Strategies and Experimental Design for Monitoring the Performance of Various Green Infrastructure Controls at Cincinnati Demonstration Project Sites

- A Preliminary Strategy and Plan -

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Summary of Monitoring Strategy and Experimental Design

Introduction

Designing a monitoring program must consider many site characteristics and the objectives. A monitoring program includes several components, including a clear statement of the objectives (descriptive objectives and data quality objectives), identification of parameters and constituents to be monitored (focusing on performance and maintenance issues), the experimental design (quantifying the sampling efforts needed to meet the study objectives), selection of sampling and monitoring equipment and instrumentation, and laboratory support (such as analytical methods, required detection limits, QA/QC components), and statistical analysis methods to be used to evaluate the data and to meet the project objectives. This report is the initial effort to address these needed components to the monitoring plan. Specifically, this report addresses special issues and considerations that need to be addressed for each type of stormwater control category, along with some overall issues that affect most of the controls. This report starts by listing the overall project objectives and priorities, and then discusses some of the overall issues. A few of the unique issues associated with each monitoring area are also summarized.

Project Monitoring Objectives

The project objectives are of the highest priority when designing a monitoring program. The Cincinnati green infrastructure demonstration project has the following project object priorities:

- The first monitoring priority is to quantify the overall runoff volume reduction actually achieved at the demonstration locations. The runoff volume performance of a selection of the green infrastructure controls are also to be quantified.
- The second priority is to collect data that enables these results to be used in other locations in order to quantify the runoff volume reductions quantified at the demonstration sites.
- The third priority is to collect water quality data to assess the performance of the controls in reducing specific water quality parameters.

The first priority can be easiest to accomplish by establishing a large-scale flow monitoring network that drains areas that are almost completely affected by the site controls. It would be best to have control areas for comparison, but that will be very difficult to establish at the three areas as they are unique land uses at those areas. Therefore, comprehensive rainfall monitoring at several locations throughout each area, plus pre-construction baseline flow monitoring in the test watersheds (at least at the University of Cincinnati location which has few controls already installed compared to the other two locations) will be critical.

The second priority will involve monitoring a selection of individual controls at each of the study areas. This will enable quantification of performance of the green infrastructure devices and examine their specific levels of performance. This information will be critical when calibrating stormwater quality models that can be used to satisfy the third priority.

Therefore, monitoring will be necessary at different scales and at many different locations throughout each area.

Summary of Monitoring Plan

The monitoring plan is described in several sections of this report, and is summarized in the following paragraphs. The following table lists the reports and project plans reviewed during the preparation of this monitoring strategy plan.

List of references used in the Cincinnati Report

Name of Document	Date	Author
Biological and Water Quality Study of Mill Creek and Tributaries, and Ohio River Butler and Hamilton Counties, Ohio OEPA NPDES Permit NO. 1px00022*BD	March 2010	-
Lower Mill Creek Watershed Summary Report	November 2009	Human Nature, and Strand Associates, Inc.
Cincinnati State Technical and Community College MSDGC Green Demonstration Project – Part 2 Application – Parking Lot C Improvements	May 5, 2010	project management consultant: FRE Associates civil engineer: Woolpert bioretention design and stormwater modeling: JFNew
Cincinnati State Technical and Community College MSDGC Green Demonstration Project – Part 2 Application – Phase 2 – L.I.D. Improvements	July 13, 2010	
Recommendation For Approval Of The Part 2 Application - Cincinnati State Technical And Community College (CSTCC) Phase 2	September 23, 2010	Nancy Ellwood, MSDGC Green Demonstration Program Manager
Cincinnati Zoo & Botanical Garden, African Savannah Project, Green Demonstration Project: Part 2 – Construction	November 2009	M-E Companies
Drawing for the Construction of Africa Savannah Phase IIIa	January 2011	Ohio Utilities Protection Service – M-E Companies
Revised Recommendation For Approval Of The Cincinnati Zoo & Botanical Garden African Savannah Part 2 Application	January 27, 2010	Nancy Ellwood, MSDGC Green Demonstration Program Manager
Revised Recommendation For Approval Of The Cincinnati Zoo & Botanical Garden African Savannah Part 2 Application	April 2, 2010	Nancy Ellwood, MSDGC Green Demonstration Program Manager
Green Demonstration Project Proposal: Part I –	February	University of Cincinnati

Concept Application (revision)	3, 2011	

Local Receiving Water Problems

There have been many project reports prepared describing the Cincinnati area combined sewer system and receiving water conditions. One of the first tasks in developing this demonstration project monitoring strategy was to review many of these reports to summarize the known problems so the monitoring strategy will be able to address the specific local problems that need to be improved.

The Mill Creek biological and chemical monitoring surveys indicated a range of potential problems throughout the watershed:

- high *E. coli* and fecal coliform bacteria observations commonly exceeded the recreational use criteria
- total recoverable iron criterion for the protection of agricultural uses were periodically exceeded
- total recoverable lead, copper, and zinc criteria for outside of the mixing zones were frequently exceeded
- ammonia-nitrogen and dissolved oxygen criteria for outside of the mixing zones were rarely exceeded (Bloody Run only)
- In general, the habitat conditions in the receiving waters was a limiting factor to desired biological community performance, with evaluations ranging from poor to good.

It is likely that the bacteria (both *E. coli* and fecal coliforms), the dissolved oxygen, and ammonia-nitrogen criteria exceedences are more associated with the sewage components of the overflows than the stormwater components. However, the heavy metals (iron, copper, lead, and zinc), along with the high flows likely associated with the habitat limitations are more associated with the stormwater components. Of course, if the stormwater runoff volumes were significantly reduced, the magnitude and frequency of the CSOs would also be significantly reduced, reducing the bacteria, dissolved oxygen, and ammonia exceedances. However, even if the overflows were eliminated and separate stormwater was allowed to enter the receiving waters, the bacteria criteria would still likely be exceeded, although not by as much as when contaminated with raw sewage.

Therefore, the primary parameters to be included in the monitoring program would be:

- total runoff volume
- peak runoff rate
- rain intensity (full weather station in at least one location) at several locations within the monitoring area

Secondary parameters for monitoring would include:

- total recoverable iron, copper, lead, and zinc
- indicator bacteria (*E. coli*)

Additional parameters for monitoring would be those affecting the performance and maintenance of the green infrastructure control devices, and would include:

- SAR of runoff water (including snowmelt) and conductivity
- TSS and psd
- SAR (Ca, Mg, and Na) and CEC of back-filled media in biofilters and bioretention devices
- soil moisture sensors in back-filled media

- sediment accumulation in the infiltration areas

Monitoring Locations at Cincinnati State Technical and Community College

MSDGC personnel examined possible installations at Cincinnati State for monitoring. Based on this and prior discussions on logical monitoring locations, three areas were selected to be included in the Cincinnati State monitoring strategy:

1. Interconnected Rain Gardens 3, 4 and 5 located at the base of the hill near Central Parkway. There are clearly defined inlets and outlets that will allow for quantity and quality monitoring. There may be interesting opportunities at the inlet that drains Parking Lot A.

2. Infiltration trenches located downhill from Rain Garden 2. This is a unique, fairly large feature with one inlet point and outlet point.

3. Level Spreader/Green Wall is another large unique feature located downhill from pervious paving and Rain Garden 1. There is a distinct inlet point, but there is no single outlet point so it may require water level indicators to determine when water is discharged during wet weather events.

The following summarizes the sampling and monitoring requirements at the three Cincinnati State Technical and Community College areas:

1. Interconnected Rain Gardens 3, 4 and 5 located at the base of the hill near Central Parkway.
    3 inlet automatic water samplers and 3 inlet flow monitors
    1 outlet automatic water sampler and 1 outlet flow monitor
    3 interconnecting unit water samplers and 3 interconnecting flow monitors
    2 water level recorders for rain gardens

2. Infiltration trenches located downhill from Rain Garden 2.
    1 inlet automatic water sampler and 1 inlet flow monitor
    1 outlet automatic water sampler and 1 outlet flow monitor
    5 water level recorders for infiltration trenches

3. Level Spreader/Green Wall located downhill from pervious paving and Rain Garden 1.
    1 inlet automatic water sampler and 1 inlet flow monitor
    2 outlet automatic water samplers and 2 outlet flow monitors (a collection trough will need to be constructed below the last edge of the level spreader area to collect any overflow, with water outlets to each end)
    2 water level recorders for bioretention areas

Therefore, a total of 12 automatic samplers and 12 flow monitors will be needed at these locations. In addition, 9 water level recorders will be needed to continuously monitor standing water in the rain gardens and the water contained in the bioretention and infiltration trenches. Additional water samplers and flow monitors will also be needed for any underdrains. The locations and numbers of these will be dependent on the final designs of the treatment units and how the underdrains are collected for discharge to the collector drainage, but it is likely that another 12 samplers and monitors will be needed to monitor a complete mass balance. It is also highly recommended to have at least one or two space sets of equipment to rotate through the setups as units have to be periodically removed for service (or repair). Nine soil moisture sensors are also needed to be placed in the root zones of the systems and another nine are needed for the storage zone beneath the root zones. Groundwater mounding should also be monitored under the infiltration devices. Nine groundwater level observation wells are needed beneath the infiltration areas, and another nine are needed surrounding the infiltration zones.

Three tipping bucket rain gages will also be installed in this area that will be used to initiate the automatic samplers (and to provide redundant rain data, one of the primary monitoring parameters). The flow monitors located in the adjacent combined sewers collecting pre-development flows will be maintained to collect flow data for post-construction conditions.

Monitoring Locations at Cincinnati Zoo African Savannah

Porous Pavers and Enhanced Turf and Vegetation

Replace the existing parking lot with pervious paving and enhanced turf and vegetation. The pervious paving is designed to cover 42,207 ft^2, while the total area of the turf replacement is roughly 20,000 yd^2. Monitoring of the new porous paver installations should include locations where mass balances of the water and pollutants of interest can be conducted. This approximately one acre of porous pavers will drain towards a single internal location where excess runoff can be sampled and monitored. It is anticipated that any underdrains will also drain to this single location that is located at the lowest area on the parking area. Therefore, two automatic water samples with flow sensor modules will be needed at this location, along with a single tipping bucket rain gage.

Subsurface monitoring and water sampling is also needed to measure the quantity and quality of the percolating water. Observation wells should be established to measure any groundwater mounding or perching under the porous paver area. Three observation wells should be established within the porous paver area, with another three outside of the area to determine unaffected groundwater table elevations. A cluster of pan lysimeters can be established in a central area, with collection ports located at several depths under the pavers. These are passive samplers with no elaborate sampling equipment.

The turf and enhanced vegetation monitoring would be based on soil infiltration, texture, moisture, and density measurements. The infiltration tests should be conducted for surface and several feet deep conditions. Soil measurements of texture and chemical characteristics would also be periodically conducted. These measurements should be conducted in areas having the enhanced vegetation and in other areas having standard vegetation conditions for comparison.

Bioretention Areas and Tree Walls

Installation of three bioretention basins and two tree wells. These facilities should be monitored at the inflow, overflow, and underdrain locations, plus beneath the units using the observation wells and pan lysimeters described above. The soils/media in the units also need to be periodically monitored to measure maintenance issues and potential problems associated with snowmelt runoff entering them. Each unit being monitored would therefore require three automatic samples and flow modules plus one tipping bucket rain gage module, in addition to two observation wells (one within and one adjacent), and two pan lysimeter depths. All five devices would not need to be monitored, unless there were significant differences in their designs or engineered soil. For these initial planning purposes, it is assumed that only one bioretention area and one tree wall would be monitored.

Rainwater Harvesting, Storage and Reuse System

Construction of a large subsurface storage pipe under the African Savannah area. The storage facility will consist of 380-feet of 12-foot diameter perforated pipe, surrounded by open graded aggregate. In order to conduct a mass balance of this unit, all inflows need to be monitored, along with the outflows. If the outlet water is being treated, samples would also be taken before and after any treatment. The plans are not clear on how many inlet and outlet locations exist, but this initial planning calculation assumes a total of five locations. Besides the inlet and outlet sampling, water elevation measurements in the pipes and gravel storage areas will be needed, possibly by using only a single water level sensor.

Storm Sewer Separation and Roof Leader Disconnection

Disconnect these systems from the combined sewer system through a storm sewer separation project and redirection of roof leaders to the subsurface storage facility. Monitoring of these activities would need to be conducted close to the roof leaders in a small-scale. It is suggested that a set of sheetflow sampler stations be established at varying distances from a disconnected roof leader for the measurement of flows and to measure water quality for the site soil conditions. Soil tests and measurements (infiltration, texture, moisture, and density, in addition to soil chemistry) would also be needed in the areas being examined. No automatic samplers are expected for these tests, unless areas can be isolated for paired area analyses.

Summary of Sampling and Monitoring Locations at Cincinnati Zoo African Savannah

The following table summarizes the total number of samplers and monitoring activities expected for the Cincinnati Zoo African Savannah exhibit stormwater management activities:

	Number of units and/or size	Automatic water samplers, flow sensors and rain gage	Soil monitoring	Vadose zone monitoring
Porous pavers and enhanced turf and vegetation	Enhanced vegetation plus 1 porous paver parking area; 42,207 ft^2	2 samplers 2 flow modules 1 rain module	Infiltration, texture, moisture, and density, plus chemical analyses (surface and at depth)	6 observation wells with level recorders 1 pan lysimeter cluster
Bioretention areas and tree walls	3 bioretention areas (monitor 1) 2 tree wells (monitor 1)	6 samplers 6 flow modules 2 rain modules	Infiltration, texture, moisture, and density, plus chemical analyses	4 observation wells with level recorders 2 pan lysimeter clusters
Rainwater harvesting, storage, and reuse system	1 storage tank (assuming 5 inlets and outlets total) and treatment unit	6 samplers 6 flow modules 1 rain module 1 water level recorder in storage tank	none	none
Storm sewer separation and roof leader disconnections	Not specified	6 sheetflow samplers	Infiltration, texture, moisture, and density, plus chemical analyses	none
Total for Cincinnati Zoo		14 automatic samplers	Infiltration, texture, moisture,	10 observation wells (with water

African Savannah		6 sheetflow samplers 14 flow modules 4 rain modules 1 water level recorder 7 to 10 equipment shelters	and density, plus chemical analyses at about 10 locations (conducted seasonally)	level recorders) 3 pan lysimeter clusters

The approximate cost of this equipment would be about $150,000, excluding the analysis costs.

Recommended Monitoring Equipment

It is recommended that as much of the sampling and monitoring equipment be obtained from a single manufacturer as possible. This will ensure the best integration of the complex components and the best support service from the manufacturer. The recommended equipment supplier is Teledyne ISCO, of Lincoln, NE. They are highly experienced, having supported stormwater monitoring projects for several decades, and offer a wide range of equipment. The following lists some of the major equipment needs:

- Model 6712 Sequential/Composite Automatic Sampler (full-size). 10L composite plastic sampler container plus 24 plastic bottle sample base to allow flow-weighted composite sampling (recommended) and periodic discrete (high-resolution) sampling. These samplers also accept 700 Series Modules. The 750 Area-Velocity Flow/level module is recommended for most situations, but the 730 Bubbles Flow/level module would be used for monitoring water elevation.

- Communications. The samplers should also be outfitted with cell phone interfaces allowing remote access, interrogation, adjustments, and downloading of data. As noted previously, ISCO 674 tipping bucket rain gages will also connect to the samplers and data loggers to initiate the sampler sequence. This is the most reliable triggering option for most situations. Terminal program and Internet interfacing would also be used to automatically download and assemble the data and present it on a project web page.

- Continuous Water Quality Sondes. The MSDGC already had several YSI water quality sondes that can be used at the monitoring locations. These can also be directly interfaced to the ISCO sampler/data loggers. The sondes can be programmed to collect pH, temperature, turbidity, DO, ORP, and conductivity data every several minutes during runoff events. They should be repositioned during interevent periods to continuously monitor the quality of standing water.

About 24 sets of this equipment may be needed at the Cincinnati State Technical and Community College monitoring sites and about 14 at the Zoo locations to enable complete mass balance measurements to water and pollutants at the stormwater control locations. The cost of this equipment is expected to be in the range of $200,000 to $250,000 for the Cincinnati State monitoring and another $150,000 for the Zoo. Sample analytical costs and maintenance of the sampling equipment would be additional.

Installation of this equipment will be very critical to ensure accurate measurements. The flow sensors have to be properly installed with the correct approach conditions, for example. If at all possible, flume inserts should be used to measure open channel flow conditions in the pipes. If the pipes are completely full, then the velocity sensor alone will be suitable without an insert. Different sized plastic flumes are also available from Global Water, for example, that allow accurate surface flows. Again, the approach conditions must be considered, along with the expected range of flow conditions, to select the appropriate control units.

The water samplers are usually installed in steel contractor’s job boxes. However, ISCO can supply insulated fiberglass units that are more suitable. All of the equipment will need to be operated off of deep cycle batteries if AC line power is not available (much more convenient). The sampler intakes need to be located in total flow locations. Intakes located along the invert of a storm drain pipe frequently over-samples sediment as they preferentially draw in bedload sediments. It is not possible to create an artificial mixing zone in a pipe to allow well-mixed conditions. Therefore, the recommended approach is to install sampling boxes at the sampling locations that provide 6 to 12 inches of drop. The water then cascades into a sample tray containing the inlet, creating a well-mixed sample. Unfortunately, these are difficult, but often necessary, to construct after the stormwater control devices are already installed. These are most critical for inlets, where larger particles are more common (they should all be removed by the control and are therefore not likely to be present at outlets or in underdrains). Inlets can hopefully be easily modified (temporarily) to accommodate these sampler structures.

Sampling Effort/Experimental Design

The monitoring plan for Cincinnati will contain methods to determine the needed sampling effort, including the number of samples for the three monitoring areas. These procedures can be utilized for many different conditions and situations, but some prior knowledge of the conditions to be monitored is needed. A phased sampling approach is therefore recommended, allowing some information to be initially collected and used to make preliminary estimates of the sampling effort. Later sampling phases are then utilized to obtain the total amount of data expected to be needed.

1) small scale monitoring to measure the benefits of infiltration devices. Several pairs of monitoring stations will be established to determine the direct benefits of infiltration devices (land use scale biofiltration devices in parking lots, along streets, institutional rain gardens, etc.). These will all be paired analyses with concurrent influent and effluent monitoring of flows and pollutants. Stratified random sampling will be used to separate the data into groups corresponding to different rain depths per season. Initial modeling of the area will be conducted to identify rain categories for the stratifications, but prior experience suggests the following rain depth strata: <0.5, 0.5 to 3, >3 inches. In addition, seasonal variations (relating to soil moisture and other antecedent period factors) will also be examined for appropriate strata. The desired number of events in each strata will depend on the expected variability of the factors being monitored, and the data quality objectives. Most stormwater constituent coefficients of variation range from about 0.5 to 1. If performance levels (treatment benefits) defined by percentage reductions of about 25% are desired to be statistically identified, with confidence levels of 0.95 and power of 0.8, then about 75 pairs of samples may be needed. With a multi-year project, about 30 plus events per year should be targeted for evaluation. Flows are relatively inexpensive to monitor, after the equipment is installed, so data should be collected for almost every rain event. Water quality evaluations are secondary for this project, so less demanding data quality objectives may be warranted. If 50% differences to be detected are a suitable goal, then about 25 pairs of samples will be needed. When the data are obtained, it will be separated into the different seasonal and rain depth strata for comparison tests. In the past, this approach has resulted in more complete understandings of device performance and better quality data than simply lumping all together. Of course, many more small events will be available for monitoring than the large category, so this initial plan may not be feasible, depending on the actual rains during the monitoring period.

2) large scale watershed monitoring to confirm benefits of multiple green infrastructure controls throughout the drainage areas. Monitoring stations will be located at the discharge of the large areas to quantify these benefits in combined sewage flows from the complete site. A control monitoring station is not likely to be available, as the land use areas being monitored are unique (only one zoo!). Therefore, pre- and post-installation monitoring will be compared, with independent (not paired) analyses. Flow (along with concurrent rainfall) is the primary parameter for monitoring at these locations and data should be collected for every event that occurs during the monitoring period. Large scale monitoring is much more challenging than small scale monitoring, as the benefits of the devices in the drainage area will have less of a benefit that the individual monitoring described above. It is expected that many small-scale controls will be installed throughout each area, with most of the runoff subjected to controls. With about 25 events each year that may produce measureable increased flows in the combined sewers, data from all of these events during the monitoring program may result in about 50 total events. With a larger COV expected (about 1.0), differences between the pre- and post-installation monitoring periods of about 60%, or larger, should be reliably detected.

3) monitoring to calibrate stormwater models. The three institutional land uses will have biofiltration devices installed along with some site beneficial uses, to reduce stormwater discharges to the combined sewers. The influent data from the monitored devices can be used to calibrate the stormwater models. In addition, the large watershed (pre- and post-installation periods) data can be used to verify the calibration at a larger scale. Additional monitoring information for other commonly occurring land uses in the region will be needed to expand the model calibration for the whole city, as the data collected during this monitoring project only represents institutional land uses. These other data may be available from MS4 stormwater permit monitoring programs. Otherwise, it may be necessary to establish semi-permanent monitoring equipment at other areas. In order to obtain the necessary calibration information, data from at least 15 events for each area has been shown to usually be sufficient. Flow and rainfall data is the most critical need, along with detailed site descriptions.

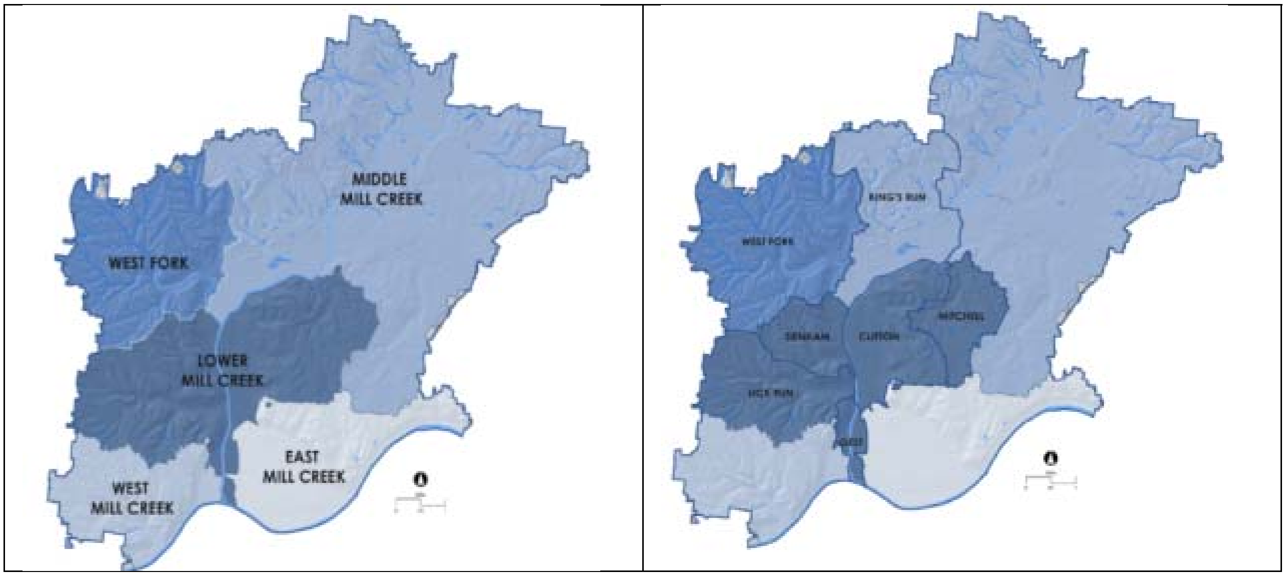
For the small-scale monitoring addressed in this project, numerous individual control practices will be monitored during this demonstration project. These will include small to large biofilters of differing designs, along with porous pavers, and beneficial use installations. As described previously, each type of device will require specialized monitoring locations and methods. In general, there are 2 to 4 monitoring locations per device (influent, overflow/effluent, underdrain, and subsurface percolating water). Each of these locations will require flow monitoring, and water sampling and analysis. If there are six devices for each of the three areas, three monitoring locations per device, and 30 events per device (spread over two years), a total of about 1600 samples will be collected representing about 500 separate events. Flow monitoring (and associated rainfall) are the priority analyses. Chemical analyses will be on flow-weighted composite samples (one per event per sampling location), although continuous water quality sondes can be very useful to supplement these data. Few constituents will be analyzed for each sample (TSS, turbidity will be most common, with particle size analyses on fewer samples, and bacteria (E. coli and enterococci), nutrients and copper and zinc on fewer samples). It may be possible to rotate sampling and monitoring equipment amongst the sampling locations. There would be about 54 separate sampling locations, and it may be possible to have about half that number of sampling and flow monitoring equipment, with the goal of about 30 events spread out over two years.

Descriptions of Watersheds and Identified Regional Problems

There have been many project reports prepared describing the Cincinnati area combined sewer system and receiving water conditions. One of the first tasks in developing this demonstration project monitoring strategy was to review many of these reports to summarize the known problems so the monitoring strategy will be able to address the specific local problems that need to be improved. The following is therefore a brief summary of these numerous previously prepared reports.

Lower Mill Creek Watershed

The Lower Mill Creek watershed is part of the larger South Branch Mill Creek watershed, and covers approximately 8,712 acres. The Lower Mill Creek watershed, West Fork watershed, and a portion of the Middle Mill Creek watershed were divided into seven different sub-basins (see below). The study locations for this demonstration project (the Cincinnati Zoo, Cincinnati State Technical and Community College, and the University of Cincinnati) are located in the Clifton sub-basin, which is further described below.



South Branch Mill Creek watershed and sub-basins, including the Clifton sub-basin containing the study locations.

