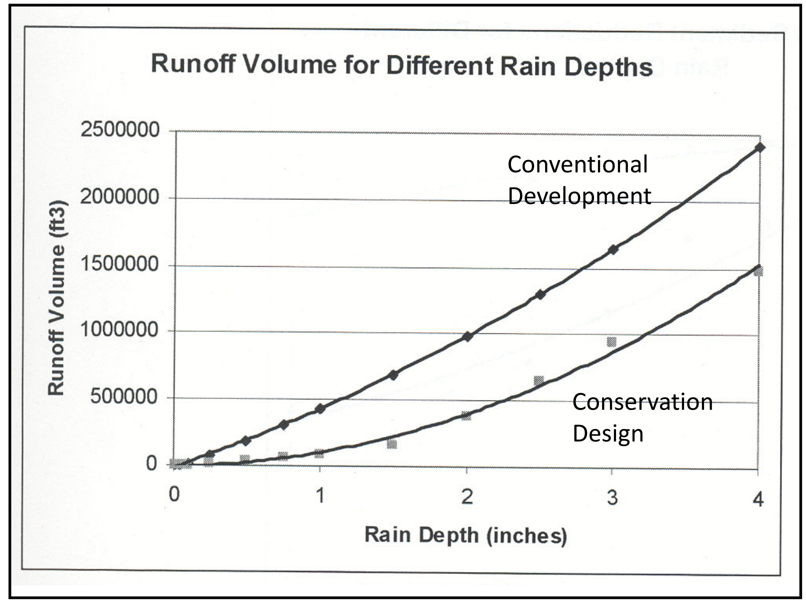


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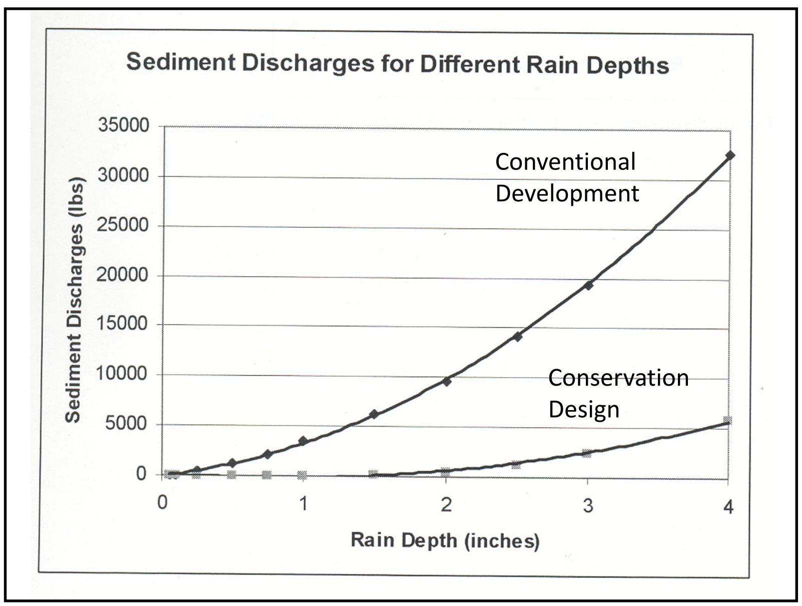


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## Millburn, NJ

**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.

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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.

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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.

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## 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 3 ft deep). The slow drainage rate may have been caused by saturated conditions from groundwater mounding, or a high water table.
- Several sites experienced periodic slowly draining conditions, mainly in the early spring, that could have been associated with SAR problems associated with high salts from inflowing snowmelt. The slow infiltration rates could be due to poor soils (with the clays resulting in SAR problems), or saturated soil conditions

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## 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.

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## Conclusions

- There are a large number of infiltration-based stormwater controls that can be applied to a variety of land uses to reduce the volume and rates of stormwater discharged to combined sewers.
- Beneficial uses of stormwater can also be a useful tool to reduce these discharges, while still conserving important resources.
- Continuous WinSLAMM simulations can calculate the benefits of these controls in many combinations for an area.

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## 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.


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