Land area: 15,355 acres

	West Fork	King's Run	Denham	Clifton	Mitchell	Gest	Total
Land area (acres)	5,524	3,846	1,317	2,622	1,575	471	15,335
Total number of CSOs	12	20	5	12	1	5	55
Annual CSO volume (MG)	753	688	365	1,054	703	40	3,603
Annual CSO events	508	856	238	720	105	235	2,622
Direct Entry Point: Annual Runoff (MG)	1,055	512	176	482	86	15	2,326
Direct projects: Annual Runoff (MG)	884	501	114	239	0	0	1,738
Enabled Projects: Annual Runoff (MG)							258

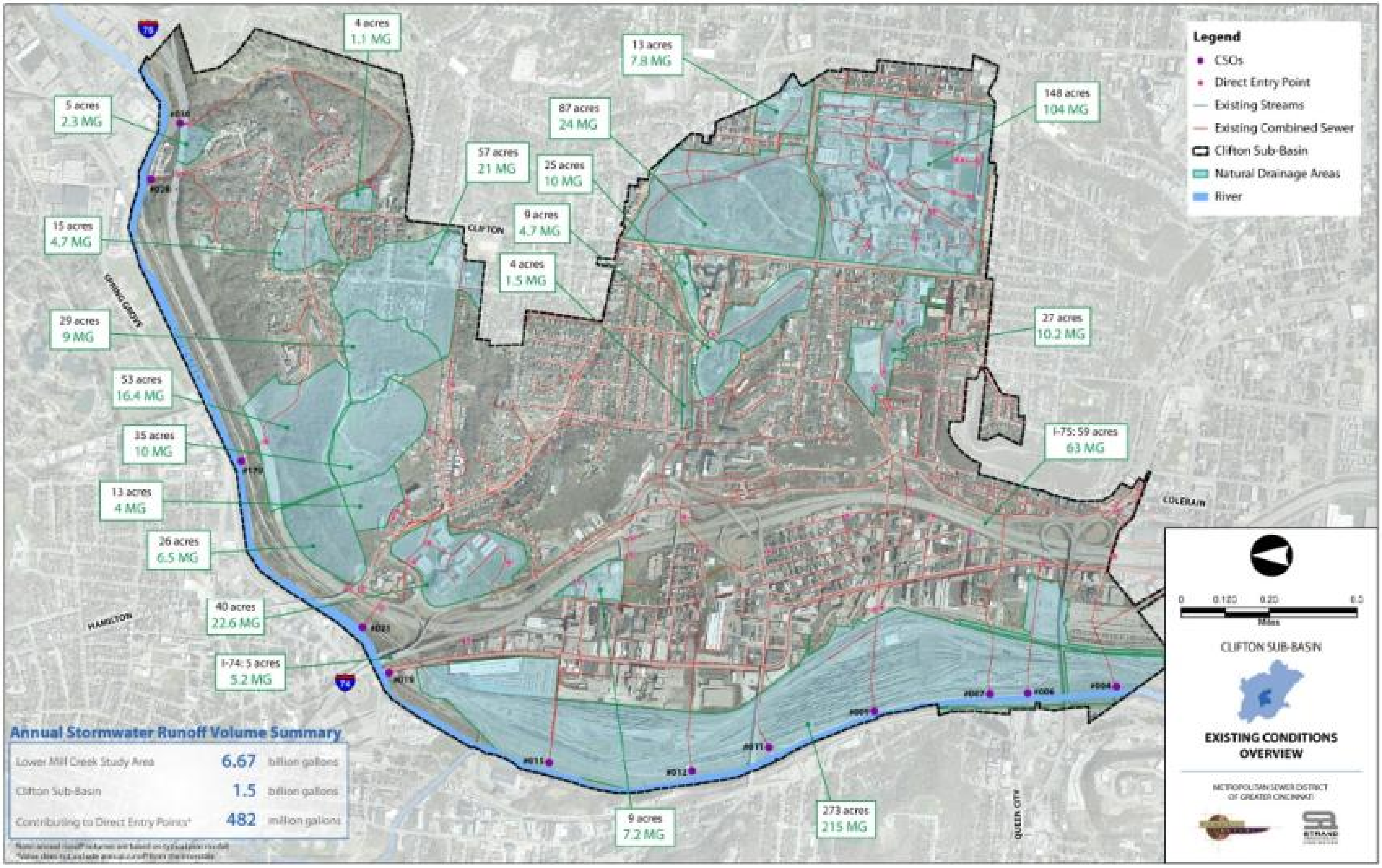
Inform & Influence Projects: Annual Runoff (MG)	224	190	231	329	222	0	1,196

Clifton Sub-Basin

The Clifton sub-basin covers 4.1 square miles. There are 12 CSO locations within the Clifton sub-basin, contributing to an annual overflow volume of 1.05 billion gallons. Direct project areas identified during the initial evaluation contribute a total of 239 MG of stormwater runoff annually.

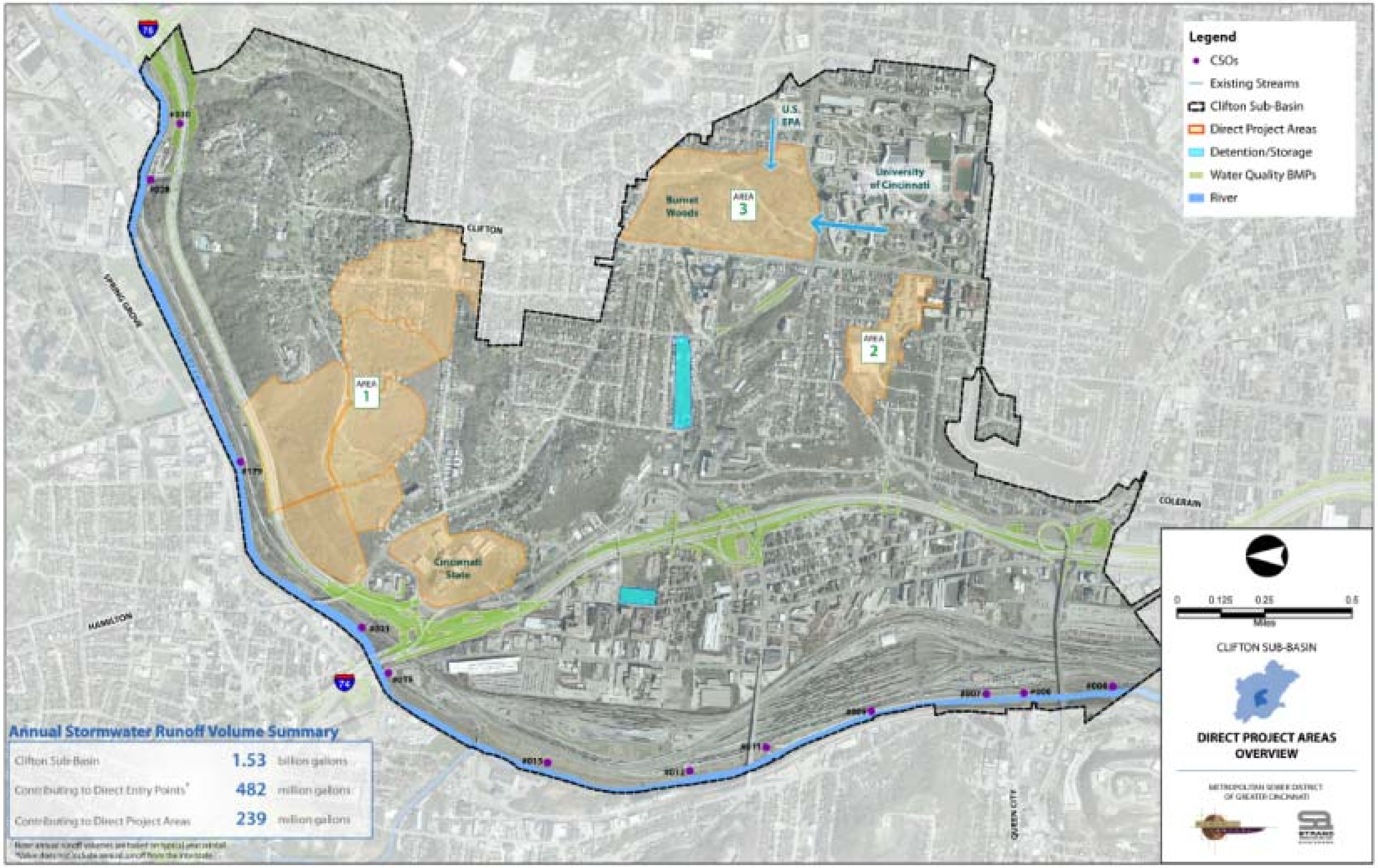
CSO Number	Annual CSO Statistics			Direct Project (MG)
	Events	Overflow (MG)	Control (%)	
4	74	37	18	0
6	70	52	25	0
7	77	92	19	0
9	49	162	67	10
11	65	28	37	0
12	68	325	36	136
15	35	39	79	0
19	13	1	92	0
21	73	159	27	71
28	64	36	48	0
30	59	66	60	0
179	73	60	13	23
Total	720	1,054		239

In the previous study, several opportunities were identified to reduce the volume of stormwater runoff entering the combined sewer system and the resulting CSO volume in the Clifton sub-basin, as shown on the following maps.



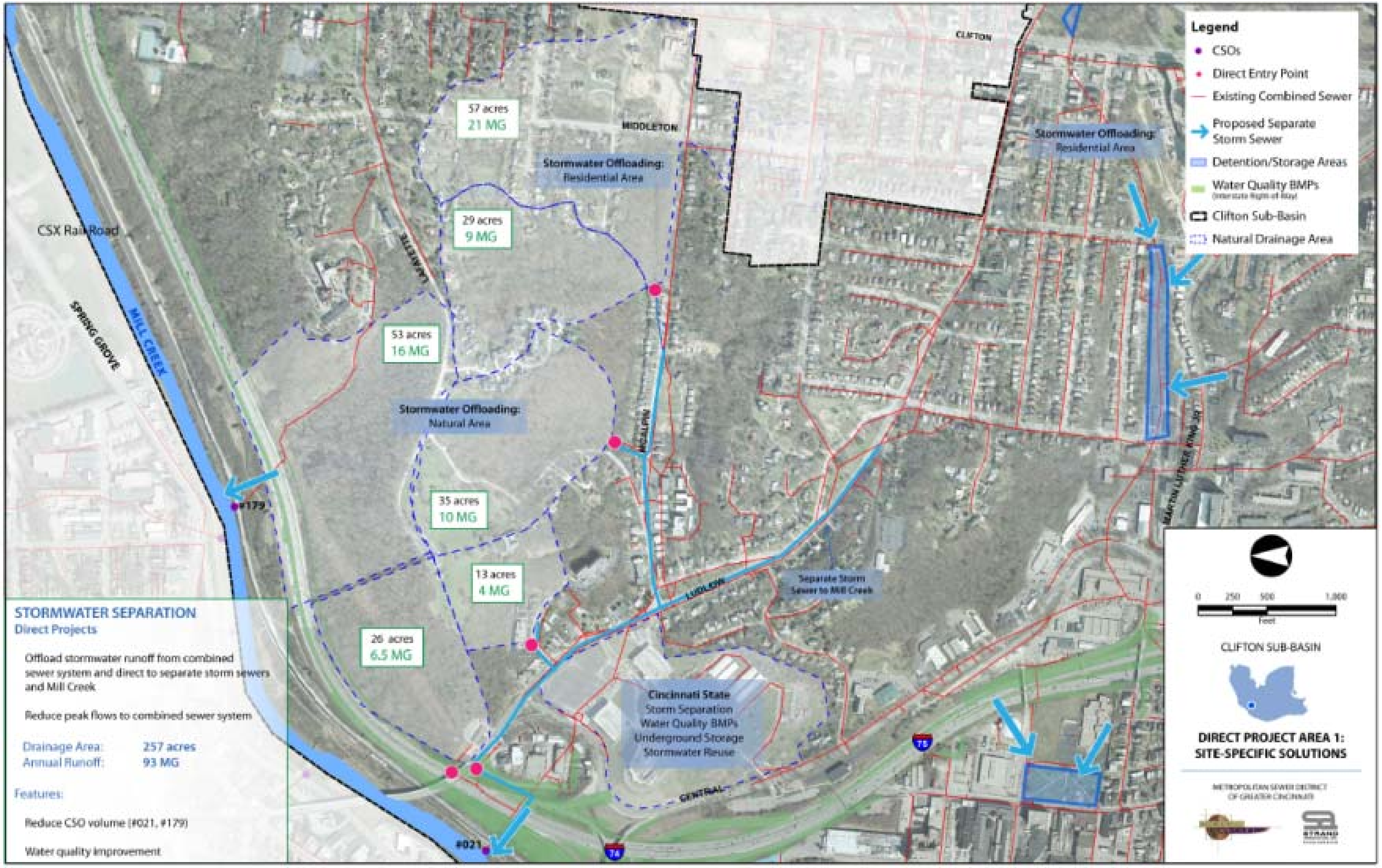
Annual Stormwater Runoff Volume Summary

Lower Mill Creek Study Area	6.67	billion gallons
Clifton Sub-Basin	1.5	billion gallons
Contributing to Direct Entry Points*	482	million gallons



Annual Stormwater Runoff Volume Summary

Clifton Sub-Basin	1.53	billion gallons
Contributing to Direct Entry Points*	482	million gallons
Contributing to Direct Project Areas	239	million gallons



STORMWATER SEPARATION
Direct Projects

Offload stormwater runoff from combined sewer system and direct to separate storm sewers and Mill Creek

Reduce peak flows to combined sewer system

Drainage Area:	257 acres
Annual Runoff:	93 MG

Features:

Reduce CSO volume (#021, #179)

Water quality improvement

DIRECT PROJECT AREA 1: SITE-SPECIFIC SOLUTIONS

DETENTION: UNDERGROUND STORAGE

Coy Field

Offload stormwater runoff from combined sewer system and direct to separate storm sewers (existing and proposed) and underground storage tank

Reduce peak flows of stormwater runoff to combined sewer system

Drainage Area:	27 acres
Annual Runoff:	10 MG

Features:

Reduce CSO volume (#009)

Water quality improvement

DIRECT PROJECT AREA 2: SITE-SPECIFIC SOLUTIONS

In Collaboration with:

Uptown Consortium, Inc.
&
Cincinnati Park Board

Uptown Parks & Neighborhood Revitalization Plan

Burnet Woods & Clifton Study Area
Final Master Plan

"The Oasis"

Park Elements:

① Improved Linkages to / from Digg's Plaza
② Ludlow Gateway
③ New Street Trees Along Ludlow
④ Streetscape Linkages to / from Zoo
⑤ Restored Stream Corridor with Trail Interpretive Stops: Stormwater BMP's
⑥ Clifton Gateway: Realigned with Dixmyth
⑦ Bandstand
⑧ Improved Parking & Picnic/Play Rental Area
⑨ Realigned Street with Parking, Pedestrian Promenade, & Connecting Gardens
⑩ Enhanced Trailside, Boathouse, & Terrace
⑪ Existing Shelter and Playground
⑫ Existing Road Removed to Strengthen Forest & Stream Linkage
⑬ Terrace, Cafe, and Restaurant on Clifton
⑭ Park Drop-Off & Parking
⑮ Enhanced Lake Promenade
⑯ New Scenic Drive Alignment
⑰ "Green" Park Maintenance Building
⑱ Enhanced Streetscape Along Clifton Avenue
⑲ UC Permit Parking
⑳ Expanded Disc Golf Course
㉑ Native Landscape Restoration & Biofiltration
㉒ Entry Plaza & Improved Intersection
㉓ Landscape Gallery
㉔ Enhanced Streetscape Along Martin Luther King Avenue
㉕ King Gateway
㉖ Cul-de-sac Alternative

Boulevard Streetscape Enhancements:
- Landscaped Medians with Trees
- Boulevard Lighting
- ADA Curb Ramps
- Curb Extensions ("Bulb-Outs")
- Bike Lanes (Space Permitting)
- Crosswalk Enhancements

Residential Streetscape Enhancements:
- ADA Curb Ramps
- Curb Extensions
- Traffic Calming Elements
- Crosswalk Enhancements

December 20, 2006

DESIGN TEAM:
Human Nature
Goody Clancy
ZHA, Inc.
Fearing + Hagenauer
Kolar Design
Leisure Services Management
Davey Resource Group
LISC

BURNET WOODS
Stormwater Master Plan

Offload stormwater runoff from the U.S. EPA site and the University of Cincinnati's West Campus and direct to stormwater management features within in Burnet Woods

Drainage Area:	248 acres
Annual Runoff:	136 MG

Components:

AREA A	Retention forebay/bioinfiltration
AREA B	Stream daylighting opportunity
AREA C	Detention opportunity

Components:

Reduce CSO volume (#012)

Reduce peak flows to combined sewer system

Water quality improvement

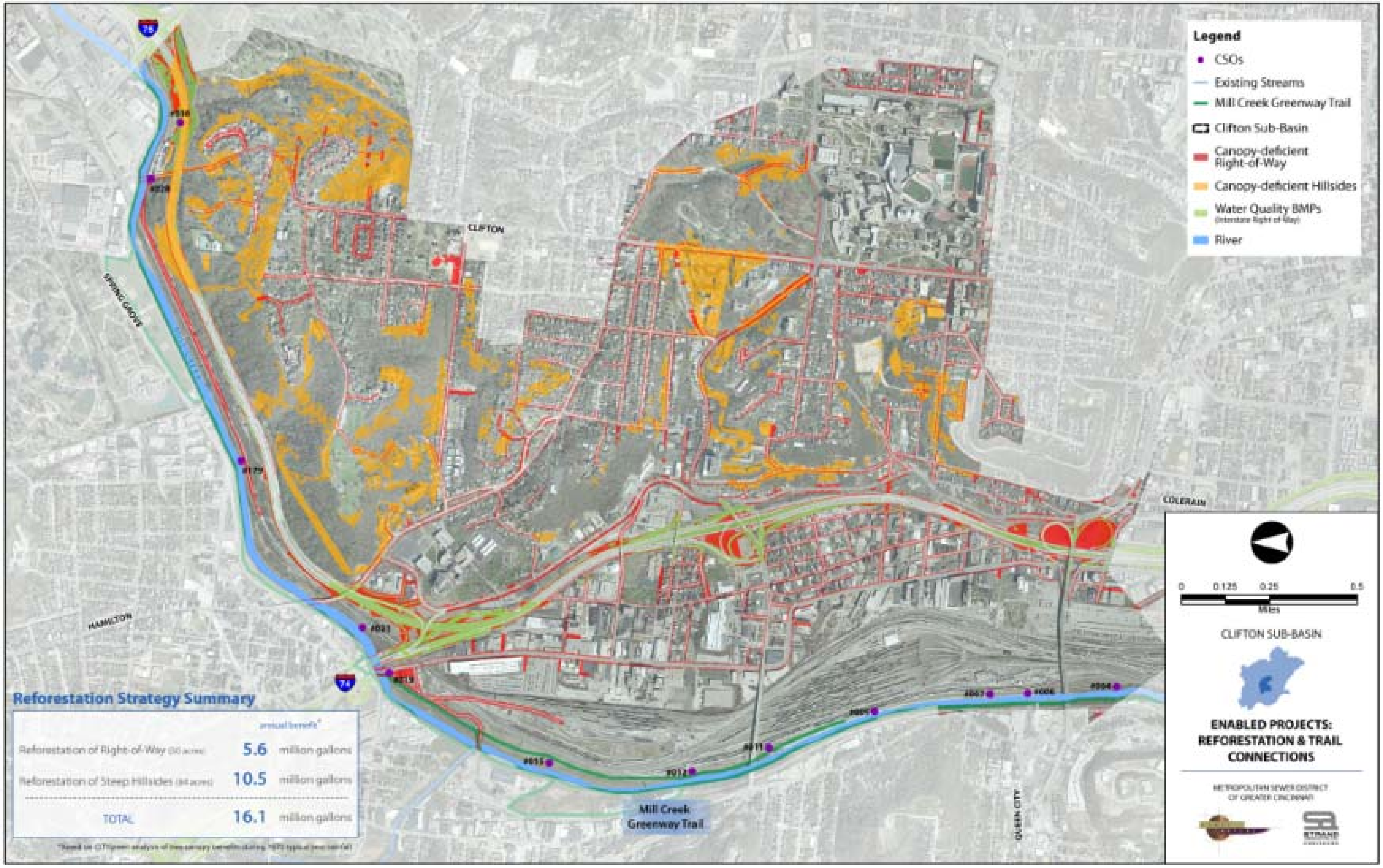
0 150 300 600
Feet

CLIFTON SUB-BASIN

DIRECT PROJECT AREA 3:
BURNET WOODS

METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI

STRAND



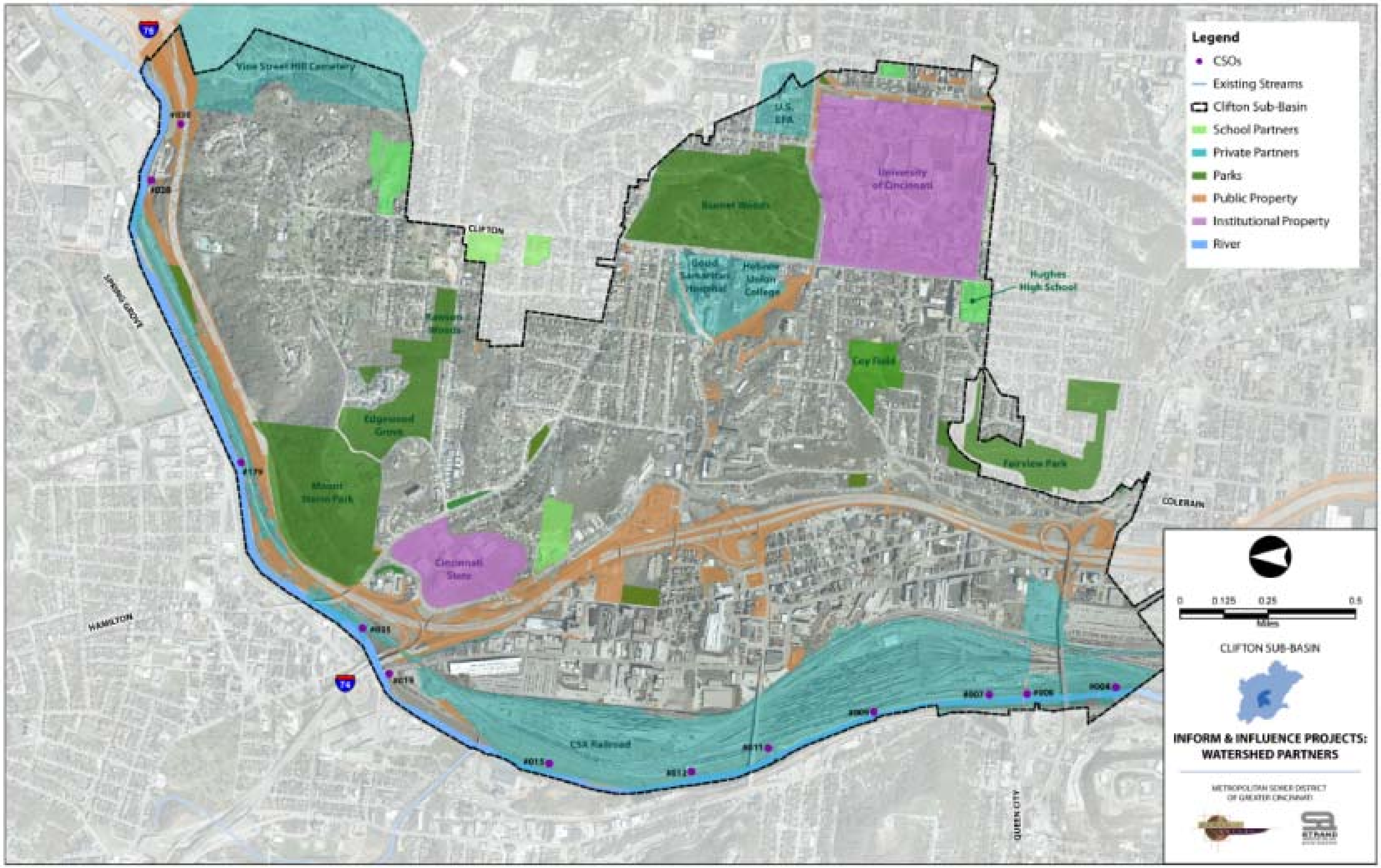
Reforestation Strategy Summary

	annual benefit*	
Reforestation of Right-of-Way (30 acres)	5.6	million gallons
Reforestation of Steep Hillsides (84 acres)	10.5	million gallons
TOTAL	16.1	million gallons

*Based on CITYgreen analysis of tree canopy benefits during 1970 typical year rainfall

ENABLED PROJECTS: REFORESTATION & TRAIL CONNECTIONS

METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI


Legend
● CSOs
— Existing Streams
Clifton Sub-Basin
School Partners
Private Partners
Parks
Public Property
Institutional Property
River
75
74
Vine Street Hill Cemetery
U.S. EPA
University of Cincinnati
Burnet Woods
CLIFTON
Good Samaritan Hospital
Hebrew Union College
Hughes High School
Rawson Woods
Edgewood Grove
Mount Storm Park
Cincinnati State
Fairview Park
COLERAIN
SPRING GROVE
HAMILTON
QUEEN CITY
CSX Railroad
#179
#015
#012
#011
#009
#007
#006
#004
0
0.125
0.25
0.5
Miles
CLIFTON SUB-BASIN
INFORM & INFLUENCE PROJECTS: WATERSHED PARTNERS
METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI

Biological and Water Quality Study of Mill Creek and Tributaries, and Ohio River Butler and Hamilton Counties, Ohio

The 2009 monitoring activities in the Mill Creek watershed included sampling for chemical analyses as well as biological assessment. For this purpose 39 stations were monitored during two dry weather surveys and two wet weather surveys for chemical analyses, while 11 stations were monitored for biological assessment. Due to the timing of the sampled events during the 2009 field season, biological monitoring was only completed twice. A map of the Mill Creek study area with associated monitoring stations is shown below:

Number of chemical and biological stations in region:

Locations	Number of Chemical Stations	Number of Biological Stations
Mill Creek	18	6
Ohio River	5	0
East Fork Mill Creek	5	1
West Fork Mill Creek	5	3
Tributary stream (including Town Run, Sharon Creek, cooper Creek, GE Trib. And Bloody Run)	6	1
Total	39	11

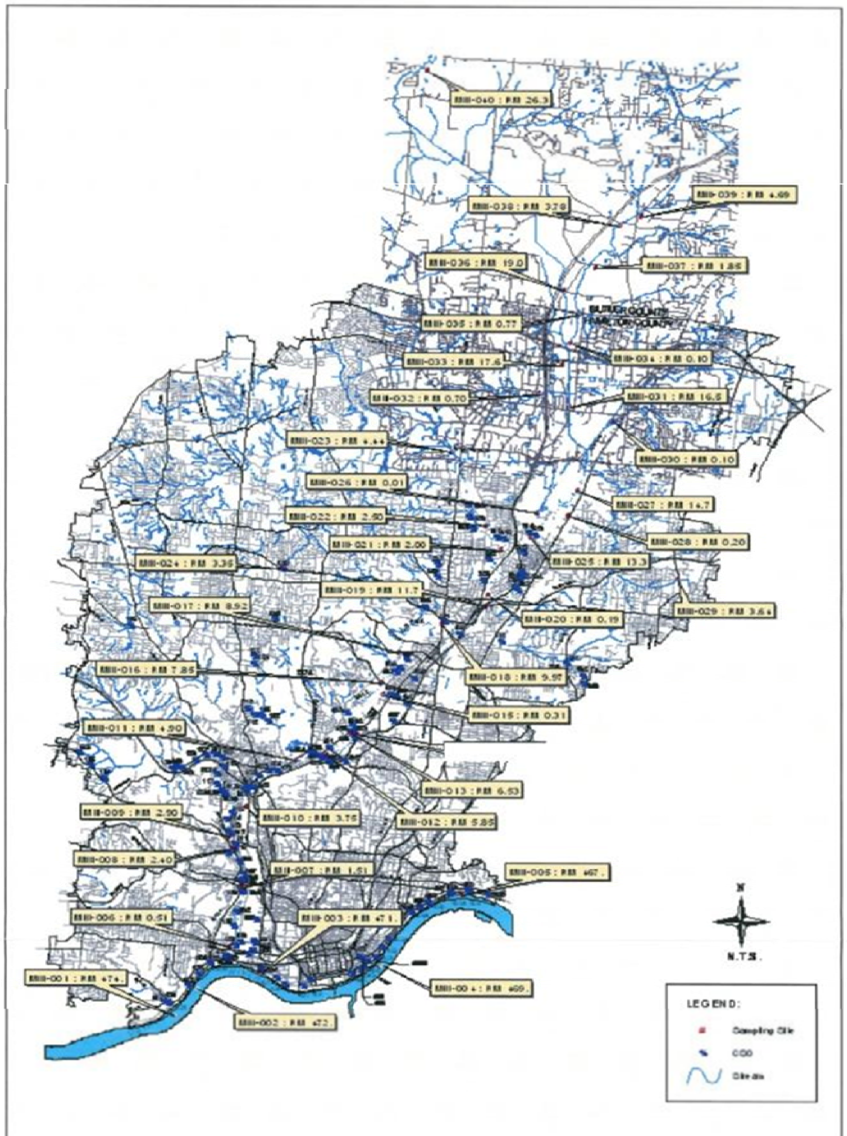


FIGURE 1

MILL CREEK
INSTREAM SAMPLING LOCATIONS

Chemical Results

Mill Creek

- Coliforms and E. coli: Eighteen monitoring stations had exceedences of the primary contact recreational use designation criterion for both fecal coliforms and *E. coli* during at least two sampling periods, while only one monitoring station exhibited exceedence of the primary contact recreational use designation criteria for both fecal coliform and *E. coli* during all four chemical sampling periods.
- Metals: Some of monitoring stations exhibited exceedence of the standard for iron, lead, copper and zinc. Seventeen monitoring stations experienced exceedences of the total recoverable iron criterion for the protection of agricultural uses. Sixteen monitoring stations exhibited exceedences of the OMZA (Outside Mixing Zone Average) criterion for total recoverable lead during multiple sampling

periods. Fourteen monitoring stations exhibited exceedences of the total recoverable copper criterion. Five monitoring stations exhibited exceedences of both the OMZA and OMZM (Outside Mixing Zone Maximum) standards for total recoverable zinc.

East Fork Mill Creek

- Coliforms and *E. coli*: Three monitoring stations had exceedences of the secondary contact recreational use designation criteria for both fecal coliform and *E. coli*, while only two monitoring stations had exceedences of the primary contact recreational use designation criterion for both fecal coliform and *E. coli*.
- Metals: Two monitoring stations out of five stations had exceedences of the total recoverable iron OMZA criterion for the protection of agricultural uses. Two monitoring stations exceeded the OMZA standard for total recoverable lead

Ohio River

- Coliforms and *E. coli*: Only one monitoring station had individual violations of the recreational use designation bathing waters criteria for both fecal coliform and *E. coli*.
- Metals: Four monitoring stations had exceedences of the total recoverable zinc OMZM criterion.

West Fork Mill Creek

- Coliforms and *E. coli*: All five monitoring stations had multiple exceedences of the recreational use designation PCR criteria for both fecal coliform and *E. coli*.
- Metals: Two monitoring stations out of five monitoring stations had exceedences of the total recoverable copper OMZM criterion. Two monitoring stations had single exceedences of the total recoverable iron OMZA criterion for the protection of agricultural uses. Two monitoring stations had single exceedences of the total recoverable lead OMZA criterion, while three monitoring stations had two exceedences of this same standard.

Tributary streams

a) Town Run

- Coliforms and *E. coli*: Exceedences of the recreational use designation SCR criterion for fecal coliform were documented during two of four sampling periods. Also, the recreational use designation SCR criterion for *E. coli* was exceeded during three of four sampling periods..
- Metals: Exceedences of the total recoverable copper OMZA criterion was documented during a single survey performed during the 2009 field activities, along with two exceedences of the total recoverable lead OMZA criterion.

b) Sharon Creek

- Coliforms and *E. coli*: Violations of the recreational use designation PCR criterion for fecal coliform was observed during two of four sampling periods. Also the recreational use designation PCR criterion for *E. coli* was exceeded during three of four sampling periods, including one dry weather and two wet weather periods.
- Metals: A single exceedence of the total recoverable copper OMZM standard was observed. One exceedence of the total recoverable iron OMZA criterion for the protection of agricultural uses was observed at this monitoring station. Two exceedences of the total recoverable lead OMZA criterion were observed at this location.

c) Cooper Creek

- Coliforms and *E. coli*: Violations of the recreational use designation SCR criteria for both fecal coliform and *E. coli* were recorded for two monitoring stations during two sampling periods performed during the 2009 field activities.
- Metals: One monitoring station had one recorded exceedence of the total recoverable copper IMZM (Inside Mixing Zone Maximum) criterion, while the other monitoring station had a single exceedence of the total recoverable copper OMZM criterion. Individual exceedences of the total recoverable lead OMZA criterion were observed at each of the two monitoring stations. One of the monitoring stations at Cooper Creek exceeded the total recoverable iron OMZA criterion for the protection of agricultural uses, while the other one had a single exceedence of the OMZM criterion for total recoverable zinc.

d) GE Tributary

- Coliforms and *E. coli*: A single violation of the proposed recreational use designation PCR criterion for *E. coli* was observed during wet weather sampling.
- Metals: A single exceedence of the OMZM criterion for total recoverable copper was observed at this location along with two exceedences of the total recoverable lead OMZA criterion.

e) Bloody Run

Coliforms and *E. coli:* Exceedences of the recreational use designation SCR criteria for fecal coliform and *E. coli* were observed twice at this station during the 2009 in-stream surveys.

- Metals: Exceedence of the total recoverable copper OMZA criterion was observed during two sampling periods at this location. Exceedence of the total recoverable lead OMZA criterion was documented during two sampling periods at this monitoring station.
- Nutrients: A single exceedence of the OMZA criterion for ammonia-nitrogen was observed during the wet weather sampling periods.

Biological Results

Mill Creek

Six locations on the Mill Creek had biological assessments conducted during the 2009 study

- Species diversity ranged from 11 to 17 total taxa.
- Species density ranged from a low of 21 organisms to a high of 94 organisms per site.
- EPT taxa collected per site ranged from 3 to 6 species.
- Habitat remains a limiting factor to biological community performance in many areas of Mill Creek.
- Narrative evaluations ranged from “Fair” to “Good” for the Mill Creek stations.

West Fork Mill Creek

Three locations were sampled for biological conditions on the West Fork Mill Creek during the 2009 study.

- Species diversity ranged from 4 to 207 taxa per site.
- Species density ranged from a low of 37 organisms to a high of 97 organisms per site.
- EPT taxa collected per site ranged from 1 to 7 species.
- Habitat remains a limiting factor to biological community performance in many areas of West Fork Mill Creek.
- Narrative evaluations for the three West Fork Mill Creek stations ranged from “Poor” to “Good”.

GE Tributary

A single location on this tributary stream, was sampled to assess biological conditions during the 2009 study

- Species diversity remained essentially the same with 9 taxa collected during 2009 versus 4 taxa collected during the 2006 study.
- Species density totaled 9 organisms for this location.
- No EPT taxa were collected at the site during the 2009 study.
- This site has good habitat available including a series of runs and falls with riprap and margin habitats found along the stream banks.

East Fork Mill Creek

A single location was sampled to evaluate biological conditions on East Fork Mill Creek during the 2009 study.

- Species diversity for 2009 was 7 species.
- Species density decreased to 65 organisms for this location.
- EPT taxa collected decreased, with only one taxa collected during the 2009 study compared with 2 taxa recorded during the 2006 study.

Summary of Regional Receiving Water Problems and Primary Monitoring Objectives

The Mill Creek biological and chemical monitoring surveys indicated a range of potential problems throughout the watershed:

- high *E. coli* and fecal coliform bacteria observations commonly exceeded the recreational use criteria
- total recoverable iron criterion for the protection of agricultural uses were periodically exceeded
- total recoverable lead, copper, and zinc criteria for outside of the mixing zones were frequently exceeded
- ammonia-nitrogen and dissolved oxygen criteria for outside of the mixing zones were rarely exceeded (Bloody Run only)
- In general, the habitat conditions in the receiving waters was a limiting factor to desired biological community performance, with evaluations ranging from poor to good.

It is likely that the bacteria (both *E. coli* and fecal coliforms), the dissolved oxygen, and ammonia-nitrogen criteria exceedences are more associated with the sewage components of the overflows than the stormwater components. However, the heavy metals (iron, copper, lead, and zinc), along with the high flows likely associated with the habitat limitations are more associated with the stormwater components. Of course, if the stormwater runoff volumes were significantly reduced, the magnitude and frequency of the CSOs would also be significantly reduced, reducing the bacteria, dissolved oxygen, and ammonia exceedences. However, even if the overflows were eliminated and separate stormwater was allowed to enter the receiving waters, the bacteria criteria would still likely be exceeded due to typical high bacteria levels found in stormwater, although not by as much as when contaminated with raw sewage.

Therefore, the primary parameters to be included in the monitoring program would be:

- total runoff volume
- peak runoff rate
- rain intensity (full weather station in at least one location) at several locations within the monitoring area

Secondary parameters for monitoring would include:

- total recoverable iron, copper, lead, and zinc

Additional parameters for monitoring would be those affecting the performance and maintenance of the green infrastructure control devices, and would include:

- SAR of runoff water (including snowmelt) and conductivity
- TSS and psd

- SAR (Ca, Mg, and Na) and CEC of back-filled media in biofilters and bioretention devices
- soil moisture sensors in back-filled media

Descriptions of Green Infrastructure Controls Located at Demonstration Project Locations

The following site descriptions were summarized from existing reports prepared for the Metropolitan Sewer District of Greater Cincinnati.

Cincinnati State Technical and Community College

Cincinnati State Technical and Community College has developed a comprehensive stormwater management plan for the 44 acre Central Parkway Campus. The first phase of this plan focuses on Parking Lot C. This phase follows the below stated goals:

- Redevelopment of the main gateway entry of Parking lot “C”
- Porous paving of different types,
- Bio-islands in the parking area,
- Bioretention areas
- Modified detention ponds

The 6.58 acre of Parking Lot C, is projected to remove 3.25 to 4.8 million gallons of stormwater from the combined sewer system on an annual basis. The proposed plan is designed to harvest the 9-month 24-hours storm on site in order to have zero runoff to the MSDCG system.

Site description

Total Cincinnati State Property	44.75 Acres
Total Project (Parking Lot C) Area:	6.58 Acres
Total Drainage Area	5.45 Acres
Runoff Coefficient Pre-Construction1	0.64
Runoff Coefficient Post-Construction1:	0.54
Runoff Coefficient Decrease	0.10
Impervious Area Pre-Construction	91%
Impervious Area Post-Construction	73%
Impervious Area Reduction	18%

Type of BMP	**BMP Area (SF)**	**Drainage Area (SF)**	**total inflow**	**total outflow**	**% vol. reduction**	**peak inflow**	**peak outflow**	**% peak reduction**
pervious pavement	14,300	105,100	1,901,653	220,421	88%	0.27	0.16	41%
bioretention	1,240	24,850	396,206	248,563	37%	0.1	0.08	20%
pond	6,900	217,580	1,163,572	354,330	70%	0.39	0.38	3%
tree canopy*	3,600	3,600	93,020	43,670	53%	n/a	n/a	n/a
SUM	26,040	217,580	3,554,451	866,984	76%			

annual run 2008 dataset (pond infilt = 0.1 in/hr)

* volume reduction based on 10-year canopy area (average of installed and mature canopy)

Drainage Areas Pre Construction

Drainage Areas Post Construction

Phase 2:

The Cincinnati State campus is located in two combined sewer areas. Runoff from the southern half of campus flows south into the Bates Run Regulator combined sewer system which is upstream from CSO 12, while runoff from the northern half of campus flows north into the Streng Street Diversion Dam combined sewer system which is upstream from CSO 21,.

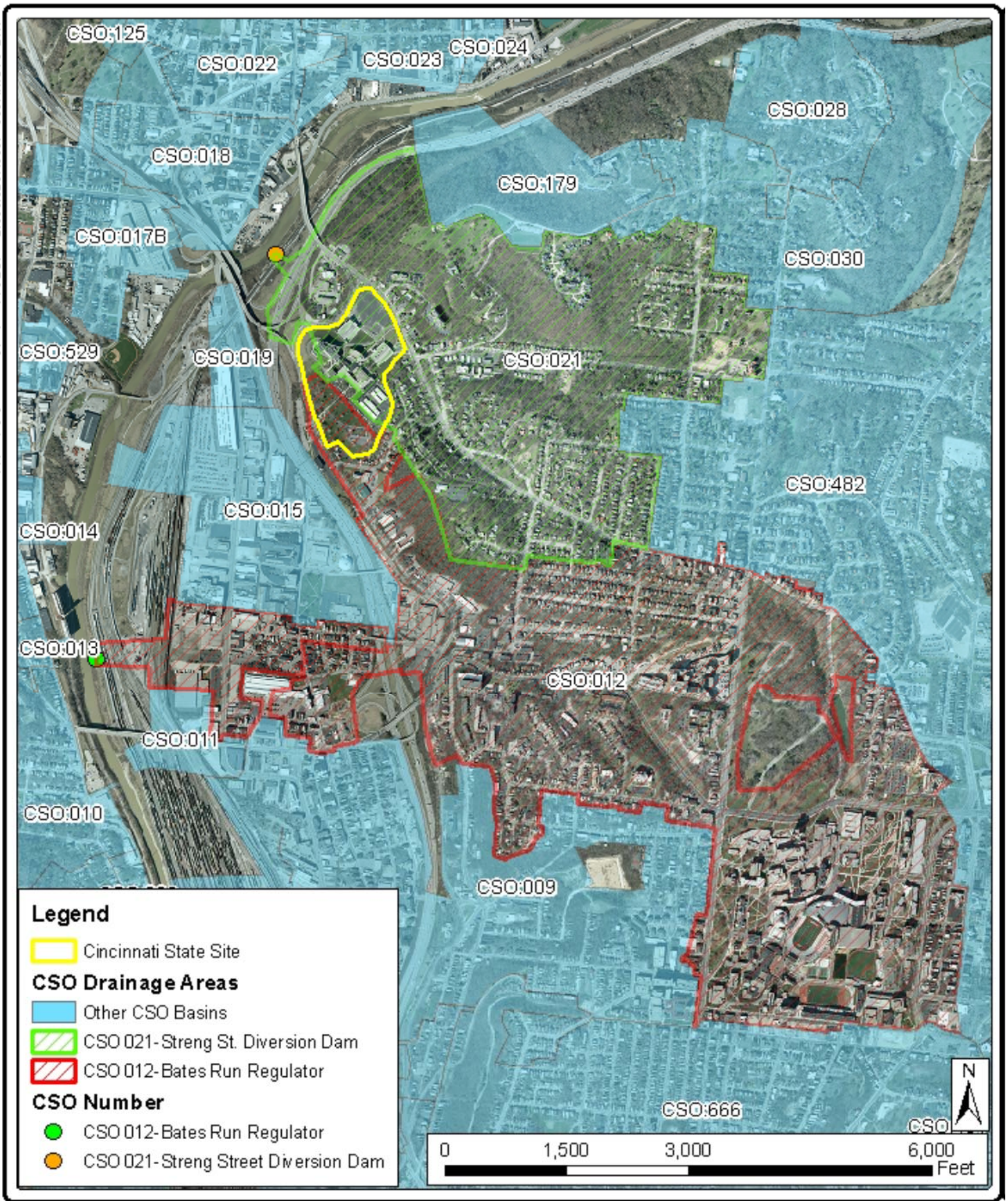
Phase 2 Covers the remainder of campus plan and includes:

- Disconnection of roof drains
- Separation of combined sewers on site
- Replacement of paving with porous pavers
- Installation of rain gardens
- Infiltration trenches
- Biodetention areas
- Cistern/irrigation systems

The existing campus stormwater drains to the combined MSDGC sewer without any stormwater treatment to reduce flows. With the proposed project, about 45% of the site will drain through treatment trains of stormwater controls and there is an expected 90% reduction in annual stormwater runoff volume for the treated area.

site location map

Showing the Cincinnati State property boundary, project location, major roadways, and immediate receiving waters



CINCINNATI STATE TECHNICAL AND COMMUNITY COLLEGE
3520 CENTRAL PARKWAY
CSO BASIN MAP
GREEN DEMONSTRATION PART 2 APPLICATION
METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI
CINCINNATI, OHIO

STRAND ASSOCIATES, INC.®
ENGINEERS

3560.006

Project Area 1 is located on the northwest side of the campus, near the Central Parkway parking garage. Existing runoff from the parking garage and hillside area is directed into the storm sewer system via floor drains, retaining wall drains, and yard drain catchbasins. The proposed rain garden (RG6), with a surface of 4,140 ft^2, will capture all of these drains and allow infiltration and evapotranspiration of the runoff prior to the overflow connecting back into the storm sewers system.

Project Area 2 is the greenhouse cistern. This cistern will be an above-ground tank with a storage volume capacity of 4,000 gallons. The water collected from the 5,200 square feet greenhouse roof will be utilized for watering plants in and around the greenhouse. This reused water is estimated to replace at least 105,000 gallons of irrigation water annually.

Project Area 3 is located on the south side of the ATLC building, and involves replacing conventional pavers in a circular plaza with pervious pavers and an underdrain. This area is proposed to have 908 square feet of porous pavers.

Project Area 4 collects rainfall from approximately 10,000 ft^2 of rooftop area and conducts the water to a 10,000 gallon underground tank before being pumped to a lawn irrigation system. The cistern in Project Area 4 collects rooftop runoff from the north half of building B wing.

Project Area 5 is located on the eastside of the buildings, in the faculty parking lot area. Rain gardens 3 and 4 are supposed to capture roof drains via a new stormwater line. Previously, the roof runoff from this area flowed to a combined sewer. 16,730 square feet of porous pavers are also planned in the parking areas to decrease the total impervious area and reduce peak flows. Pervious paver underdrains will also drain to the new stormwater line downhill to RG3 and RG4.

Project Areas 6 and 7 includes the courtyard, parking, and driveway areas on the southside of the buildings which currently flow to the combined sewer. The proposed plan is to conduct the captured stormwater into raingardens 1 and 2 (RG1andRG2) and add pervious pavers in the parking areas. Overflow from RG1 will be rerouted into a series of bioretention trenches which will infiltrate any remaining water. Overflow from RG2 will be directed into the new storm system that flows into RG3. Project Area 8 is located at the entrance to the Central Parkway driveway, and involves expanding the swale adjacent to the sidewalk into a small shallow bioretention basin and replacing a concrete swale with a bioswale which will slow water and provide some opportunity for infiltration and evapotranspiration. A curb cut will also capture some of the runoff from the entrance driveway and direct it into the bioswale.

Project Area 9 includes most of the Central Park way hillside entrance drive, which currently drains to the combined sewer system. The storm sewer separation in this area will reroute stormwater from catchbasins to the new stormwater line that flows to RG3.

Project Area 10 includes parking lot A and RG3, RG4, andRG5, along with a portion of the Central Parkway hillside drive. Runoff from parking lot A will is proposed to routed to RG3, while runoff from the drive will be routed to RG5. Both RG3 and RG5 will overflow into RG4, which then overflows back to the combined sewer system just before it leaves the CSTCC Campus.

The Project Area 11 is similar to Project area 4 and the cistern in this area collects rooftop runoff from a portion of the ATLC building.

Location and size of project areas:

Project Area 1 –Garage Rain Garden	4,140 square feet rain garden
Project Area 2 – Greenhouse Cistern	4,000 gallon cistern
Project Area 3 – ATLC Courtyard	908 square feet of porous pavers
Project Area 4 – Main Building Roof Cistern	10,000 gallon cistern with irrigation system
Project Area 5 – Faculty Parking Lot	16,730 square feet of porous pavers
Project Area 6 – South Drive and Parking	2,750 square feet of porous pavers 4,055 square feet of rain garden 420 square feet of bioretention (level spreaders)
Project Area 7 – South Drive and Parking:	8,200 square feet of porous pavers 11,290 square feet of rain garden 1,540 square feet of infiltration trenches
Project Area 8 – Central Parkway Bioswale:	972 square feet of bioswale
Project Area 9 – Combined Sewer Separation	740 square feet of porous pavers (at pedestrian crossing)
Project Area 10 – Rain Gardens / Disc Golf:	22,565 square feet of rain garden
Project Area 11 – ATLC Roof Cistern:	10,000 gallon cistern with irrigation system

Note: data from "Cincinnati State Technical and Community College MSDGC Green Demonstration Project" report (July 13, 2010)

Site description

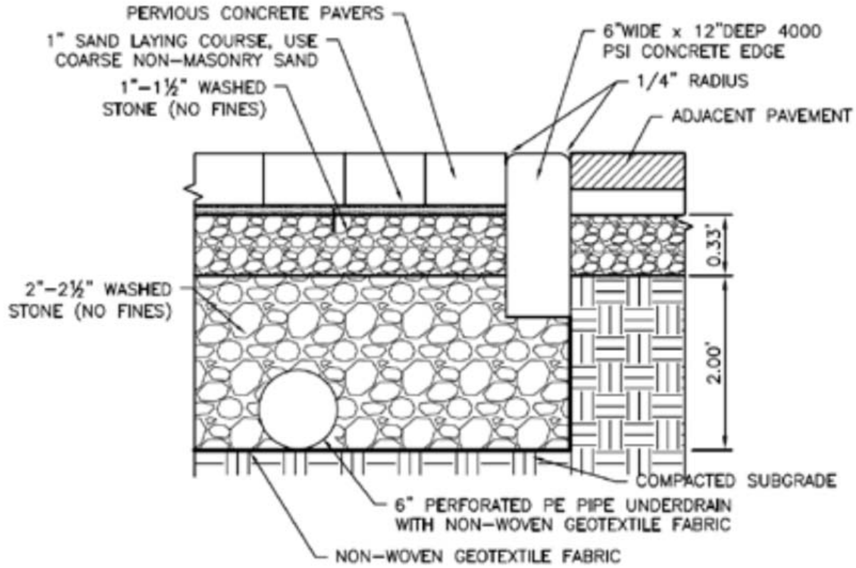
Total Cincinnati State Property:	40.63 Acres
Total Project Area (Phase 2):	32.31 Acres
Total Drainage Area:	11.7 Acres
Total Project (Disturbed) Area:	3.88 Acres
Runoff Coefficient Pre-Construction 1:	0.325
Runoff Coefficient Post-Construction 1:	0.325
Runoff Coefficient Improvement:	0.00
Impervious Area Pre-Construction:	27% (Phase II Area/Total Site)
Impervious Area Post-Construction:	25% (Phase II Area/Total Site)
Impervious Area Reduction:	2%

"Prior Land Uses: Land was previously owned and operated by CPSB as a technical high school. The land was mostly covered with turf and mowed on a routine cycle. CSTCC operates the property as a community college. The site has had extensive investments and development with regard to landscape improvements and care which is regularly used for academic lab studies by the horticulture department. Also the area has a 9 hole Frisbee Golf Course which is open to the public." (Cincinnati State report, July 13, 2010)

The estimated average annual capture volume from Cincinnati State Technical and Community College project, phase 2, ranges from 7.4 and 8.3 million gallons. When added to the anticipated capture from Phase 1, the total anticipated annual capture volume for the campus is between 11.1 and 12.5 million gallons. This project has different components of stormwater management including cisterns, pervious pavers, infiltration trenches, bioretention areas, etc.

Pervious Pavers

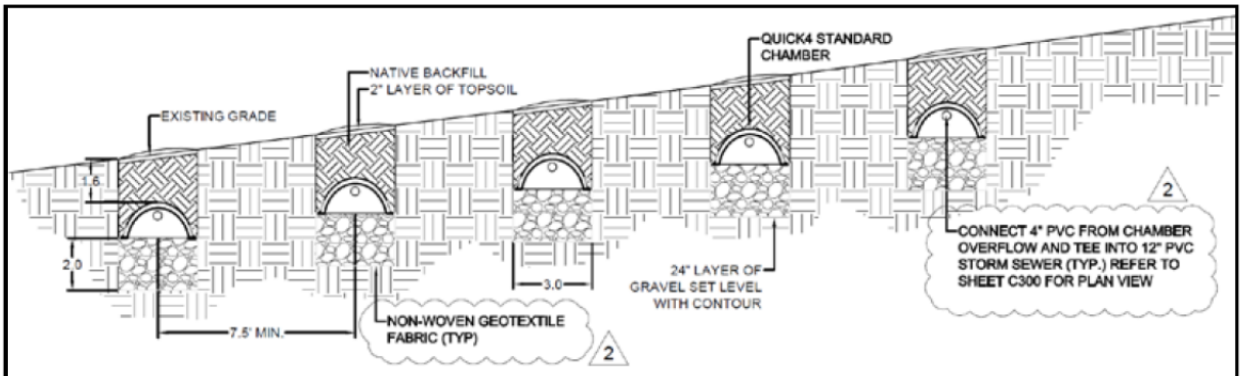
Pervious pavers are planned to decrease the total impervious area and reduce peak flows. For this project, pervious pavers are proposed to be installed in Areas 3, 5, 6, 7 and 9 on campus in parking lot stalls, sidewalk crossings, and a courtyard area. The pervious pavers consist of a layer of pavers, a 1-inch sand laying course, a 28-inch layer of aggregate, and a 6-inch perforated underdrain at the base of the aggregate layers.



PERVIOUS CONCRETE PAVERS
NO SCALE

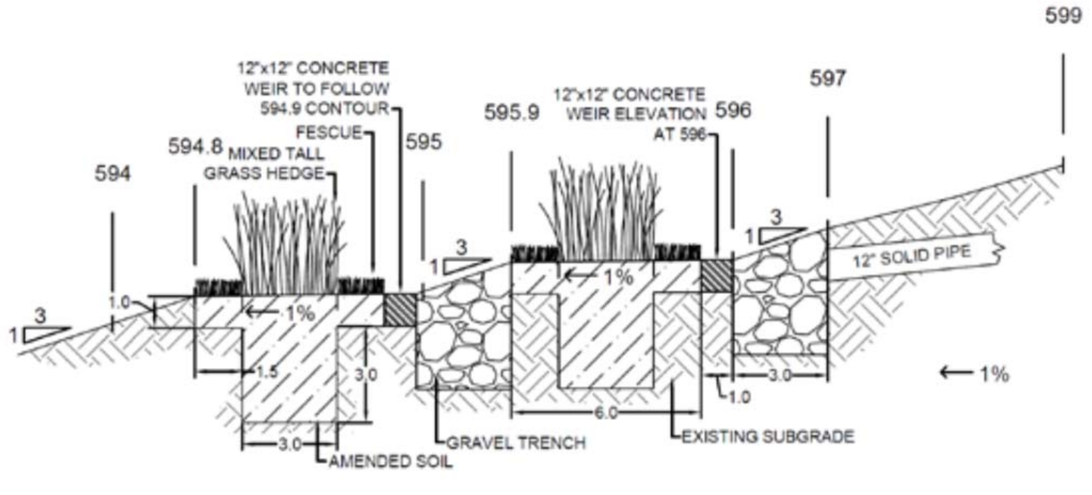
Infiltration Trenches

Infiltration trenches are planned to be installed on the hillside in Area 2 below rain garden 2. Two sets of five infiltration trenches will be constructed parallel to one another on either side of a central collection pipe. There will be a minimum distance of 7.5 feet between trenches. The design includes a 2 inch layer of topsoil and a 1.5 foot layer of native backfill above the Quick 4 High Capacity infiltrator chambers. Any runoff out of the infiltration trenches will be conveyed via new storm sewer to rain garden 3 in Area 10.



INFILTRATION TRENCH - SECTION C-C'
1/8" = 1' 0"

Bioretention (Level Spreaders)
Bioretention (level spreaders) are proposed for the hillside in Area 6 below rain garden 1. The control will consist of 2 sets of level spreaders constructed parallel to one another. A set includes a 3 foot wide by 3 foot deep trench (with the top at a 3:1 slope) filled with aggregate. Any water not infiltrated through this system is conveyed as surface runoff down the hillside.



NOTE: ALL WEIRS SHOULD BE LEVEL

BIODETENTION (LEVEL SPREADER) - DETAIL
NOT TO SCALE

Cisterns
Three cisterns/rainwater harvesting units are included in Areas 2, 4 and 11. The cisterns have storage capacities ranging from 4,000 gallons to 10,000 gallons. The cisterns will collect stormwater runoff for irrigation use.

Rain Gardens/Bioswale

The bioswale and rain gardens 1, 2, and 6 have an 18-inch layer of amended soil mix, while rain gardens 3, 4, and 5 have a 5-foot layer. The deeper soil mix at these rain gardens allows better access to a natural sandy seam with higher infiltration rates. All features will include a 4-inch layer of pea gravel, and a 6-inch underdrain.

Projected average annual storm water runoff capture volumes for project areas 1 through 11

Area	Specific BMP	Total Inflow (GAL)	Total Outflow (GAL)	Low End Estimate - Total Loss (GAL)	High End Estimate - Total Loss (GAL)
1	RG6	705,024	287,072	417,952	436,863
2	Cistern - Greenhouse	134,362	29,362	105,000	105,000
3	Pavers - ATLC	112,567	20,197	92,370	111,584
4	Cistern - Building B	221,612	109,612	112,000	112,000
5	Pavers – btw - buildings	737,878	26,391	711,487	879,486
5	Pavers – faculty lot	288,150	269	287,881	466,027
			Area 5 Total	999,368	1,345,513
6	Pavers - RG1	210,861	13,465	197,396	237,966
6	RG1	179,084	48,743	130,341	144,635
6	Bioretention	48,474	0	48,474	56,843
			Area 6 Total	376,211	439,444
7	Pavers - RG2	400,447	2,693	397,754	576,197
7	RG2	536,443	77,558	458,885	523,561
7	Infiltration Trench	460,770	8,887	451,883	482,571
			Area 7 Total	1,308,522	1,582,329
8	Entrance Swale	775,042	716,873	58,169	59,882
9 & 10	RG3	2,938,857	0	2,938,857	3,016,597
9 & 10	RG4	456,731	0	456,731	499,633
9 & 10	RG5	505,474	74,057	431,417	441,154
			Area 9&10 Total	3,827,005	3,957,384
11	Cistern - ATLC	221,612	109,612	112,000	112,000
TOTALS				7,408,597	8,261,999

Estimated cost per gallon of stormwater captured

Area	Specific Green BMP	Low End Estimate - Total Loss (GAL)	High End Estimate - Total Loss (GAL)	Cost	Low Loss Estimate - Cost/Gal.	High Loss Estimate - Cost/Gal.
1	Rain Garden 6	417,952	436,863	$58,233.41	$0.14	$0.13
2	Cistern - Greenhouse	105,000	105,000	$9,500.00	$0.09	$0.09
3	Porous pavers -ATLC	92,370	111,584	$13,436.00	$0.15	$0.12
4	Cistern - Building B	112,000	112,000	$101,105.00	$0.90	$0.90
5	Pavers btw buildings	711,487	879,486			
5	Pavers faculty lot	287,881	466,027			
		999,368	1,345,513	$285,745.00	$0.29	$0.21
6	Porous pavers at Rain Garden 1	197,396	237,966			
6	Rain Garden 1	130,341	144,635			
6	Bioretention	48,474	56,843			
		376,211	439,444	$179,892.95	$0.48	$0.41
7	Porous pavers at Rain Garden 2	397,754	576,197			
7	Rain Garden 2	458,885	523,561			
7	Infiltration Trench	451,883	482,571			
		1,308,522	1,582,329	$346,768.90	$0.27	$0.22
8	Entrance Swale	58,169	59,882	$23,013.59	$0.40	$0.38
9 & 10	Rain Garden 3	2,938,857	3,016,597			
9 & 10	Rain Garden 4	456,731	499,633			
9 & 10	Rain Garden G5	431,417	441,154			
		3,827,005	3,957,384	$321,175.89	$0.08	$0.08
11	Cistern - ATLC	112,000	112,000	$87,765.00	$0.78	$0.78
TOTALS		7,408,597	8,261,999	$1,426,635.74	$0.19	$0.17

Cincinnati Zoo and Botanical Garden (African Savannah)

The African Savannah exhibit is planned to be added on the east side of the Cincinnati Zoo and Botanical Garden (Zoo) property. Figure 1 shows the Cincinnati Zoo location.

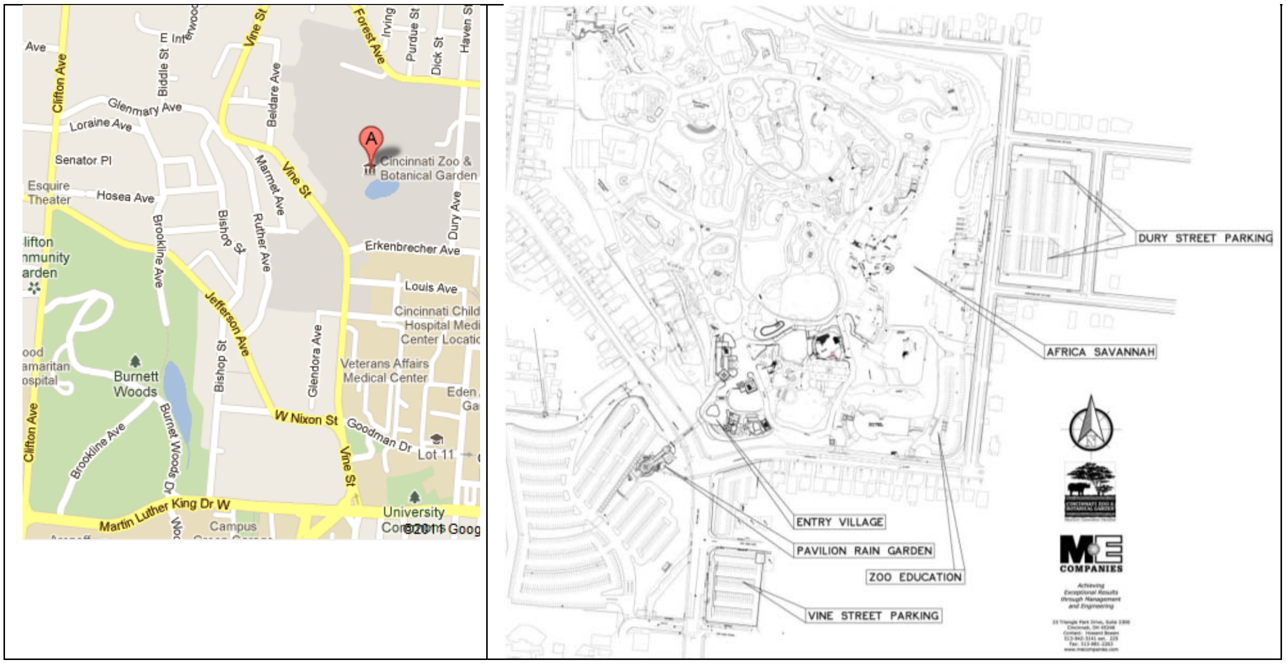


Figure 1 Location of the Cincinnati Zoo

The Cincinnati Zoo project area is located along Dury Avenue in the Uptown area of Cincinnati with the proposed reconstruction acreage of 5.46. The existing land use of the Cincinnati Zoo consists of parking lots, open space areas, and steep wooded hillsides, along with the animal enclosures and related infrastructure. Stormwater runoff currently flows in a northeastern direction into catchbasins and storm sewers which are directly rerouted to the Mitchell Avenue Regulator combined sewer system upstream from combined sewer overflow (CSO) 482. Figure 2 describes the existing conditions plan. Redirected stormwater runoff from the site’s 17.2 acre drainage area is expected to exceed 12.5 million gallons annually.

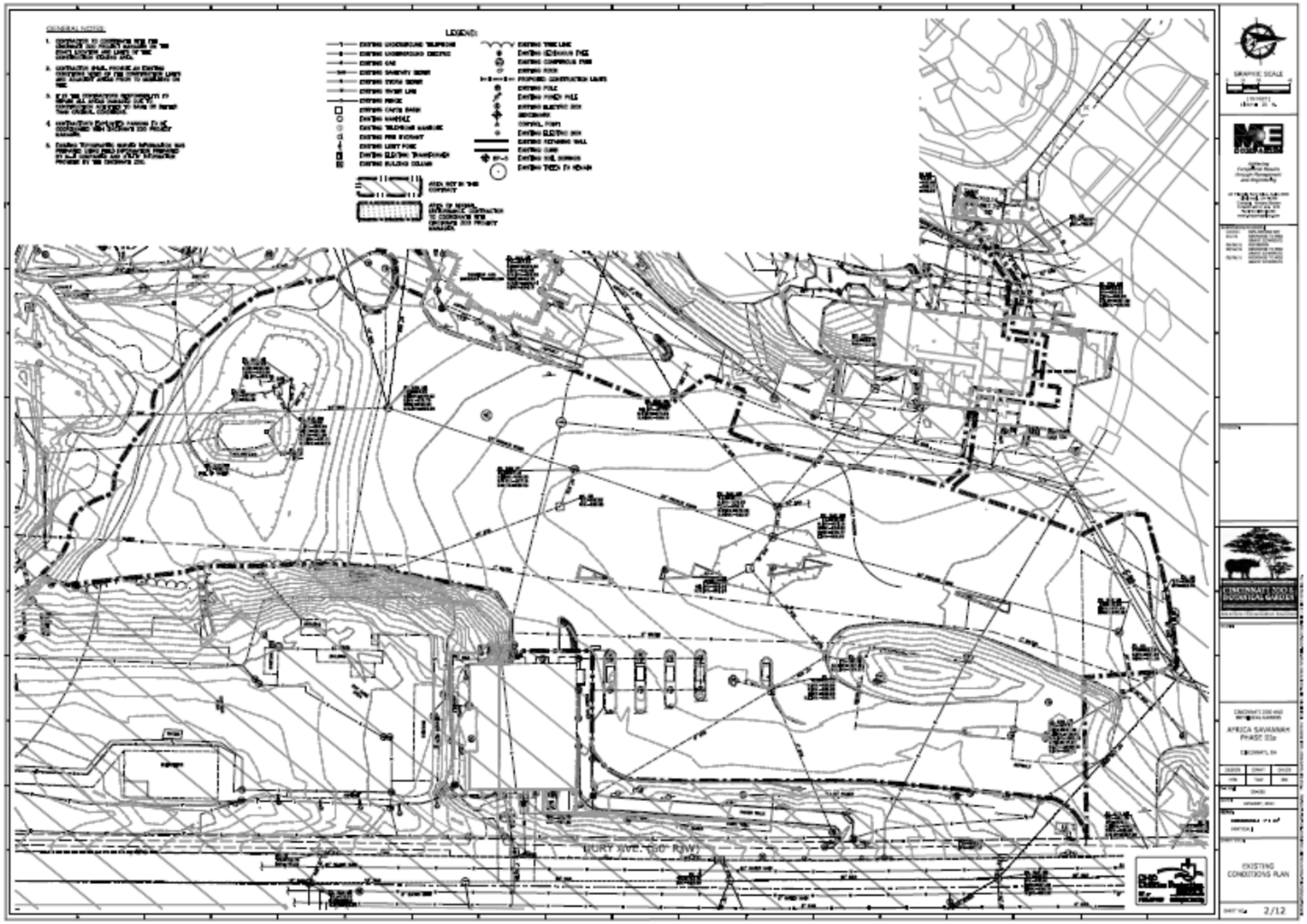


Figure 2 Existing Conditions Plan.

The proposed project consists of different stormwater management components, including;

- Replacement of Pavement with Pervious Pavers and Enhanced Turf and Vegetation
- Bioretention Areas and Tree Wells
- Rainwater Harvesting, Storage and Reuse System
- Storm Sewer Separation and Roof Leader Collection

Figure 3 shows the proposed plans for the African Savannah exhibit area stormwater controls.

Replacement of Pavement with Pervious Pavers and Enhanced Turf and Vegetation

The main goal in this phase of the African Savannah project is to replace the existing parking lot with pervious paving and enhanced turf and vegetation. The pervious paving is designed to cover 42,207 ft^2, while the total area of the turf replacement is roughly 20,000 yd^2. Below is a summary of the African Savannah pervious concrete calculation. Figure 4 shows the existing asphalt to be removed area.

Replacing the existing pavement with a pervious system is expected to result in reductions of stormwater runoff entering the combined sewer system by approximately 975,000 gallons annually. This value is the potential reduction in stormwater runoff; however, the actual reduction volumes will vary based on infiltration capacity of underlying soils and location of paved areas on level ground. Moreover, according to the information provided in the application, the turf replacement system is planned to reduce the stormwater runoff entering the combined sewer system by approximately 2,120,000 gallons annually due to the use of a permeable filter fabric around the aggregate instead of an impermeable membrane, as shown in Figure 5.

Bioretention Areas and Tree Wells

Installation of three bioretention basins and two tree wells in the African Savannah exhibit is another component of stormwater management plan of the Cincinnati Zoo.

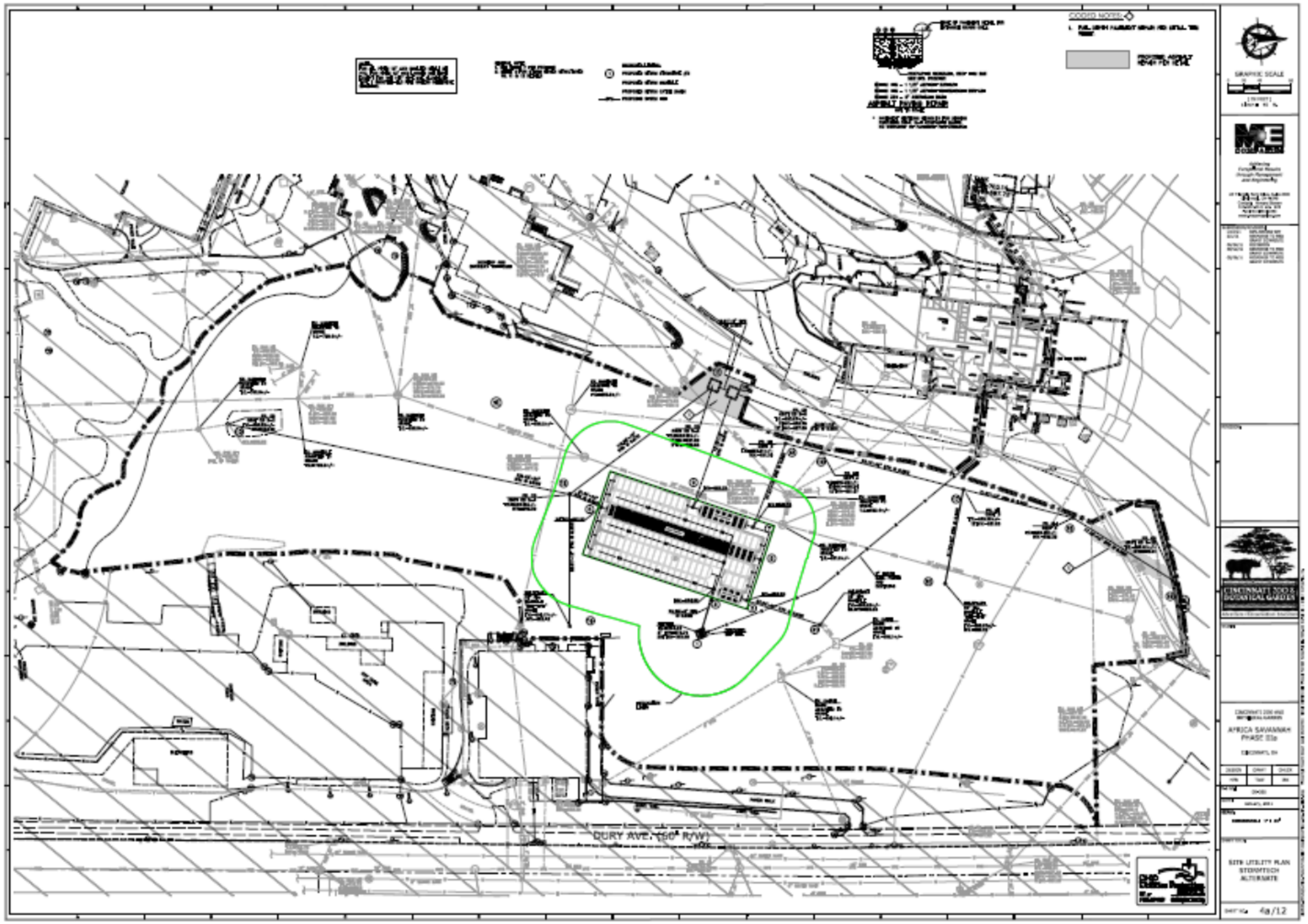


Figure 3 Proposed Stormwater Management Componenets of African Savannah Zoo

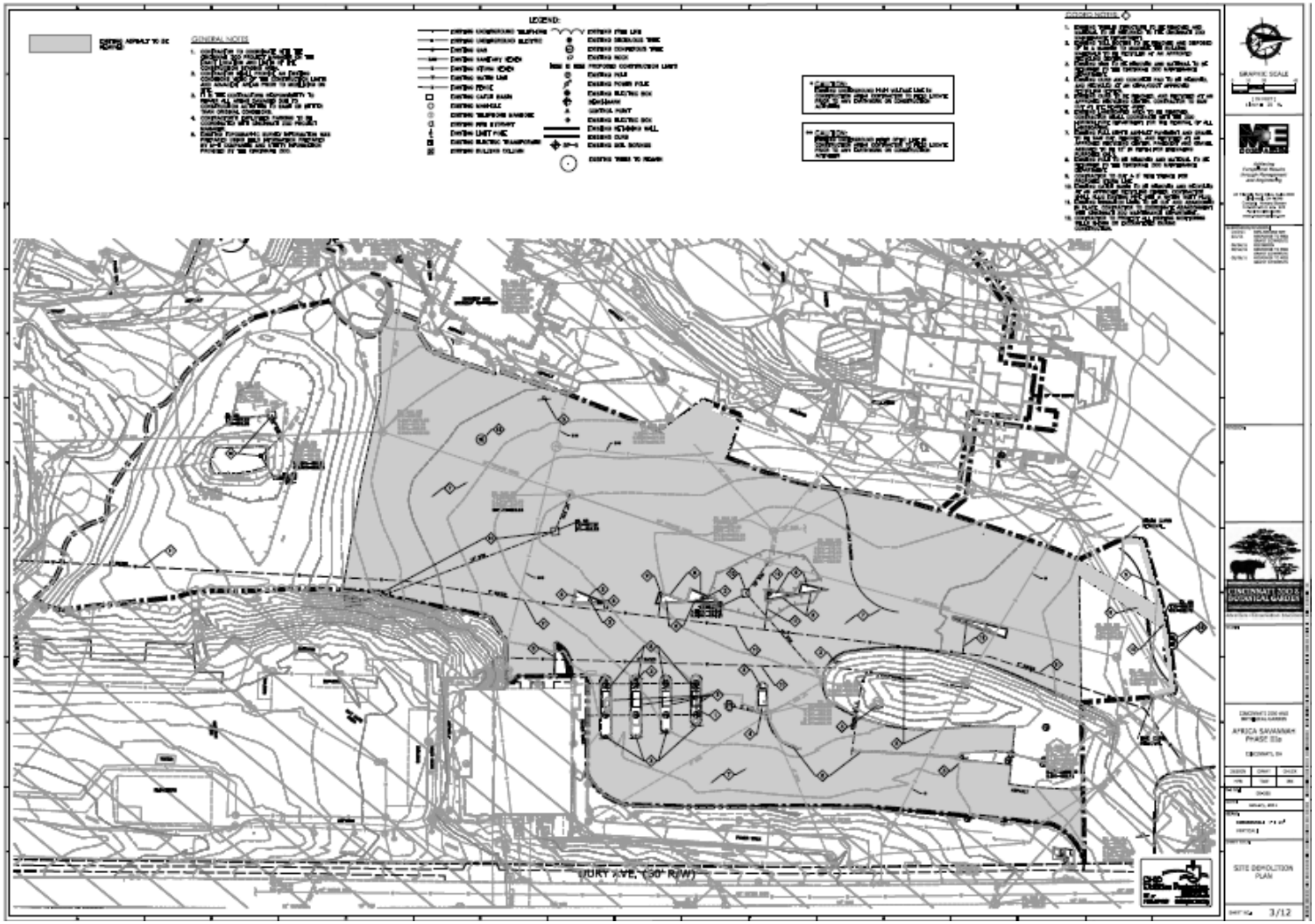


Figure 4 Plan of Existing Asphalt to be removed.

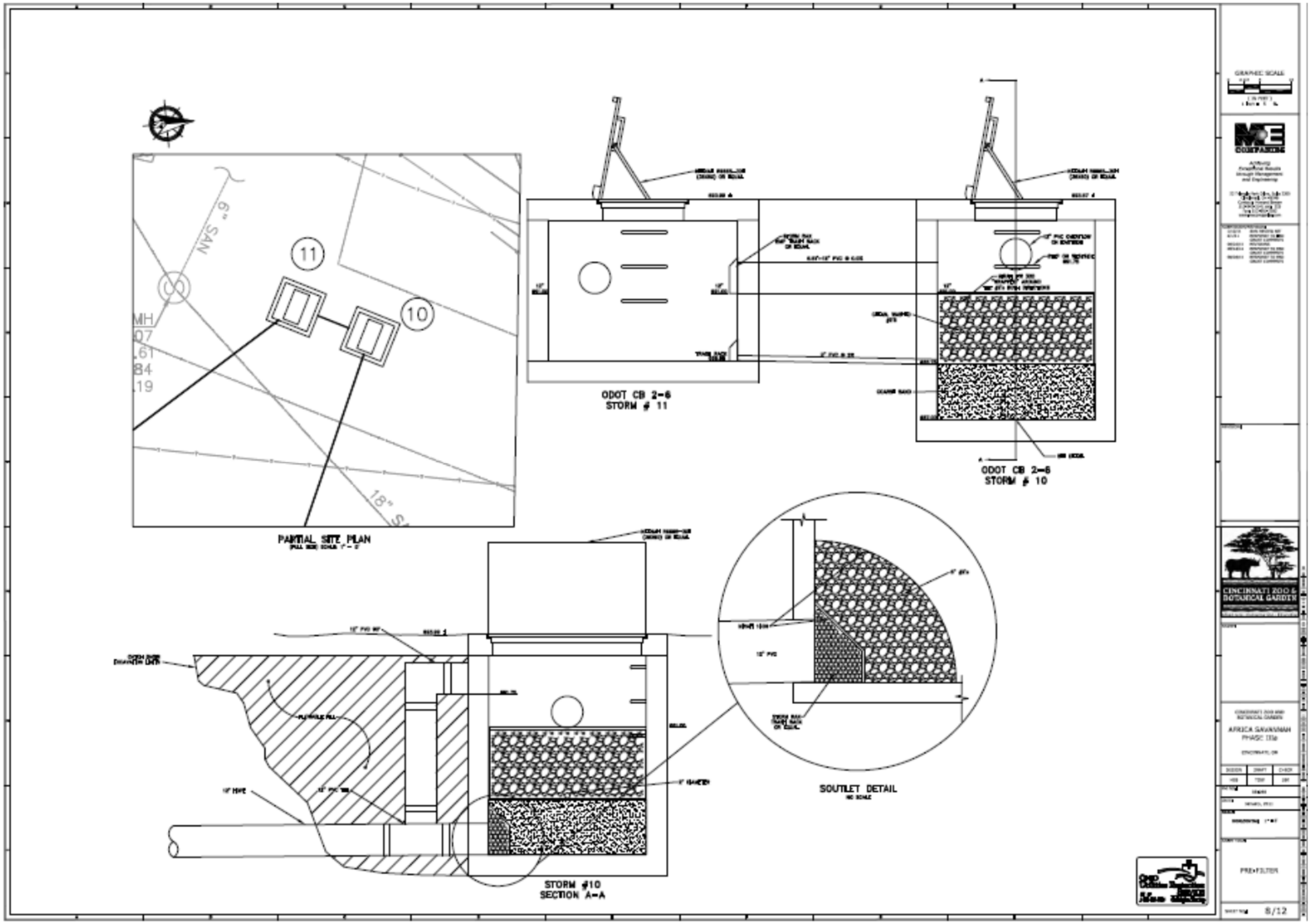


Figure 5 Permeable Filter Fabric Details under Storage Reservoir of the Porous Pavement

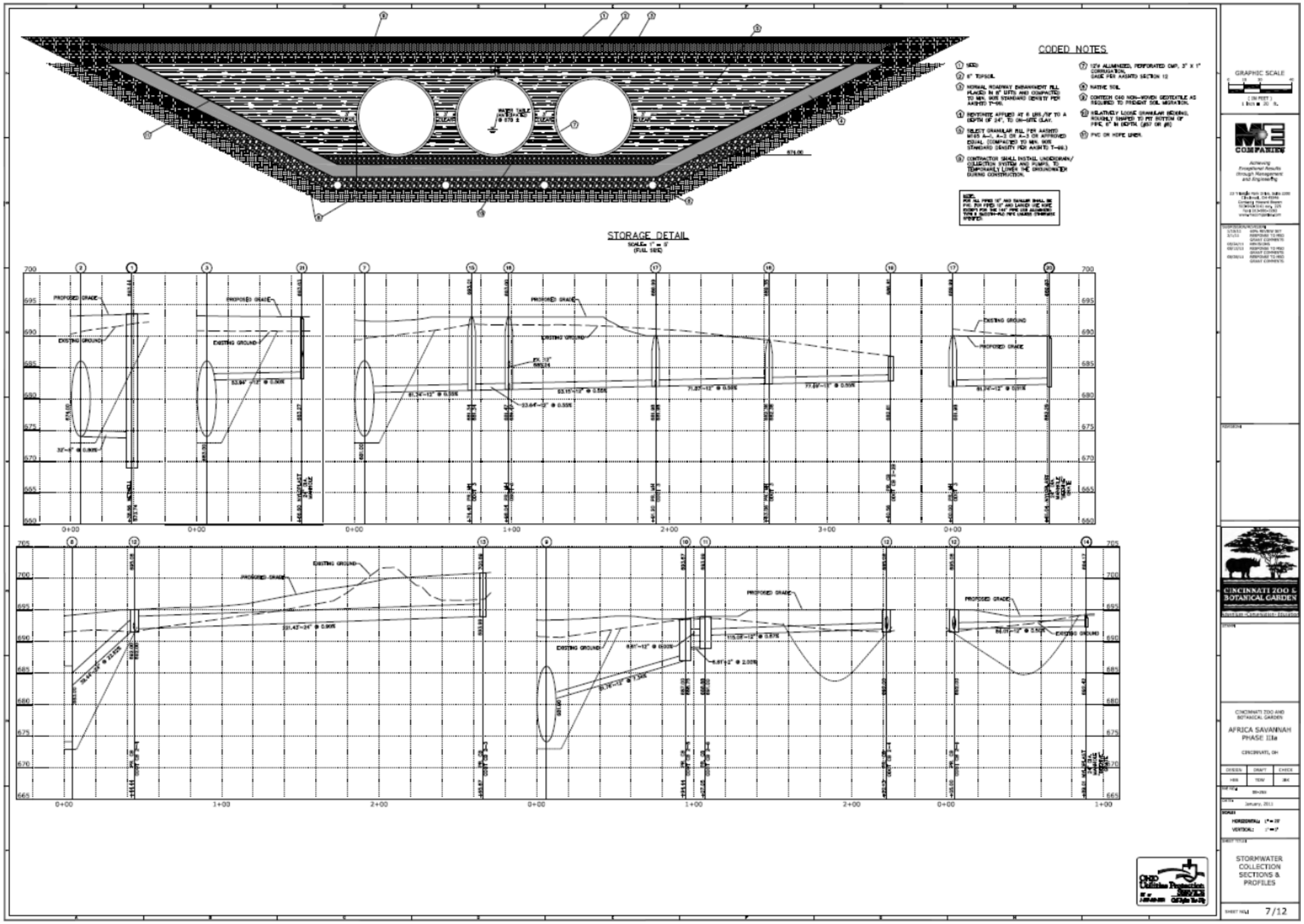
Rainwater Harvesting, Storage and Reuse System

The main goal in this phase is to reduce stormwater runoff from entering the combined sewer system through construction of a large subsurface storage pipe under the African Savannah area.

The storage facility will consist of 380-feet of 12-foot diameter perforated pipe, surrounded by open graded aggregate. Underneath the pipe there is relatively loose granular bedding with depth of 6 inches. The whole system is then lined with an impermeable membrane providing an approximate storage volume of 55,000 ft^3. Figure 6 describes the stormwater collection section and profiles.

Storm Sewer Separation and Roof Leader Collection

The existing storm sewer and roof leader system in the project area currently discharges directly into the Mitchell Avenue Regulator combined sewer system upstream from combined sewer overflow (CSO) 482. One of the goals of this project is to disconnect these systems from the combined sewer system through a storm sewer separation project and redirection of roof leaders. The proposed system will collect stormwater runoff and roof drainage and reroute it to the subsurface storage facility (Figure 3).



CODED NOTES

① SEED
② 6" TOPSOIL
③ NORMAL ROADWAY EMBANKMENT FILL PLACED IN 8" LIFTS AND COMPACTED TO MIN. 90% STANDARD DENSITY PER AASHTO T-99.
④ BENTONITE APPLIED AT 6 LBS./SF TO A DEPTH OF 24", TO ON-SITE CLAY.
⑤ SELECT GRANULAR FILL PER AASHTO M145 A-1, A-2 OR A-3 OR APPROVED EQUAL. (COMPACTED TO MIN. 90% STANDARD DENSITY PER AASHTO T-99.)
⑥ CONTRACTOR SHALL INSTALL UNDERDRAIN/ COLLECTION SYSTEM AND PUMPS, TO TEMPORARILY LOWER THE GROUNDWATER DURING CONSTRUCTION.
⑦ 12'Ø ALUMINIZED, PERFORATED CMP, 3" X 1" CORRUGATION, GAGE PER AASHTO SECTION 12
⑧ NATIVE SOIL
⑨ CONTECH C40 NON-WOVEN GEOTEXTILE AS REQUIRED TO PREVENT SOIL MIGRATION.
⑩ RELATIVELY LOOSE GRANULAR BEDDING, ROUGHLY SHAPED TO FIT BOTTOM OF PIPE, 6" IN DEPTH. (#57 OR #8)
⑪ PVC OR HDPE LINER.

NOTE:
FOR ALL PIPES 10" AND SMALLER SHALL BE PVC. FOR PIPES 12" AND LARGER USE HDPE EXCEPT FOR THE 144" PIPE USE ALUMINIZED TYPE II SMOOTH-FLO PIPE UNLESS OTHERWISE SPECIFIED.

Figure 6 Stormwater Collection Sections and Profiles.

Water Reuse Options

Collected runoff could be reused providing water for filling Swan Lake, irrigation, and providing water for the bear ponds. It is the Zoo's intention to capture and direct all of this runoff to the proposed subsurface storage system. Information provided in the application indicates there is more than sufficient onsite capacity to reuse the captured runoff via irrigation and replenishing Swan Lake and the bear moats to use all captured runoff from the drainage basin.

- **Swan Lake**

  Swan Lake is located on the north part of the Cincinnati Zoo, and east part of Elephant House, with a surface area of 50,000 ft^2. The lake is currently filled by domestic water. The pond requires 6-9" of make-up water every month of the year. Swan Lake needs replenishing 10 months each year and will be able at accept 8,000,000 gallons annually

- **Irrigation**

  Based on provided information, the Zoo is a heavy user of irrigation water (using close to 2" per week), compared to typical regional uses of 1" per week. Within the Africa Savannah project there will be 4 acres of irrigated area. Irrigation needs for the African Savannah exhibit will therefore total 4,240,000 gallons annually.

- **Bear Moat**

  The bear moats require water continuously throughout the year and a system needs to be installed to provide up to 5,230,000 gallons annually. The Zoo will construct a pump and filtration system that directs 10 gpm of water to the moat continuously.

These facilities will require more than the expected annual runoff of 12.5 million gallons, thus providing adequate reuse options for the rainwater harvesting system. Figure 7 to 9 describe pump stations and filtration system details.

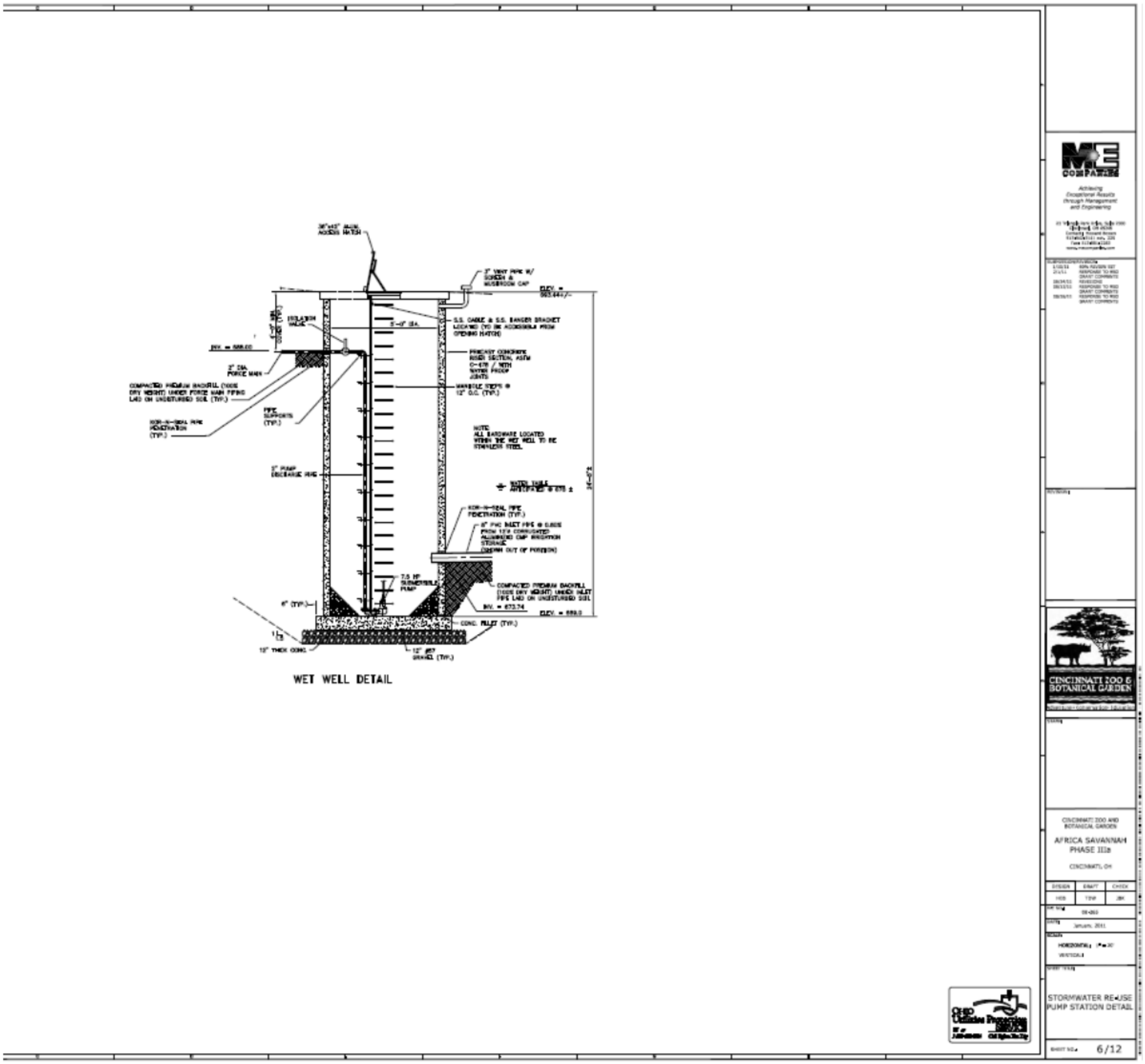


Figure 7 Stormwater Reuse Pump Station Detail

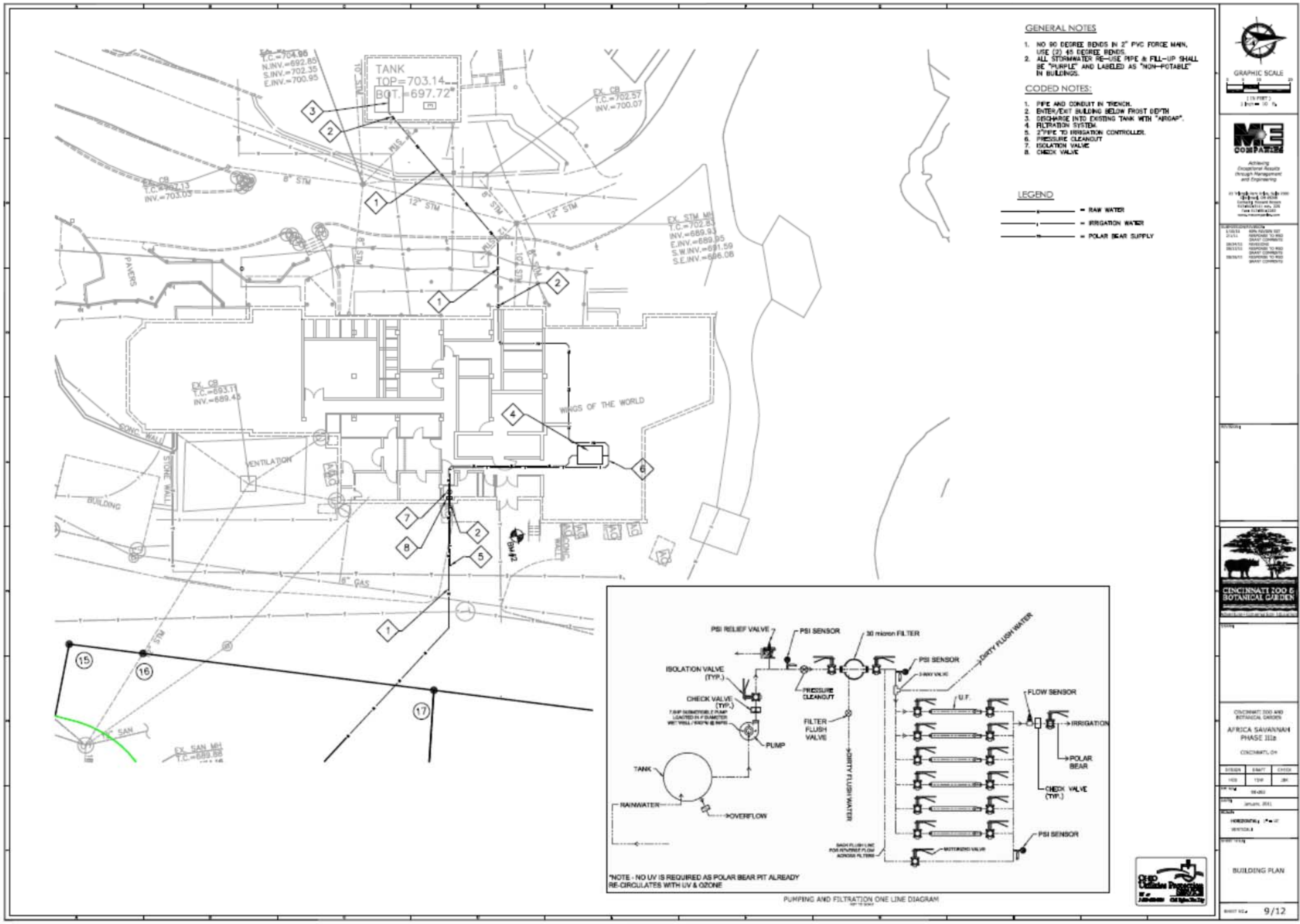


Figure 8 Pumping and Filtration One Line Diagram

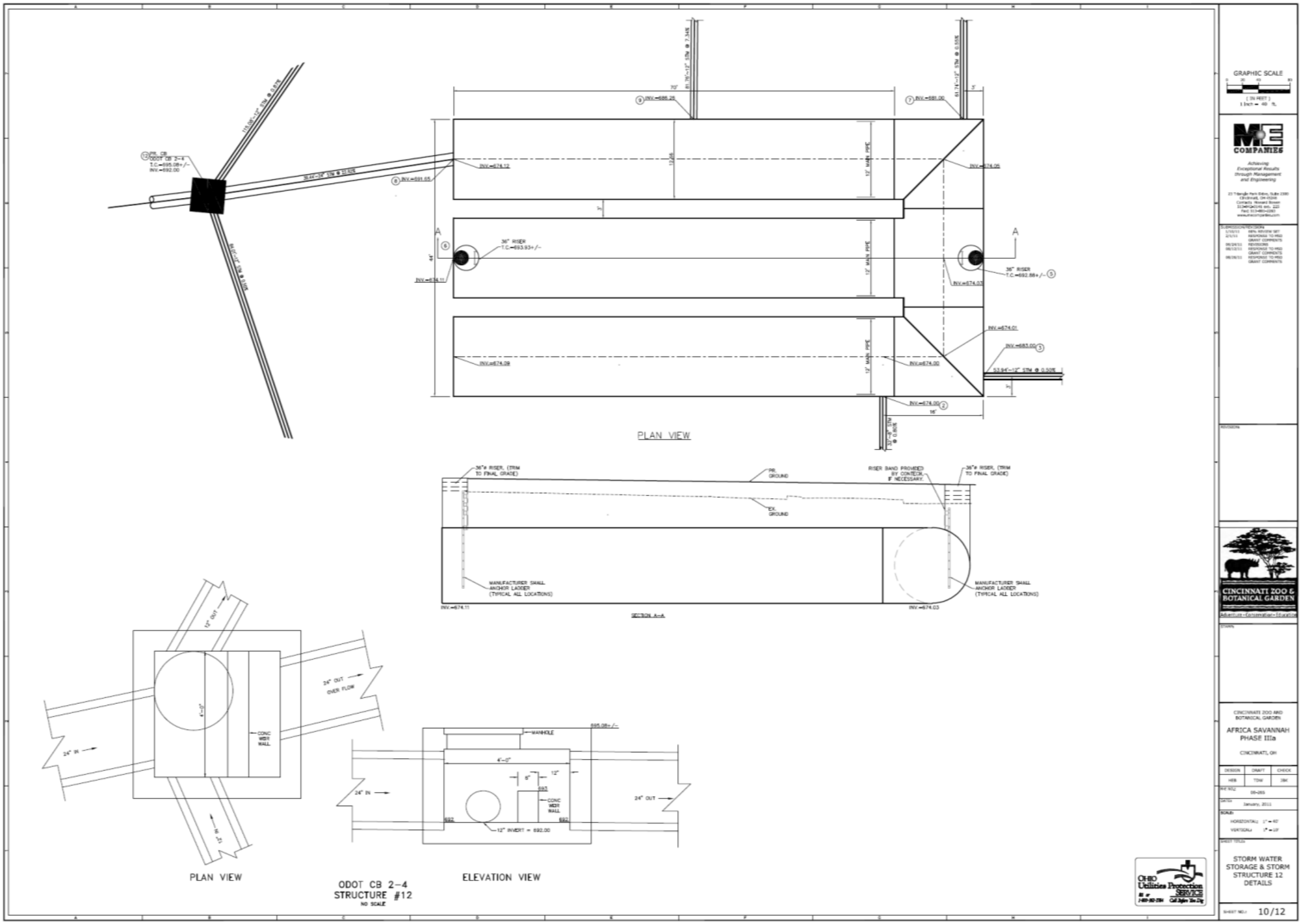
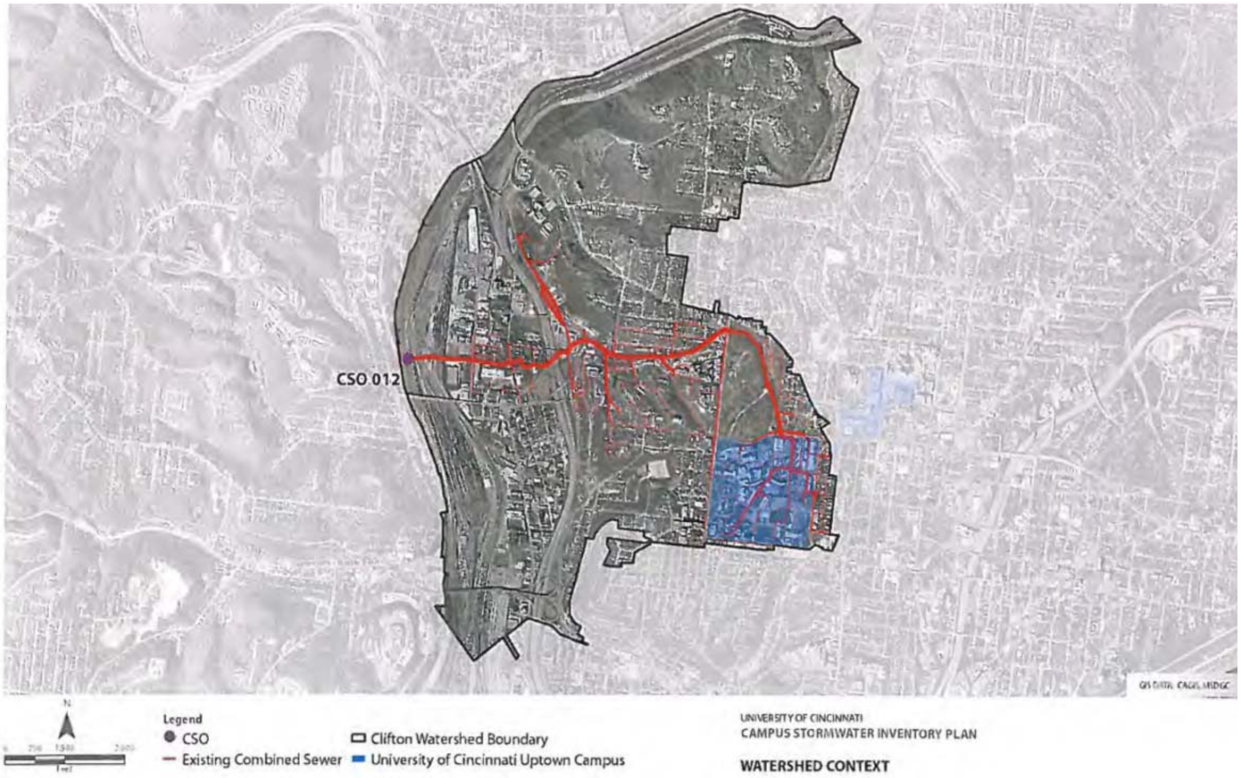


Figure 9 Stormwater Storage and Storm structure 12 Details

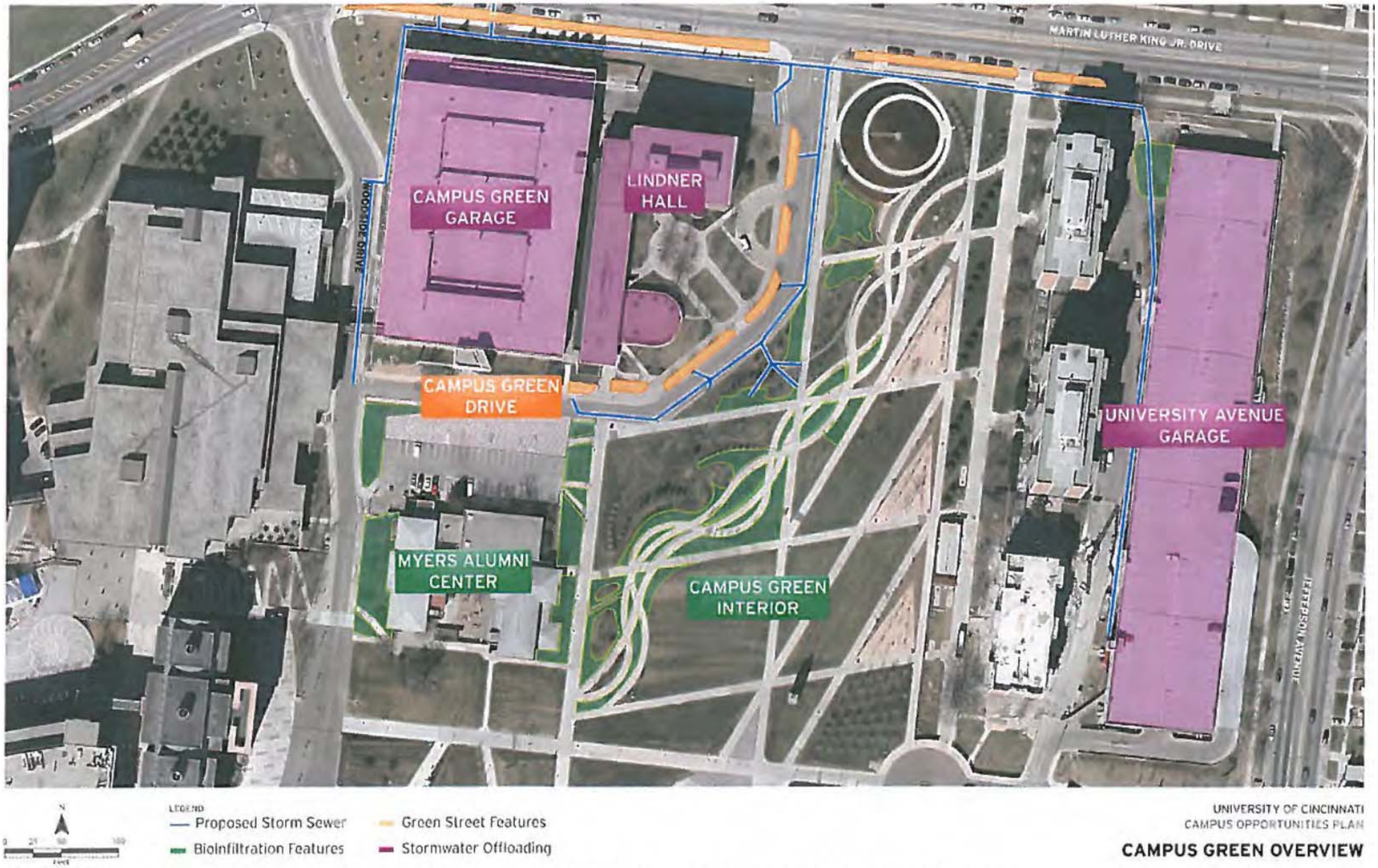
The University of Cincinnati

The University of Cincinnati's Uptown West Campus is located at the headwaters of the Clifton Sub-basin, which is one of the Lower Creek Watershed sub-basins. UC's West Campus is tributary to CSO 012 which has an average annual overflow of 32.5 million gallons. The annual runoff volume from West Campus is estimated to be approximately 100 MG.

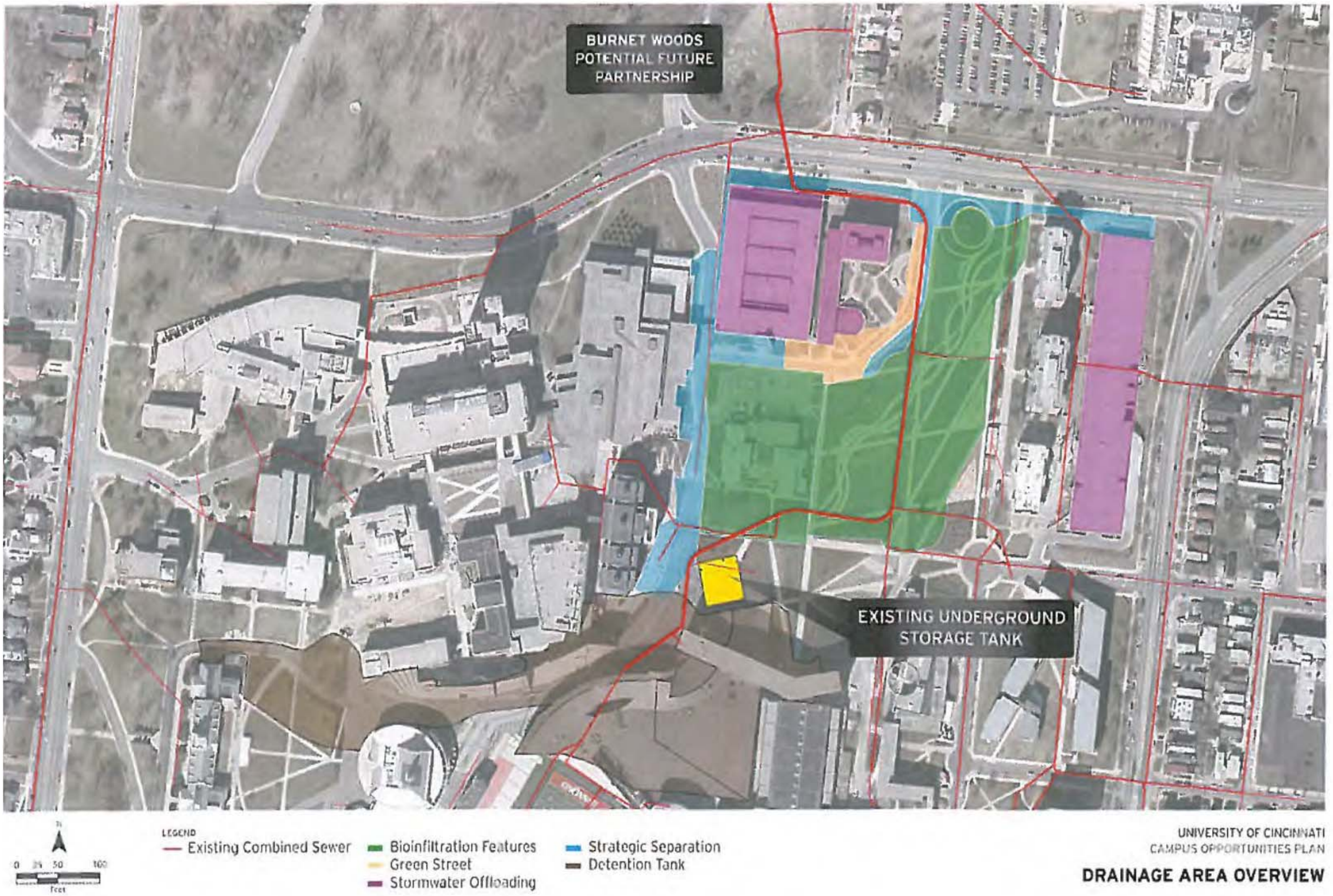


The plan for Campus Green proposes the following strategies and potential annual stormwater runoff volume capture:

strategies	On-Time Storage Volume (gallons)	potential annual runoff volume capture (gallons)	Cost/Gallon of Potential Capture	Annual Volume Reduction from Bioinfiltration (gallons)
Green Street Strategies along Campus Green Drive	78,800	448,000	$0.26	286,000
Bioinfiltration Areas within the Campus Green Interior: intercept stormwater runoff from sidewalks and surrounding open space	342,562	2,118,000	$0.33	1,269,000
Site stormwater controls at the Myers Alumni: intercept stormwater runoff from the building roof and existing parking lot and direct to bioinfiltration areas and a porous pavement system.	151,989	1,575,000	$0.23	674,000
Stormwater Offloading: Existing separate storm sewers from Lindner Hall and two parking garages will be intercepted from the combined sewer system and directed into a proposed separate storm network	N/A	3,864,000	$0.10	N/A
Strategic Separation: capture existing sections of separate storm, existing street inlets, and overflow from the proposed stormwater management features	N/A	1,751,000	$0.10	N/A
Retrofitting the Steger Student Life Center Detention Tank	822,200	4,640,000	$0.01	N/A
Total	1,395,551	14,396,000	$0.15	



Concept plan showing proposed stormwater management strategies for Campus Green



Drainage areas tributary to proposed stormwater management strategies for Campus Green

Specific Monitoring Locations at Cincinnati State Technical and Community College

MSDGC examined possible installations at Cincinnati State for monitoring. Based on this and prior discussions on logical monitoring locations, three areas were selected to be included in the Cincinnati State monitoring strategy. The following highlighted map shows these areas, as well as potential monitoring equipment locations.

These three Cincinnati State monitoring areas are:
1. Interconnected Rain Gardens 3, 4 and 5 located at the base of the hill near Central Parkway. There are clearly defined inlets and outlets that will allow for quantity and quality monitoring. There may be interesting opportunities at the inlet that drains Parking Lot A.

2. Infiltration trenches located downhill from Rain Garden 2. This is a unique, fairly large feature with one inlet point and outlet point.

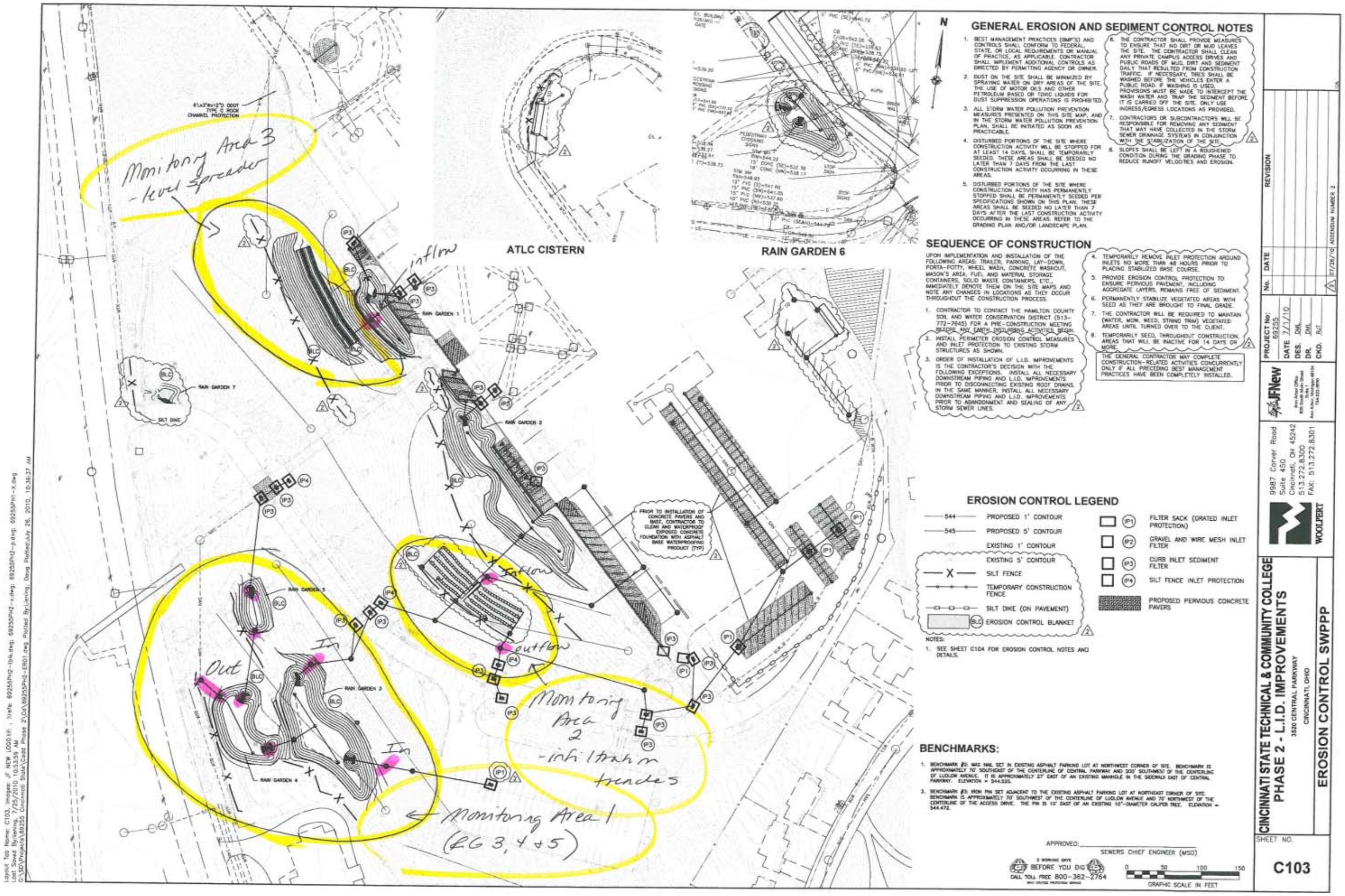
3. Level Spreader/Green Wall is another large unique feature located downhill from pervious paving and Rain Garden 1. There is a distinct inlet point, but there is no single outlet point so it may require water level indicators to determine when water is discharged during wet weather events.

There are also two below-ground cisterns to be used for RWH and irrigation that may be worth considering. There are access ports and exit outlets for the irrigation system feed.

Note that USEPA is actively monitoring the pervious paver areas in Parking Lot D. There are also the three flow meters installed in the combined system where MSD has been collecting pre-construction flow data from the site. These will remain in place to compare post-construction flows.

The following discussion summarizes these potential monitoring locations at the Cincinnati State Technical and Community College in more detail.

Cincinnati State Technical and Community College will allow the installation of monitoring equipment. To improve maintenance and energy efficiency, an online system will be developed by Cincinnati State in corporation with CMC Technologies and FacilityONE. The following figure shows the suggested monitoring areas.



PRIOR TO INSTALLATION OF CONCRETE PAVERS AND BASE, CONTRACTOR TO CLEAN AND WATERPROOF EXPOSED CONCRETE FOUNDATION WITH ASPHALT BASE WATERPROOFING PRODUCT (TYP)

GENERAL EROSION AND SEDIMENT CONTROL NOTES

1. BEST MANAGEMENT PRACTICES (BMP'S) AND CONTROLS SHALL CONFORM TO FEDERAL, STATE, OR LOCAL REQUIREMENTS OR MANUAL OF PRACTICE, AS APPLICABLE. CONTRACTOR SHALL IMPLEMENT ADDITIONAL CONTROLS AS DIRECTED BY PERMITTING AGENCY OR OWNER.
2. DUST ON THE SITE SHALL BE MINIMIZED BY SPRAYING WATER ON DRY AREAS OF THE SITE. THE USE OF MOTOR OILS AND OTHER PETROLEUM BASED OR TOXIC LIQUIDS FOR DUST SUPPRESSION OPERATIONS IS PROHIBITED.
3. ALL STORM WATER POLLUTION PREVENTION MEASURES PRESENTED ON THIS SITE MAP, AND IN THE STORM WATER POLLUTION PREVENTION PLAN, SHALL BE INITIATED AS SOON AS PRACTICABLE.
4. DISTURBED PORTIONS OF THE SITE WHERE CONSTRUCTION ACTIVITY WILL BE STOPPED FOR AT LEAST 14 DAYS, SHALL BE TEMPORARILY SEEDED. THESE AREAS SHALL BE SEEDED NO LATER THAN 7 DAYS FROM THE LAST CONSTRUCTION ACTIVITY OCCURRING IN THESE AREAS.
5. DISTURBED PORTIONS OF THE SITE WHERE CONSTRUCTION ACTIVITY HAS PERMANENTLY STOPPED SHALL BE PERMANENTLY SEEDED PER SPECIFICATIONS SHOWN ON THIS PLAN. THESE AREAS SHALL BE SEEDED NO LATER THAN 7 DAYS AFTER THE LAST CONSTRUCTION ACTIVITY OCCURRING IN THESE AREAS. REFER TO THE GRADING PLAN AND/OR LANDSCAPE PLAN.
6. THE CONTRACTOR SHALL PROVIDE MEASURES TO ENSURE THAT NO DIRT OR MUD LEAVES THE SITE. THE CONTRACTOR SHALL CLEAN ANY PRIVATE CAMPUS ACCESS DRIVES AND PUBLIC ROADS OF MUD, DIRT AND SEDIMENT DAILY THAT RESULTED FROM CONSTRUCTION TRAFFIC. IF NECESSARY, TIRES SHALL BE WASHED BEFORE THE VEHICLES ENTER A PUBLIC ROAD. IF WASHING IS USED, PROVISIONS MUST BE MADE TO INTERCEPT THE WASH WATER AND TRAP THE SEDIMENT BEFORE IT IS CARRIED OFF THE SITE. ONLY USE INGRESS/EGRESS LOCATIONS AS PROVIDED.
7. CONTRACTORS OR SUBCONTRACTORS WILL BE RESPONSIBLE FOR REMOVING ANY SEDIMENT THAT MAY HAVE COLLECTED IN THE STORM SEWER DRAINAGE SYSTEMS IN CONJUNCTION WITH THE STABILIZATION OF THE SITE. 2
8. SLOPES SHALL BE LEFT IN A ROUGHENED CONDITION DURING THE GRADING PHASE TO REDUCE RUNOFF VELOCITIES AND EROSION.

SEQUENCE OF CONSTRUCTION

UPON IMPLEMENTATION AND INSTALLATION OF THE FOLLOWING AREAS: TRAILER, PARKING, LAY-DOWN, PORTA-POTTY, WHEEL WASH, CONCRETE WASHOUT, MASON'S AREA, FUEL AND MATERIAL STORAGE CONTAINERS, SOLID WASTE CONTAINERS, ETC., IMMEDIATELY DENOTE THEM ON THE SITE MAPS AND NOTE ANY CHANGES IN LOCATIONS AS THEY OCCUR THROUGHOUT THE CONSTRUCTION PROCESS.

1. CONTRACTOR TO CONTACT THE HAMILTON COUNTY SOIL AND WATER CONSERVATION DISTRICT (513-772-7645) FOR A PRE-CONSTRUCTION MEETING BEFORE ANY EARTH DISTURBING ACTIVITIES BEGIN.
2. INSTALL PERIMETER EROSION CONTROL MEASURES AND INLET PROTECTION TO EXISTING STORM STRUCTURES AS SHOWN.
3. ORDER OF INSTALLATION OF L.I.D. IMPROVEMENTS IS THE CONTRACTOR'S DECISION WITH THE FOLLOWING EXCEPTIONS. INSTALL ALL NECESSARY DOWNSTREAM PIPING AND L.I.D. IMPROVEMENTS PRIOR TO DISCONNECTING EXISTING ROOF DRAINS. IN THE SAME MANNER, INSTALL ALL NECESSARY DOWNSTREAM PIPING AND L.I.D. IMPROVEMENTS PRIOR TO ABANDONMENT AND SEALING OF ANY STORM SEWER LINES. 2
4. TEMPORARILY REMOVE INLET PROTECTION AROUND INLETS NO MORE THAN 48 HOURS PRIOR TO PLACING STABILIZED BASE COURSE.
5. PROVIDE EROSION CONTROL PROTECTION TO ENSURE PERVIOUS PAVEMENT, INCLUDING AGGREGATE LAYERS, REMAINS FREE OF SEDIMENT.
6. PERMANENTLY STABILIZE VEGETATED AREAS WITH SEED AS THEY ARE BROUGHT TO FINAL GRADE.
7. THE CONTRACTOR WILL BE REQUIRED TO MAINTAIN (WATER, MOW, WEED, STRING TRIM) VEGETATED AREAS UNTIL TURNED OVER TO THE CLIENT.
8. TEMPORARILY SEED, THROUGHOUT CONSTRUCTION, AREAS THAT WILL BE INACTIVE FOR 14 DAYS OR MORE. 2

THE GENERAL CONTRACTOR MAY COMPLETE CONSTRUCTION-RELATED ACTIVITIES CONCURRENTLY ONLY IF ALL PRECEDING BEST MANAGEMENT PRACTICES HAVE BEEN COMPLETELY INSTALLED.

EROSION CONTROL LEGEND

544	PROPOSED 1' CONTOUR
545	PROPOSED 5' CONTOUR
	EXISTING 1' CONTOUR
	EXISTING 5' CONTOUR
—X—	SILT FENCE
—◆—◆—	TEMPORARY CONSTRUCTION FENCE
—□—□—	SILT DIKE (ON PAVEMENT)
▭ (BLC)	EROSION CONTROL BLANKET
☐ (IP1)	FILTER SACK (GRATED INLET PROTECTION)
☐ (IP2)	GRAVEL AND WIRE MESH INLET FILTER
☐ (IP3)	CURB INLET SEDIMENT FILTER
☐ (IP4)	SILT FENCE INLET PROTECTION
▨	PROPOSED PERVIOUS CONCRETE PAVERS

NOTES:

1. SEE SHEET C104 FOR EROSION CONTROL NOTES AND DETAILS.

BENCHMARKS:

1. BENCHMARK #2: MAG NAIL SET IN EXISTING ASPHALT PARKING LOT AT NORTHWEST CORNER OF SITE. BENCHMARK IS APPROXIMATELY 70' SOUTHEAST OF THE CENTERLINE OF CENTRAL PARKWAY AND 200' SOUTHWEST OF THE CENTERLINE OF LUDLOW AVENUE. IT IS APPROXIMATELY 27' EAST OF AN EXISTING MANHOLE IN THE SIDEWALK EAST OF CENTRAL PARKWAY. ELEVATION = 544.525.
3. BENCHMARK #3: IRON PIN SET ADJACENT TO THE EXISTING ASPHALT PARKING LOT AT NORTHEAST CORNER OF SITE. BENCHMARK IS APPROXIMATELY 70' SOUTHWEST OF THE CENTERLINE OF LUDLOW AVENUE AND 70' NORTHWEST OF THE CENTERLINE OF THE ACCESS DRIVE. THE PIN IS 10' EAST OF AN EXISTING 10"-DIAMETER CALIPER TREE. ELEVATION = 544.472.

APPROVED: ______________________
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CINCINNATI STATE TECHNICAL & COMMUNITY COLLEGE
PHASE 2 - L.I.D. IMPROVEMENTS

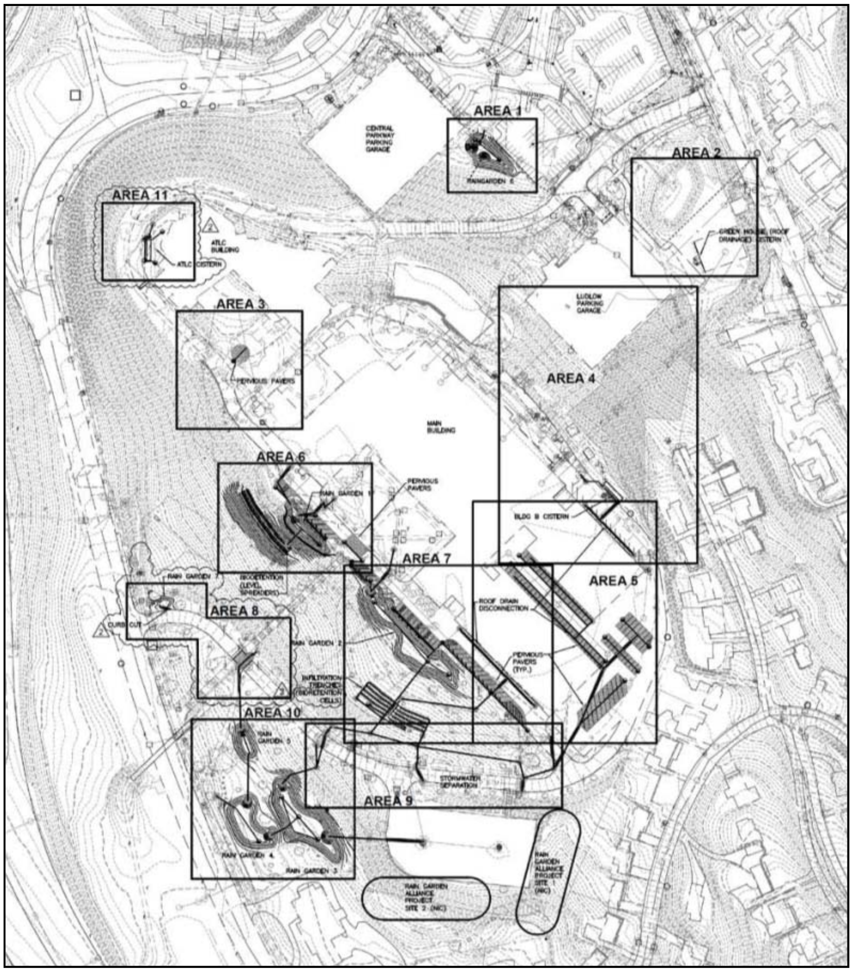
EROSION CONTROL SWPPP

Future Monitoring Locations Highlighted

Monitoring Area 1, Interconnected Rain Gardens 3, 4 and 5

The Monitoring Area 1 is located in Project Area “10” which is proposed to have rain gardens 3, 4 and 5. In this area parking lot A and the driveway currently flow directly to a combined sewer via catchbasins and inlets. Rain garden 3 will collect runoff from parking lot A, while rain garden 5 will capture runoff from the driveway. Both rain gardens 3 and 5 will overflow into rain garden 4, which then overflows back to the combined sewer system just before it leaves the CSTCC Campus.

Roof runoff and pervious paver underdrains from Project Area “5” – located on the east side of the buildings, in the faculty parking lot area - will be sent downhill via a new stormwater line to a series of two rain gardens 3 and 4 (RG3 and RG4). Overflow from rain garden 2 (RG2), located in Project Area “7”, will be directed into the new storm system that flows into rain garden 3 (RG3). Also the storm sewer separation in Project Area “9” will re-route stormwater from catch basins to the new stormwater line that flows to rain garden 3 (RG3).



Locations of proposed project areas and associated green controls

For rain gardens 3, 4 and 5 storage areas, infiltration rates for sand (9.27 in/hr) and silty sand (2.35 in/hr) have been assumed. These infiltration rates came from the SWMM guidance for recommended Green-Ampt parameters based on soil texture. Unfortunately, these rates are likely overly-optimistic as they do not consider the likely soil compaction will occur at these areas.

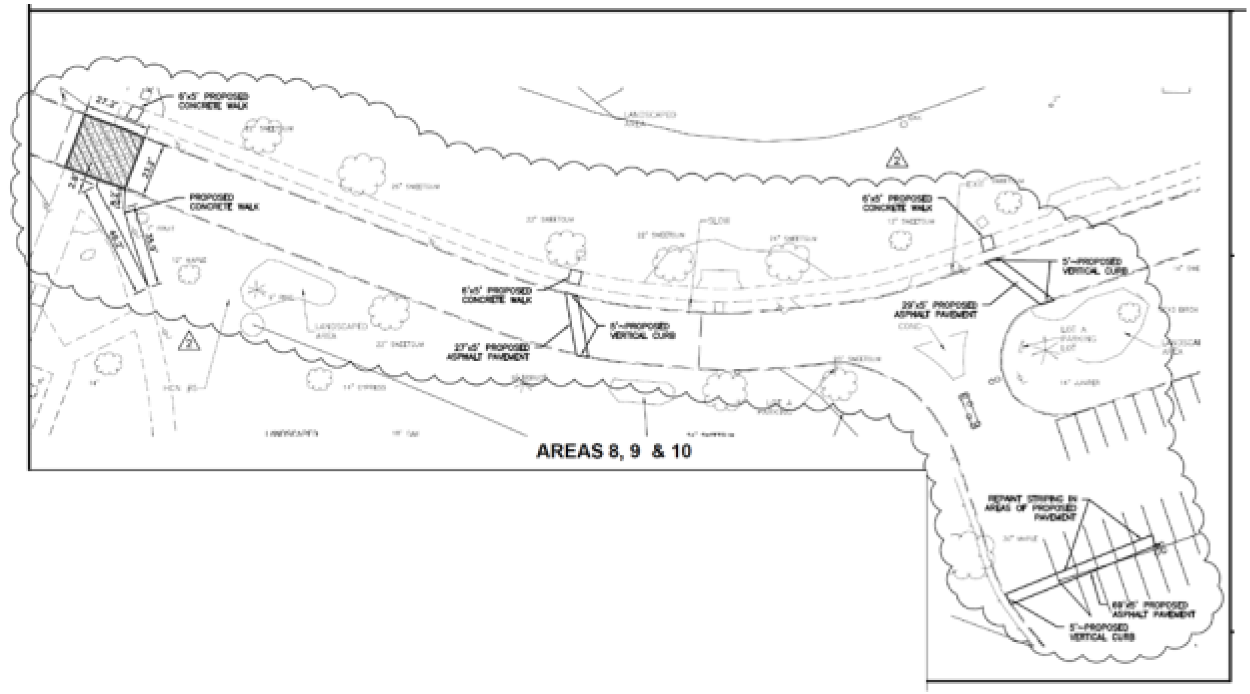
“Rain gardens are designed to have a minimum of 12-inches of amended soils (highly porous sand and compost planting mixture), a ponding depth of 12 to 36 inches, and 12-inches of freeboard. RG3 and RG4 are designed to have 5-feet of amended soils in order to excavate down to the existing sand seam. Rain garden outlet structures will consist of a 2 to 4-foot diameter standpipe with beehive grate and underdrain connections.”

The underdrains for RG3 and RG4 will be constructed with a valve which will be initially left opened, but will have the potential to be closed to capture more water, and then re-opened if ponding duration issues arise. The underdrain will be surrounded by a pea gravel diaphragm (with filter fabric above the underdrain pipe) and covered with the amended soil mixture. Low-flow orifices (three 8-inch diameter orifices) will be added at an elevation approximately half of the ponding depth for RG3 and RG4 outlet structures in order to relieve some of the standing water and provide additional capacity during large storm events. Rain gardens will be planted with a variety of plugs appropriate for the expected hydroperiod.

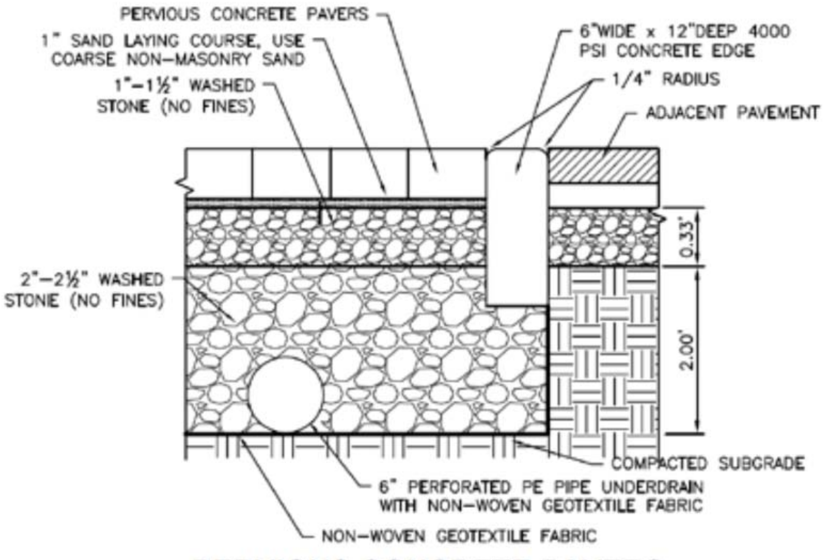
Projected average annual storm water runoff capture volumes for project areas 7, 9 and 10

Area	Specific BMP	Total Inflow (GAL)	Total Outflow (GAL)	Low End Estimate - Total Loss (GAL)	High End Estimate - Total Loss (GAL)
7	pavers_RG2*	400,447	2,693	397,754	576,197
7	RG2*	536,443	77,558	458,885	523,561
9 &10	RG3	2,938,857	0	2,938,857	3,016,597
9 &10	RG4	456,731	0	456,731	499,633
9 &10	RG5	505,474	74,057	431,417	441,154

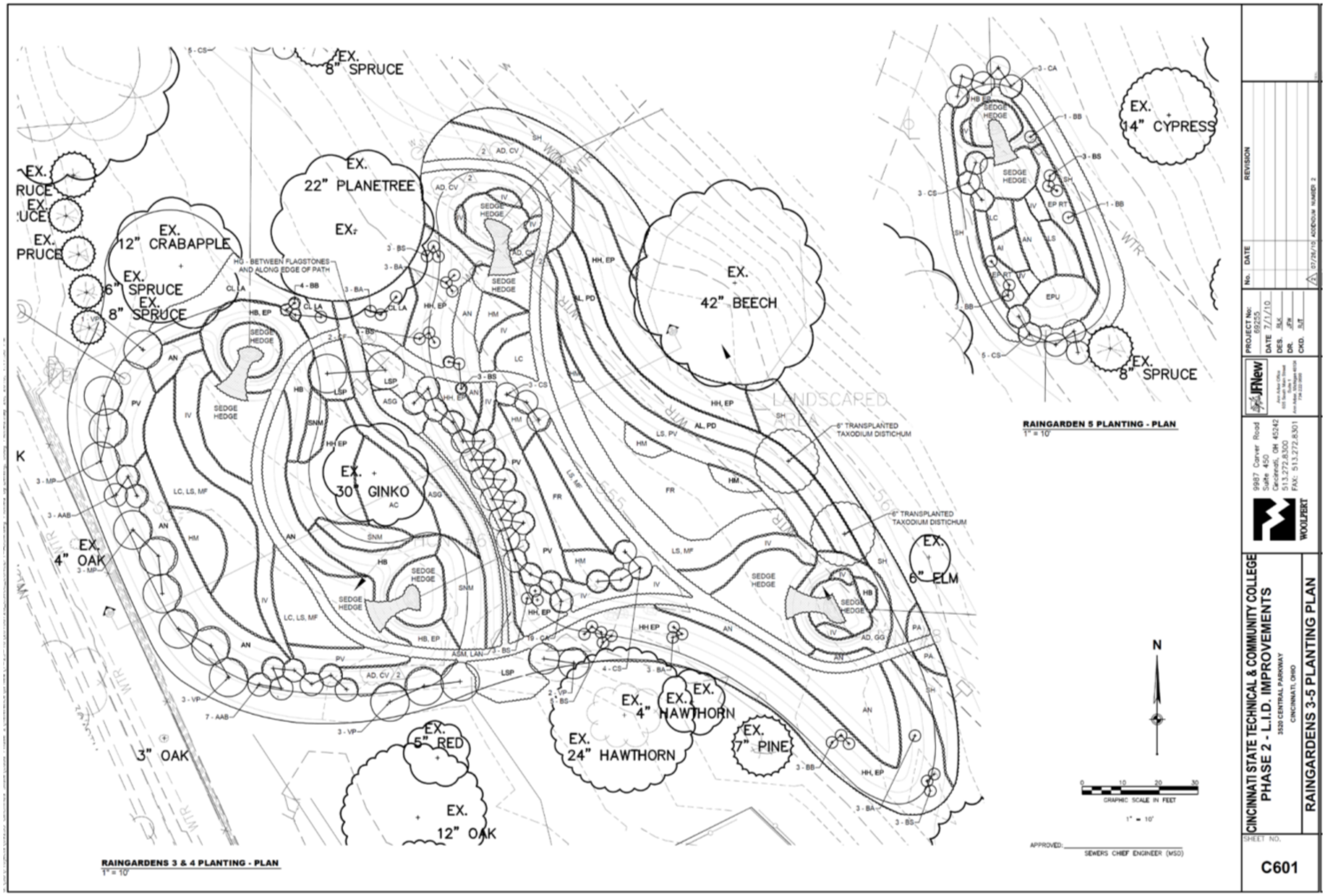
* Overflow RG2 will be directed into the new storm system that flows into RG3



Plans for porous paving areas



PERVIOUS CONCRETE PAVERS
NO SCALE

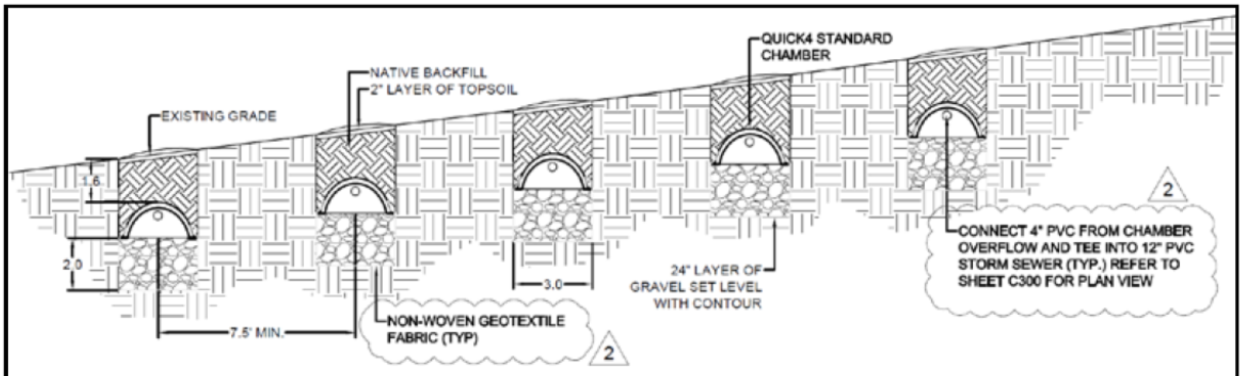


Plans for rain gardens 3, 4 and 5

Monitoring Area 2

Monitoring Area 2 is located in Project Area 7. This area includes the courtyard, parking, and driveway areas on the south side of the buildings. The runoff from mentioned areas currently flow to combined sewer via yard drains and catch basins which is proposed to re-route into rain gardens 1 and 2 (RG1 and RG2). Also pervious pavers will be added in the parking areas. The proposed plan area in Project Area 7 consists 8,200 square feet of porous pavers 11,290 square feet of rain garden, and 1,540 square feet of infiltration trenches. Overflow from RG2 will be directed into the new storm system that flows into RG3.

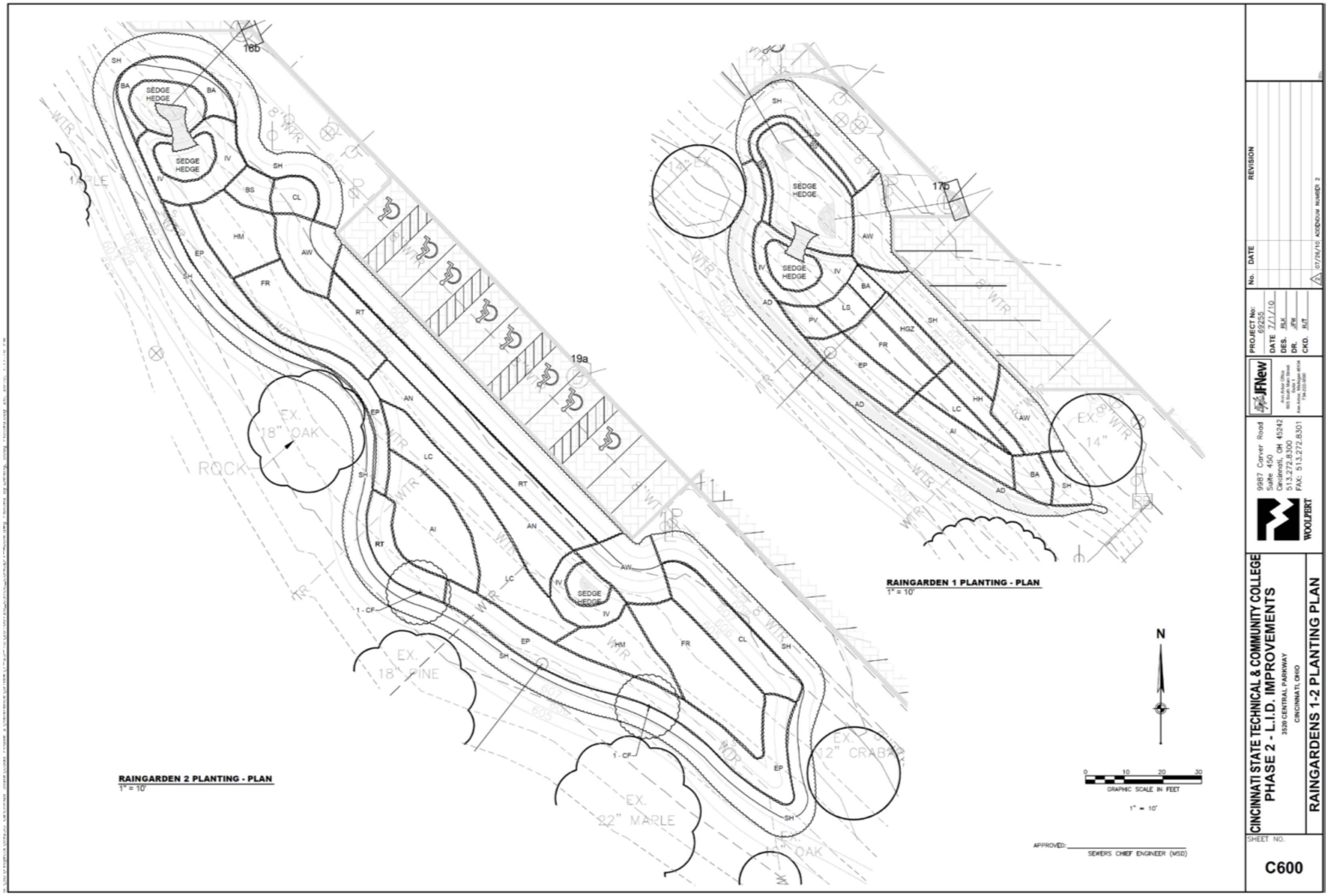
Infiltration trenches are proposed to be installed on the hillside in Area 7 below rain garden 2. Two sets of five infiltration trenches will be constructed parallel to one another on either side of a central collection pipe. There will be a minimum distance of 7.5 feet between trenches. The design includes a 2 inch layer of topsoil and a 1.5 foot layer of native backfill above the Quick4 High Capacity infiltrator chambers. A minimum 6 inch layer of gravel will underlie the cambers. Additionally, 24 inches of gravel was assumed to exist below the base of the chambers to provide extra storage area needed for large design rainfall events. Any runoff out of the infiltration trenches will be conveyed via new storm sewer to rain garden 3 in Project Area 10 and Monitoring Area 1.



INFILTRATION TRENCH - SECTION C-C'
1/8" = 1' 0"

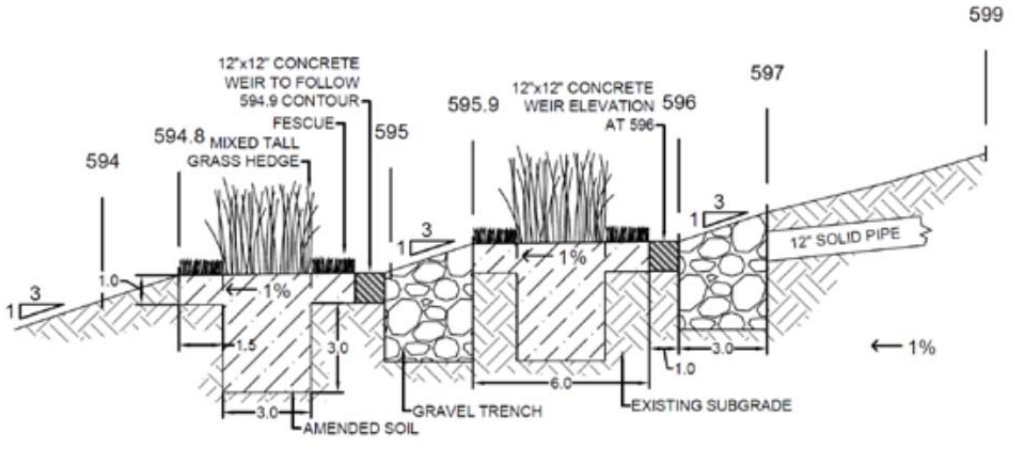
Projected average annual storm water runoff capture volumes for project areas 7

Area	Specific BMP	Total Inflow (GAL)	Total Outflow (GAL)	Low End Estimate - Total Loss (GAL)	High End Estimate - Total Loss (GAL)
7	Pavers - RG2	400,447	2,693	397,754	576,197
7	RG2	536,443	77,558	458,885	523,561
7	Infiltration Trench	460,770	8,887	451,883	482,571
			Area 7 Total	1,308,522	1,582,329



Plans for rain gardens 1 and 2

Monitoring area 3
Monitoring area 3 is located in Project Area 6. The proposed plan in Project Area 6 consists of 2,750 square feet of porous pavers, 4,055 square feet of rain gardens and 420 square feet of bioretention (level spreaders). Overflow from RG1 will be directed into a series of bioretention trenches which will infiltrate any remaining water. Bioretention (level spreaders) will be installed on the hillside in Area 6 below rain garden 1. The control will consist of 2 sets of level spreaders placed parallel to one another. A set includes a 3 foot wide by 3 foot deep trench (with the top at a 3:1 slope) filled with aggregate. Any water not infiltrated through this system is conveyed as surface runoff down the hillside.

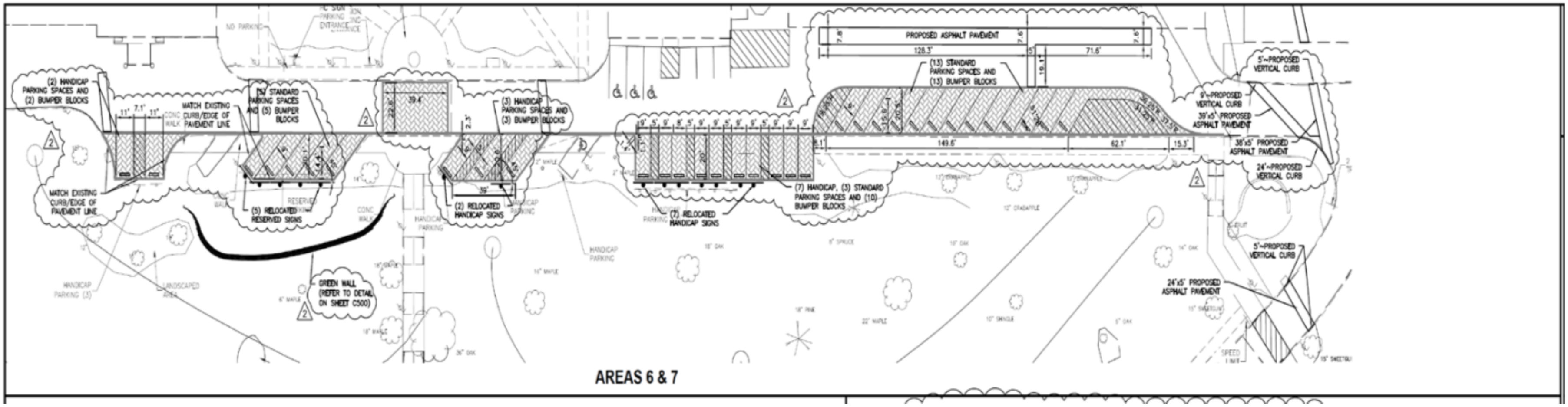


NOTE: ALL WEIRS SHOULD BE LEVEL

BIODETENTION (LEVEL SPREADER) - DETAIL
NOT TO SCALE

Projected average annual storm water runoff capture volumes for project areas 6

Area	Specific BMP	Total Inflow (GAL)	Total Outflow (GAL)	Low End Estimate - Total Loss (GAL)	High End Estimate - Total Loss (GAL)
6	pavers_RG1	210,861	13,465	197,396	237,966
6	RG1	179,084	48,743	130,341	144,635
6	Bioretention (*Level Spreaders)*	48,474	0	48,474	56,843



Plans for porous paving areas in Project Areas 6 and 7

Summary of Sampling and Monitoring Locations at Cincinnati State Technical and Community College

The following summarizes the sampling and monitoring requirements at the three Cincinnati State Technical and Community College areas:

1. Interconnected Rain Gardens 3, 4 and 5 located at the base of the hill near Central Parkway.
    3 inlet automatic water samplers and 3 inlet flow monitors
    1 outlet automatic water sampler and 1 outlet flow monitor
    3 interconnecting unit water samplers and 3 interconnecting flow monitors
    2 water level recorders for rain gardens

2. Infiltration trenches located downhill from Rain Garden 2.
    1 inlet automatic water sampler and 1 inlet flow monitor
    1 outlet automatic water sampler and 1 outlet flow monitor
    5 water level recorders for infiltration trenches

3. Level Spreader/Green Wall located downhill from pervious paving and Rain Garden 1.
    1 inlet automatic water sampler and 1 inlet flow monitor
    2 outlet automatic water samplers and 2 outlet flow monitors (a collection trough will need to be constructed below the last edge of the level spreader area to collect any overflow, with water outlets to each end)
    2 water level recorders for bioretention areas

Therefore, a total of 12 automatic samplers and 12 flow monitors will be needed at these locations. In addition, 9 water level recorders will be needed to continuously monitor standing water in the rain gardens and the water contained in the bioretention and infiltration trenches. Additional water samplers and flow monitors will also be needed for any underdrains. The locations and numbers of these will be dependent on the final designs of the treatment units and how the underdrains are collected for discharge to the collector drainage, but it is likely that another 12 samplers and monitors will be needed to monitor a complete mass balance. It is also highly recommended to have at least one or two space sets of equipment to rotate through the setups as units have to be periodically removed for service (or repair). Nine soil moisture sensors are also needed to be placed in the root zones of the systems and another nine are needed for the storage zone beneath the root zones. Groundwater mounding should also be monitored under the infiltration devices. Nine groundwater level observation wells are needed beneath the infiltration areas, and another nine are needed surrounding the infiltration zones.

Three tipping bucket rain gages will also be installed in this area that will be used to initiate the automatic samplers (and to provide redundant rain data, one of the primary monitoring parameters). The flow monitors located in the adjacent combined sewers collecting pre-development flows will be maintained to collect flow data for post-construction conditions.

Specific Monitoring Locations at Cincinnati Zoo African Savannah

The following paragraphs briefly describe the types of sampling and monitoring that can be used in the African Savannah exhibit area to verify the performance of the planned stormwater control practices.

Porous Pavers and Enhanced Turf and Vegetation

Replace the existing parking lot with pervious paving and enhanced turf and vegetation. The pervious paving is designed to cover 42,207 ft^2, while the total area of the turf replacement is roughly 20,000 yd^2. Monitoring of the new porous paver installations should include locations where mass balances of the water and pollutants of interest can be conducted. This approximately one acre of porous pavers will drain towards a single internal location where excess runoff can be sampled and monitored. It is anticipated that any underdrains will also drain to this single location that is located at the lowest area on the parking area. Therefore, two automatic water samples with flow sensor modules will be needed at this location, along with a single tipping bucket rain gage. A berm will need to be constructed around the parking area perimeter to direct all runoff to this single sampling location. If this is not possible, either the effective runoff source area would be reduced for monitoring, or additional monitoring locations would be needed.

Subsurface monitoring and water sampling is also needed to measure the quantity and quality of the percolating water. Observation wells should be established to measure any groundwater mounding or perching under the porous paver area. Three observation wells should be established within the porous paver area, with another three outside of the area to determine unaffected groundwater table elevations. A cluster of pan lysimeters (simple horizontal perforated pipes resting on small impervious layers gravity draining to a central manhole with sample bottles) can be established in a central area, with collection ports located at several depths under the pavers. These are passive samplers with no elaborate sampling equipment.

The turf and enhanced vegetation monitoring would be based on soil infiltration, texture, moisture, and density measurements. The infiltration tests should be conducted for surface and several feet deep (using a borehole) conditions. Soil measurements of texture and chemical characteristics would also be periodically conducted, possibly using the services of state soil lab extension service. These measurements should be conducted in areas having the enhanced vegetation and in other areas having standard vegetation conditions for comparison.

Bioretention Areas and Tree Walls

Installation of three bioretention basins and two tree wells. These facilities should be monitored at the inflow, overflow, and underdrain locations, plus beneath the units using the observation wells and pan lysimeters described above. The soils/media in the units also need to be periodically monitored to measure maintenance issues and potential problems associated with snowmelt runoff entering them. Each unit being monitored would therefore require three automatic samples and flow modules plus one tipping bucket rain gage module, in addition to two observation wells (one within and one adjacent), and two pan lysimeter depths. All five devices would not need to be monitored, unless there were significant differences in their designs or engineered soil. For these initial planning purposes, it is assumed that only one bioretention area and one tree wall would be monitored.

Rainwater Harvesting, Storage and Reuse System

Construction of a large subsurface storage pipe under the African Savannah area. The storage facility will consist of 380-feet of 12-foot diameter perforated pipe, surrounded by open graded aggregate. In order to conduct a mass balance of this unit, all inflows need to be monitored, along with the outflows. If the outlet water is being treated, samples would also be taken before and after any treatment. The plans are not clear on how many inlet and outlet locations exist, but this initial planning calculation assumes a total of five locations. Besides the inlet and outlet sampling, water elevation measurements in the pipes and gravel storage areas will be needed, possibly by using only a single water level sensor.

Storm Sewer Separation and Roof Leader Disconnection

Disconnect these systems from the combined sewer system through a storm sewer separation project and redirection of roof leaders to the subsurface storage facility. A paired watershed approach, with a test area completely disconnected and a control area completely directly connected, would be the most straight-forward way of measuring the benefits of these controls. However this is not likely doable for the zoo site with such heterogeneous building conditions (would be reasonable for a residential area, in contrast). Therefore, monitoring of these activities would need to be conducted close to the roof leaders in a small-scale. It is suggested that a set of sheetflow sampler stations be established at varying distances from a disconnected roof leader for the measurement of flows and to measure water quality for the site soil conditions. Soil tests and measurements (infiltration, texture, moisture, and density, in addition to soil chemistry) would also be needed in the areas being examined. No automatic samplers are expected for these tests, unless areas can be isolated for paired area analyses.

Summary of Sampling and Monitoring Locations at Cincinnati Zoo African Savannah

The following table summarizes the total number of samplers and monitoring activities expected for the Cincinnati Zoo African Savannah exhibit stormwater management activities:

	Number of units and/or size	Automatic water samplers, flow sensors and rain gage	Soil monitoring	Vadose zone monitoring
Porous pavers and enhanced turf and vegetation	Enhanced vegetation plus 1 porous paver parking area; 42,207 ft^2	2 samplers 2 flow modules 1 rain module	Infiltration, texture, moisture, and density, plus chemical analyses (surface and at depth)	6 observation wells with level recorders 1 pan lysimeter cluster
Bioretention areas and tree walls	3 bioretention areas (monitor 1) 2 tree wells (monitor 1)	6 samplers 6 flow modules 2 rain modules	Infiltration, texture, moisture, and density, plus chemical analyses	4 observation wells with level recorders 2 pan lysimeter clusters
Rainwater harvesting, storage, and reuse system	1 storage tank (assuming 5 inlets and outlets total) and treatment unit	6 samplers 6 flow modules 1 rain module 1 water level recorder in storage tank	none	none
Storm sewer separation and roof leader disconnections	Not specified	6 sheetflow samplers	Infiltration, texture, moisture, and density, plus chemical analyses	none
Total for Cincinnati Zoo		14 automatic samplers	Infiltration, texture, moisture,	10 observation wells (with water

African Savannah		6 sheetflow samplers 14 flow modules 4 rain modules 1 water level recorder 7 to 10 equipment shelters	and density, plus chemical analyses at about 10 locations (conducted seasonally)	level recorders) 3 pan lysimeter clusters

The approximate cost of this equipment would be about $150,000, excluding the analysis costs.

Specific Monitoring Locations at the University of Cincinnati

The likely stormwater controls to be constructed and monitored at the University of Cincinnati is currently unkown, so no descriptions or cost estimates are possible. However, with the design of the sampling program at the same time as the selection and designs of the controls, the costs can be minimized and the quality of data improved. The following section includes some general outlines of the types of monitoring that is recommended for each type of stormwater control.

Monitoring Issues Affecting Different Types of Stormwater Controls

The following is a summary of the generic monitoring needs for each type of stormwater control to be monitored as part of this demonstration project.

Biofiltration and Biofilter Devices

Mass balance for water:

Influent water rate and volume (rain garden: simple standpipe and orifice and level sensor; biofilter: flume and level sensor)
Effluent (overflow) water rate and volume (outlet weir level sensor in ponded area; also confirms infiltration rates after inflowing water ceases)
Infiltration rates within device (Turf-tech clusters during dry weather and by season; if small, also flood with city water and measure infiltration rate; also use in-place level sensor during events)
ET losses (on-site small weather station that calculates ET based on site measurements; soil moisture sensors; even plant tissue moisture sensors possible)

Clogging potential:

Monitor infiltration rates within device seasonally during several year monitoring period
Sample influent and effluent water for total particulates (and PSD)
Monitor health of plants and their ability to incorporate sediment into soil horizon (survey surface elevations within device near inlet and at other stations seasonally)

SAR problems:

Texture analysis of media within device to quantify clay content (and if possible, type of clay)
Chemical analyses of soil (especially Na, Ca, and Mg; also nutrients and possibly metals)

Pollutant removals (lower priority):

Mostly based on SS mass balance listed above under clogging

Influent and effluent concentrations of POC (little expected differential removal of pollutants flowing thru surface of device, so effluent concentrations is likely very similar to influent conc. If underdrain, the sample those flows also (expected reduced concentrations)

Groundwater contamination potential:

Monitor GW elevation under device (within device and well outside of device to detect mounding, especially if shallow groundwater)

Pan lysimeter under device to collect and sample infiltrating water beneath device

Comparisons of different media and underdrain types can be used to identify “best” combinations of design features for local area.

Porous Pavement

Much for difficult to monitor mass balance unless no runon (or controlled runon that can be monitored) and unless use impermeable underlayer and then use underdrain to capture underain flow.

If no underdrain monitoring or impermeable underseal, could collect overflow from pavement surface is use an edge berm or gutter to collect overflow for monitoring and sampling. Can also sample underdrain effluent if directed into a sampling box.

In all cases, need complete weather station, especially accurate site rainfall measurements, to determine quantity of direct rainfall on the pavement.

Groundwater monitoring with obs wells directly under facility and well to the side for comparison to measure GW mounding. Subsurface monitoring to measure GW contamination potential also needed.

Alternative setups to measure performance: mostly use porous concrete and paver blocks. It is hard to imagine use of organic supplements in a media treatment layer beneath storage gravel layer to protect GW due to structural concerns. Coated sands have been used in PET trenches under Cincinnati porous concrete sites adjacent to highways.

Sediment loading and maintenance cleaning big issue for monitoring, along with fate of stormwater fines, and GW contamination potential.

Stormwater Beneficial Uses

Bacteria is largest concern with stormwater beneficial use evaluations (effects of storage and post-storage treatment needs and alternative disinfection methods; benefits of using source water from different areas, such as roof runoff, the likely “best” source water, vs. parking lot water likely poor quality). Mass balance of water very important; water needs vs. storage tank sizes and available water quantity.

Recommended Monitoring Equipment

It is recommended that as much of the sampling and monitoring equipment be obtained from a single manufacturer as possible. This will ensure the best integration of the complex components and the best support service from the manufacturer. The recommended equipment supplier is Teledyne ISCO, of

Lincoln, NE. They are highly experienced, having supported stormwater monitoring projects for several decades, and offer a wide range of equipment. The following lists some of the major

• Model 6712 Sequential/Composite Automatic Sampler (full-size). 10L composite plastic sampler container plus 24 plastic bottle sample base to allow flow-weighted composite sampling (recommended) and periodic discrete (high-resolution) sampling. These samplers also accept 700 Series Modules. The 750 Area-Velocity Flow/level module is recommended for most situations, but the 730 Bubbles Flow/level module would be used for monitoring water elevation.

• Communications. The samplers should also be outfitted with cell phone interfaces allowing remote access, interrogation, adjustments, and downloading of data. As noted previously, ISCO 674 tipping bucket rain gages will also connect to the samplers and data loggers to initiate the sampler sequence. This is the most reliable triggering option for most situations. Terminal program and Internet interfacing would also be used to automatically download and assemble the data and present it on a project web page.

• Continuous Water Quality Sondes. The MSDGC already had several YSI water quality sondes that can be used at the monitoring locations. These can also be directly interfaced to the ISCO sampler/data loggers. The sondes can be programmed to collect pH, temperature, turbidity, DO, ORP, and conductivity data every several minutes during runoff events. They should be repositioned during interevent periods to continuously monitor the quality of standing water.

As noted previously, about 24 sets of this equipment may be needed at the Cincinnati State Technical and Community College monitoring sites, plus about 14 sets for the zoo monitoring, to enable complete mass balance measurements to water and pollutants at the stormwater control locations. The cost of this equipment is expected to be in the range of $200,000 to $250,000 for the Cincinnati State monitoring. The cost of the equipment for the Cincinnati Zoo African Savannah area is expected to be about $150,000. These costs do not include analytical costs.

Installation of this equipment will be very critical to ensure accurate measurements. The flow sensors have to be properly installed with the correct approach conditions, for example. If at all possible, flume inserts should be used to measure open channel flow conditions in the pipes. If the pipes are completely full, then the velocity sensor alone will be suitable without an insert. Different sized plastic flumes are also available from Global Water, for example, that allow accurate surface flows. Again, the approach conditions must be considered, along with the expected range of flow conditions, to select the appropriate control units.

The water samplers are usually installed in steel contractor’s job boxes. However, ISCO can supply insulated fiberglass units that are more suitable. All of the equipment will need to be operated off of deep cycle batteries if AC line power is not available (much more convenient). The sampler intakes need to be located in total flow locations. Intakes located along the invert of a storm drain pipe frequently over-samples sediment as they preferentially draw in bedload sediments. It is not possible to create an artificial mixing zone in a pipe to allow well-mixed conditions. Therefore, the recommended approach is to install sampling boxes at the sampling locations that provide 6 to 12 inches of drop. The water then cascades into a sample tray containing the inlet, creating a well-mixed sample. Unfortunately, these are difficult, but often necessary, to construct after the stormwater control devices are already installed. These are most critical for inlets, where larger particles are more common (they should all be removed by the control and are therefore not likely to be present at outlets or in underdrains). Inlets can hopefully be easily modified (temporarily) to accommodate these sampler structures.

Common Causes for Failure and Overall Issues Affecting Stormwater Controls

During monitoring of stormwater controls, a number of maintenance and other issues have been identified that can dramatically degrade their performance. Therefore, an important element of this monitoring program will be to include specific (and low cost) data collection efforts to enable these issues to be evaluated at the Cincinnati demonstration project locations.

Certain site conditions may restrict the usefulness of some of the stormwater controls, as briefly discussed in the following subsections (mostly summarized from Pitt, *et al.* (Pitt, R. J. Voorhees, and S. Clark. “Evapotranspiration and related calculations for stormwater biofiltration devices: Proposed calculation scenario and data.” In: *Stormwater and Urban Water Systems Modeling*, Monograph 16. (edited by W. James, E.A. McLean, R.E. Pitt and S.J. Wright). CHI. Guelph, Ontario, pp. 309 – 340. 2008.) and from research reported by others at recent technical conferences.

Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio can radically degrade the performance of a biofiltration device, especially when clays are present in the infiltration layers of a device and when deicing salts are present in snowmelt water that enters a biofilter. Soils with an excess of sodium ions, compared to calcium and magnesium ions, remain in a dispersed condition, and are almost impermeable to rain or applied water. A “dispersed” soil is extremely sticky when wet, tends to crust, and becomes very hard and cloddy when dry. Water infiltration is therefore severely restricted. Dispersion caused by sodium may result in poor physical soil conditions and water and air do not readily move through the soil. An SAR value of 15, or greater, indicates that an excess of sodium will be adsorbed by the soil clay particles. This can cause the soil to be hard and cloddy when dry, to crust badly, and to take water very slowly. SAR values near 5 can also cause problems, depending on the type of clay present. Montmorillonite, vermiculite, illite and mica-derived clays are more sensitive to sodium than other clays. Additions of gypsum (calcium sulfate) to the soil can be used to free the sodium and allow it to be leached from the soil in some situations.

The SAR is calculated by using the concentrations of sodium, calcium, and magnesium (in meq) in the following formula:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{+2} + Mg^{+2})}{2}}}$$

The following example shows how the SAR is calculated:

A soils lab reported the following chemical analyses (the soil samples are taken as composites over the surface layer of a biofiltration device, usually to a depth of about 6 inches):

100 pounds/acre of sodium (Na^{+})
5000 pounds/acre of calcium (Ca^{+2})
1500 pounds/acre of magnesium (Mg^{+2})

These concentrations need to be first converted to parts per million (ppm), and then to meq/L. An acre of soil (43,560 square feet, or 4,047 square meters), 6 inches deep (15 cm), weighs about 2,000,000 pounds (910,000 kg) and contains 22,000 cubic feet of soil (620 cubic meters). The pounds reported per acre are divided by 2 to produce ppm (by weight):

100 pounds/acre of Na divided by 2 = 50 ppm of Sodium
5000 pounds/acre of Ca divided by 2 = 2500 ppm of Calcium
1500 pounds/acre of Mg divided by 2= 750 ppm of Magnesium

The ppm values are divided by the equivalent weight of the element to obtain the relative milliequivalent (meq) values. The milliequivalent weights of Na, Ca, and Mg in this example are:

50 ppm of Na divided by 23 = 2.17 meq
2500 ppm of Ca divided by 20 = 125 meq
750 ppm of Mg divided by 12.2 = 61.5 meq

The SAR for this biofilter media is therefore:

$$SAR = \frac{2.17}{\sqrt{\frac{(125+61.5)}{2}}} = 0.22$$

This value is well under the critical SAR value of 15, or even the caution value of 5 applicable for some clays. This soil is therefore not expected to be a problem. However, if the runoff water contains high levels of sodium in relationship to calcium and magnesium (such as snowmelt in areas using NaCl for de-icing control), an SAR problem may occur in the future, necessitating the addition of gypsum to the infiltration area, or more likely replacement of the surface soil with a sand that has no clay content. The amount of gypsum (calcium sulfate) needed to be added can be determined from an analysis of the soil in the infiltration area. Common amounts are about 20 lb of gypsum per 100 ft^2 as a top dressing to the biofilter (based on agricultural soil literature). However, this would not be a permanent solution if snowmelt is discharged to the biofilter in later periods.

SAR has been documented to be causing premature failures of biofiltration devices in northern communities. These failures occur when snowmelt water is allowed to enter a biofilter that has clay in the soil mixture. In order to minimize this failure, the following are recommended:

1) do not allow snowmelt water to enter a biofilter unit. As an example, roof runoff likely has little salt and SAR problems seldom occur for roof runoff rain gardens. However, if driveway or walkway runoff waters affected by saline deicing chemicals are discharged to these devices, problems may occur. The largest problem is associated with curb-cut biofilters or parking lot biofilters in areas with snowmelt entering these devices, especially if clay is present in the engineered backfill soil.

2) the biofilter fill soil should not have any clay. It appears that even a few percent of clay in the media mix can cause a problem, but little information is currently available on the tolerable clay content of biofilter soils. As a warning, some biofilter guidance documents recommend an appreciable clay content in order to slow the water infiltration rate (and therefore increase the hydraulic detention time in the system) in order to improve pollutant capture. Instead of clay used to control the infiltration rates,

restrictive underdrains, such as the SmartDrain, should be used. Guidance documents recommending "fines" in the biofilter mixture are usually from areas having mild climates with little or no snowmelt (and deicing chemical use). Gypsum applications (top dressing with about 20 lbs/100 ft^2) may help in recovering infiltration capacity, but this may not be a long term solution. Usually the replacement of the failed engineered soil mixture with a new suitable material will be needed.

3) the most robust engineered soil mixtures used in biofilters should be mixtures of sand and an organic material (such as compost, if nutrient leaching is not of concern, or Canadian peat for a more stable material having little nutrient leaching potential). Other mixtures of biofilter media can be used targeting specific pollutants, but these are usually expensive and likely only appropriate for special applications.

4) if a suitable soil mixture not having clay (should be <3% based on preliminary information), and if snowmelt water will affect the system, then biofilters should not be used in the area. As noted above, rain gardens only receiving roof runoff may be suitable in most situations due to the absence of excessive sodium in the runoff water.

Clogging of Biofiltration Devices, Grass Filters, and Swales

The designs of these infiltration devices need to be checked based on their clogging potential. As an example, a relatively small and highly efficient biofilter (in an area having a high native infiltrating rate) may capture a large amount of sediment. Having a small surface area, this sediment would accumulate rapidly over the area, possibly reaching a critical clogging load early in its design lifetime. Therefore, the clogging potential can be calculated based on the predicted annual discharge of suspended solids to the biofiltration device and the desired media replacement interval. Infiltration and bioretention devices may show significantly reduced infiltration rates after about 2 to 5 lb/ft^2 (10 to 25 kg/m^2) of particulate solids have been loaded (Clark 1996 and 2000; Urbonas 1996). Deeply-rooted vegetation and a healthy soil structure can extend the actual life much longer. However, abuse (especially compaction and excessive siltation) can significantly reduce the life of the system. If this critical load accumulates relatively slowly (taking about 10 or more years to reach this total load) and if healthy vegetation with deep roots are present, the infiltration rate may not significantly degrade as the plant's activities incorporate the imported sediment into the soil column. If this critical load accumulates in just a few years, or if healthy vegetation is not present, then premature failure due to clogging may occur. Therefore, relatively large surface areas may be necessary in areas having large sediment contents in the runoff, or suitable pre-treatment to reduce the sediment load before entering the biofilter or infiltration device would be necessary.

It is possible to use the calculated annual suspended solids loading from an area and to determine the clogging potential for a bioretention device having a specific surface area. The following three examples illustrate these simple calculations:

> Example 1
>
> A 1.0 ha paved parking lot (R_v = 0.85), TSS 50 mg/L, in an area receiving 1.0 m (3.3 ft) of rain per year:
> (50 mg SS/L) (0.85) (1 m/yr) (1 ha) (10,000 m^2/ha) (1,000 L/m^3) (g/1,000 mg)
> = 425,000 g SS/yr
>
> Therefore, if a bioretention device is to be used having an expected suspended solids capacity of 15 kg/m^2 (3 lb/ft^2) before "clogging," then 28 m^2 (300 ft^2) of this bioretention device will be needed for

each year of desired operation for this 1.0 ha (2.5 acre) site. This is about 0.3% of the paved area per year of operation, so if 10 years were desired before the media needed to be exchanged, an area of about 3% of the contributing area would be needed for the bioretention device. If this water was pretreated to a high level so the influent runoff entering the biofilter has a much reduced concentration of particulates (to about 5 mg/L suspended solids), then only about 0.03% of the contributing paved area would be needed for the bioretention area for each year of operation. Of course, the final design would need to be based on the infiltration capacity and the desired runoff volume reductions.

Example 2
A 100 ha medium density residential area ($R_v = 0.3$), TSS = 150 mg/L, 1.0 m of rain per year:
(150 mg SS/L) (0.3) (1 m/yr) (100ha) (10,000 m^2/ha) (1,000 L/m^3) (g/1,000 mg)
= 45,000,000 g SS/yr

The unit area loading of suspended solids for this residential area (425 kg SS/ha-yr) is about the same as in the previous example (450 kg SS/ha-yr), requiring about the same area dedicated for the bioretention device (the reduced amount of runoff is balanced by the higher suspended solids concentration).

Example 3
A 1.0 ha rooftop in an area ($R_v = 0.85$), TSS = 10 mg/L, having 1.0 m of rain per year:
(10 mg SS/L) (0.85) (1 m/yr) (1 ha) (10,000 m^2/ha) (1,000 L/m^3) (g/1,000 mg)
= 85,000 g SS/yr

The unit area loading of suspended solids from this area is 85 kg SS/ha-yr and would only require a rain garden of about 0.06% of the roofed drainage area per year of operation, to maintain the 15 kg/m^2 loading limit.

In many of the design calculations having biofilters, the loading rates are higher, resulting in premature failure if the minimum size was used only necessary for infiltration. Therefore, a larger area is actually needed to prevent premature failure due to clogging. Therefore, the following considerations apply to infiltration/biofiltration devices to minimize clogging failure:

1) use a sufficient infiltration area to enable at least ten years before the critical sediment loading (10 to 25 kg/m2) occurs, and maintain a healthy deep-rooted plant community to incorporate the sediment into the soil horizon.

2) use pre-treatment to reduce the sediment load entering a biofilter to reduce the TSS concentrations to match the desired maintenance or clogging interval. The use of a grass filter/grass swale before a biofilter can significantly reduce the loading to the device, extending the operational life.

Groundwater Contamination Potential and Over-Irrigation

The basic beneficial use rate using stored stormwater for irrigation is usually considered to be the difference between the evapotranspiration (ET) rate for the soil-plant mixture and the natural rainfall. For a more accurate analysis, the available infiltrating stormwater into the landscaped area can be used instead of the total rainfall, as only a fraction of the rainfall is available to the plant, especially in disturbed urban environments. The amount of stored stormwater for later use assumes a perfect match to the demand rates. Obviously, it is likely that some wastage or under-utilization will occur, unless a perfect control system is used to regulate the water use based on real-time soil moisture sensors. This level of sophistication may be available for automatic irrigation systems that are commonly used in institutional, commercial, and residential settings.

However, since the objective of the irrigation use of the stored stormwater is to use as much of the stormwater as possible, it may be appropriate to over-irrigate, as long as the plants are not damaged. This would be similar to the discharge of the stormwater to a biofilter or rain garden, where the water application is in great over-abundance to that which is required for just maintaining the plants. Therefore, an upper limit to the use of stormwater should be determined for a site. Two major restrictions on over-irrigating include damage to the plant and damage to the groundwater resources. Plants can be selected that can safely withstand the over-irrigation if that is the main objective. Groundwater issues are more complex and are site specific.

Groundwater mounding occurs under infiltrating areas and can affect local groundwater movement and interfere with the infiltration device if the mound interacts with the saturated area beneath an infiltration area. During irrigation of stormwater over an extended area, mounding is not likely to be a significant issue. However, some effects on the local groundwater movement may still occur. If the local groundwater is already contaminated, increases in infiltrating water can speed up the movement of that water, moving it towards other areas needing protection. A more serious issue is usually associated with infiltrating stormwater that is contaminated and the effects that water may have on underlying better quality waters.

The potential for infiltrating stormwaters to contaminate groundwaters is dependent on the concentrations of the contaminants in the infiltrating stormwater and how effective those contaminants may travel thru the soils and vadose zone to the groundwater. Source stormwaters from residential areas are not likely to be contaminated with compounds having significant groundwater contaminating potential (with the exception of high salinity snowmelt waters). In contrast, commercial, industrial, and some institutional areas are likely to have greater concentrations of contaminants of concern that may affect the groundwater adversely. Therefore, pretreatment of the stormwater before infiltration may be necessary, or treatment media can be used in a biofilter, or as a soil amendment, to hinder the migration of the stormwater contaminants of concern to the groundwater.

Pitt, *et al.* (Pitt, R., S.E. Clark, and R. Field. “Groundwater contamination potential from infiltration of urban stormwater runoff.” ASCE/EWRI Technical Committee Report Effects of Urbanization on Groundwater: An Engineering Case-Based Approach for Sustainable Development. Edited by: Ni-Bin Chang. ASCE Press, Reston, VA. 400 pages. ISBN: 978-0-7844-1078-3. 2010) summarized prior research on potential groundwater contamination. The following table can be used for initial estimates of contamination potential of stormwater affecting groundwaters. This table includes likely worst case mobility conditions using sandy soils having low organic content. If the soil has a high organic content, then most of the organic compounds would be less mobile than shown. The abundance and filterable fraction information is generally applicable for warm weather stormwater runoff. The concentrations and detection frequencies would likely be greater for critical source areas (especially vehicle service areas) and critical land uses (especially manufacturing industrial areas), with greater groundwater contamination potential.

Groundwater Contamination Potential for Stormwater Pollutants Post-Treatment.

Compound Class	**Compounds**	**Surface Infiltration thru organic soils with plants (bioretention, biofilters, rain gardens, grass swales and grass filters)***	**Surface Infiltration with sedimentation or filtration (pretreated with wet detention ponds or media filters)***	**Subsurface Injection with Minimal Pretreatment (dry wells, injection wells, and most porous pavements)**
Nutrients	Nitrates	Low/moderate	Low/moderate	Low/moderate
Pesticides	2,4-D	Low	Low	Low
	γ-BHC (lindane)	Moderate	Low	Moderate
	Atrazine	Low	Low	Low
	Chlordane	Moderate	Low	Moderate
	Diazinon	Low	Low	Low
Other organics	VOCs	Low	Low	Low
	1,3-dichlorobenzene	Low	Low	**High**
	Benzo(a) anthracene	Moderate	Low	Moderate
	Bis (2-ethyl-hexyl) phthalate	Moderate	Low?	Moderate
	Fluoranthene	Moderate	Moderate	**High**
	Naphthalene	Low	Low	Low
	Phenanthrene	Moderate	Low	Moderate
	Pyrene	Moderate	Moderate	**High**
Pathogens	Enteroviruses	**High**	**High**	**High**
	Shigella	Low/moderate	Low/moderate	**High**
	P. aeruginosa	Low/moderate	Low/moderate	**High**
	Protozoa	Low	Low	**High**
Heavy metals	Cadmium	Low	Low	Low
	Chromium	Low/moderate	Low	Moderate
	Lead	Low	Low	Moderate
	Zinc	Low	Low	**High**
Salts	Chloride	**High**	**High**	**High**

NOTE: Overall contamination potential (the combination of the subfactors of mobility, abundance, and filterable fraction) is the critical influencing factor in determining whether to use infiltration at a site. The ranking of these three subfactors in assessing contamination potential depends of the type of treatment planned, if any, prior to infiltration.

* Even for those compounds with low contamination potential from surface infiltration, the depth to the groundwater must be considered if it is shallow (1 m or less in a sandy soil). Infiltration may be appropriate in an area with a shallow groundwater table if maintenance is sufficiently frequent to replace contaminated vadose zone soils.

Modified from Pitt, *et al.* 1994

Therefore, groundwater contamination potential of infiltrating stormwater can be reduced by:

1) careful placement of the infiltrating devices and selection of the source waters. Most residential stormwater is not highly contaminated with the problematic contaminants, except for chlorides associated with snowmelt. Institutional stormwater varies greatly depending on source area (roof runoff, parking lot runoff, landscaped areas).

2) commercial, industrial, and some institutional area stormwater would likely need pretreatment to reduce the potential of groundwater contamination associated with stormwater. The use of specialized media in the biofilter, or external pre-treatment may be appropriate in these other areas.

Retrofitting and Availability of Land

Most of the control options for retrofitting in existing urban areas having combined sewers have to be carefully selected to best fit the areas. Their increased costs and minimal availability of land will be detrimental in developing highly effective control programs. The selection and construction of stormwater controls at the time of development is usually much more cost effective and can provide a higher level of control. However, many controls can be retro-fitted into existing areas. Practices that can usually be easily retrofitted get the most attention in stormwater management program in existing areas. The following lists various stormwater controls and their ability to be retrofitted in existing areas, and the land requirements:

Controls	**Ability to Retrofit**	**Land Requirements**
Roof Runoff Controls		
Rain Gardens	Easy in areas having landscaping	Part of landscaping area
Disconnections	Only suitable if adjacent pervious area is adequate (mild slope and long travel path)	Part of landscaping area
Rain Barrels and Water Tanks	Easy, located close to building, or underground large tanks	Supplements landscaping irrigation, no land requirements
Pavement Controls		
Disconnections	Only suitable if adjacent pervious area is adequate (mild slope and long travel path)	Most large paved areas are not adjacent to suitable large turf areas, except for schools; no additional land requirements, but land is needed.
Biofiltration	Easy if can rebuild parking lot islands as bioinfiltration areas; perimeter areas also possible (especially good if existing stormwater drainage system can be used to easily collect overflows)	Part of landscaped islands in parking areas, or along parking area perimeters
Porous Pavement	Very difficult as a retrofit, as must replace complete pavement system; possible if during re-building effort	Uses parking area, no additional land needed
Street Side Drainage Controls		
Grass Swales	Very difficult to retrofit. Suitable if existing swales are to be rebuilt.	Part of street right-of-way, but a problem fitting in ultra-urban areas

Curb-cut Biofilters	Difficult to retrofit, but much easier than simple swales. Usually built to work with existing drainage system. Can do extensions into parking lanes/shoulders to increase areas.	Part of street right-of-way, but can be major nuisance during construction and may consume street side parking. Can be used to rebuild street edge and improve aesthetics.
Public Works Practices		
Street Cleaning	Very easy, but most effective in areas having smooth streets. If in areas of extensive parking, parking restrictions on days of street cleaning may be needed. Limited effectiveness (no hydraulic or hydrology benefits).	None
Catchbasin Cleaning	Very easy, but requires sumps in catchbasin inlets and hooded outlets for most effective performance. Existing inlets can be replaced with suitable catchbasins. Limited effectiveness (no hydraulic or hydrology benefits).	None
Outfall Controls		
Wet Detention Ponds	Usually difficult as land not usually readily available. Can retrofit existing dry detention ponds. Significant pollutant reductions. No runoff volume benefits.	Land needed at outfall location, or retrofit existing stormwater control located at outfall location.

The range of difficulties and land requirements varies, mostly depending on available opportunities. In some communities, extensive retro-fitting is occurring including installation of curb-cut biofilters. These can also be installed during scheduled repaving and sidewalk repairs that usually occur in many areas every few decades. Rain gardens are usually installed by the home owners with no cost to the city. Many areas have organized efforts encouraging these, for example. The public works practices usually get the most attention, especially street cleaning, as it can be used with no change to the land. Redevelopment and new construction periods are the most suitable times for installation for many of these controls in order to have the least interferences with current residents and for the least costs.

Maintenance Issues and Costs

As noted, these stormwater controls have varied attributes as far as ease of retrofitting and land requirements. In addition, they also vary in their maintenance requirements and costs. The public works practices (street and catchbasin cleaning) are basically maintenance operations by themselves, while other practices are intended to go for extended periods with minimal maintenance. Practices like porous pavement require frequent maintenance to preserve their function and if clogged, would be extremely difficult to repair. Sizing of many practices are to minimize maintenance issues, usually by particulate clogging.

The total cost includes capital (construction and land) and annual operation and maintenance costs. Capital costs occur when the stormwater control component is installed, unless retrofits or up-sizing occurs at a later time. Capital costs also include added financing costs that are amortized over the life of the project. The operation and maintenance costs occur periodically throughout the life of the stormwater control device or practice. Capital cost consists primarily of land cost, construction cost, and related site work. Capital costs include all land, labor, equipment and materials costs, excavation and grading, control structure, erosion control, landscaping, and appurtenances. It also includes expenditures for professional/technical services that are necessary to support the construction of the stormwater control device. Capital costs depend on site conditions, size of drainage area and land costs that vary greatly from site to site.

Land costs are site specific and also depend on the surrounding land use. The land requirements vary depending on type of stormwater control, as shown in the following table. These values are the approximate areas needed for each of the listed controls, in relation to the impervious area in the watershed. As an example, wet detention ponds are normally sized to be about 2 to 3% of the total impervious area in the watershed, while grass filter strips need to be about the same size as the total impervious areas draining towards them.

Relative Land Consumption of Stormwater Controls (US EPA, 1999)

Stormwater Control Type	Land Consumption (% of Impervious Area of the Watershed)
Wet Detention Ponds	2 to 3%
Constructed Wetland	3 to 5%
Infiltration Trench	2 to 3%
Infiltration Basin	2 to 3%
Permeable Pavement	0%
Sand Filters	0 to 3%
Bioretention	5%
Swales	10 to 20%
Filter Strips	100%

Experimental Design

All sampling plans attempt to obtain certain information (usually average values, totals, ranges, etc.) of a large population by sampling and analyzing a much smaller sample. The first step in this process is to select the sampling plan and then to determine the appropriate number of samples needed. Many sampling plans have been well described in the environmental literature (Gilbert 1987). Stratified random sampling will be the basic sampling used for this monitoring project. This is the most appropriate sampling strategy for most stormwater studies, especially if combined with an initial limited field effort as part of a multistage sampling effort. The goal is to define strata that results in little variation within any one strata, and great variation between different strata. Samples are randomly obtained from several population groups that are assumed to be internally more homogeneous than the population as a whole, specifically by separating an annual sampling effort by season and or rain depth. This results in the individual groups usually having smaller variations in the characteristics of interest than in the population as a whole. Therefore, sample efforts within each group will vary, depending on the variability of characteristics for each group, and the total sum of the sampling effort may be less than if the complete population was sampled as a whole. In addition, much additional useful information is likely if the groups are shown to actually be different.

Box, *et al*. (1978) contains much information concerning sampling strategies, specifically addressing problems associated with randomizing the experiments and blocking the sampling experiments. Blocking (such as in paired analyses to determine the effectiveness of a control device) eliminates unwanted sources of variability. Another way of blocking is to conduct repeated analyses (such for different seasons) at the same locations. Most of these probability sampling strategies should include randomization and blocking within the final sampling plans.

Number of Samples Needed to Characterize Conditions

An important aspect of any monitoring effort is the assurance that the samples collected represent the conditions to be tested and that the number of samples to be collected are sufficient to provide statistically relevant conclusions. Unfortunately, sample numbers are most often not based on a statistically-based process and follow traditional "best professional judgments," or are resource driven. The sample numbers should be equal between sampling locations if comparing station data (EPA 1983) and paired sampling should be conducted, if at all possible (the samples at the two comparison sites should be collected at the "same" time, for example), allowing for much more powerful paired statistical comparison tests (see module on statistical analyses). If not possible, such as likely for the Cincinnati demonstration project sites, then unpaired sampling representing pre- and post-installation of the control devices can be used.

In addition, subsamples must also be collected and then combined to provide a single sample for analysis for many types of sampling, such as collecting discrete subsamples during a rain event. The subsamples are then combined before a single analysis (to reduce analysis expenses) or kept as separate samples (more costly, but provides a legitimate measure of variation/precision) to represent the runoff conditions.

An experimental design process can be used that estimates the number of needed samples based on the allowable error, the variance of the observations, and the degree of confidence and power needed for each parameter. A basic equation that can be used (Burton and Pitt 2001, after Cameron, undated) is as follows:

$$n = [COV(Z_{1-\alpha} + Z_{1-\beta})/(error)]^2$$

where:

n = number of samples needed

α= false positive rate (1-α is the degree of confidence. A value of α of 0.05 is usually considered statistically significant, corresponding to a 1-α degree of confidence of 0.95, or 95%.)

β= false negative rate (1-β is the power. If used, a value of β of 0.2 is common, but it is frequently ignored, corresponding to a β of 0.5.)

$Z_{1-\alpha}$ = Z score (associated with area under normal curve) corresponding to 1-α. If α is 0.05 (95% degree of confidence), then the corresponding $Z_{1-\alpha}$ score is 1.645 (from standard statistical tables).

$Z_{1-\beta}$= Z score corresponding to 1-β value. If β is 0.2 (power of 80%), then the corresponding $Z_{1-\beta}$ score is 0.85 (from standard statistical tables). However, if power is ignored and β is 0.5, then the corresponding $Z_{1-\beta}$ score is 0.

error = allowable error, as a fraction of the true value of the mean

COV = coefficient of variation (sometimes notes as CV), the standard deviation divided by the mean (Data set assumed to be normally distributed.)

This equation is only approximate for most stormwater data, as it requires that the data set be normally distributed. However, if the coefficient of variation (COV) values are low (less than about 0.4), then there is likely no significant difference in the predicted sampling effort. This equation is only appropriate as an approximation in many cases, as normal distributions are rare (log-normal distributions are appropriate for most water quality parameters) and the COV values are typically relatively large (closer to 1). The presentation of the results and the statistical procedures used to evaluate the data consider the actual degree of confidence of the measured values, but the power is based on these initial calculations based on the number of samples.

Figure 1 (Pitt and Parmer 1995) is a plot of this equation showing the approximate number of samples needed for an α of 0.05 (degree of confidence of 95%), and a β of 0.2 (power of 80%). As an example, if an allowable error of about 25% is desired and the COV is estimated to be 0.4, then about 20 samples would have to be collected and analyzed. The samples could be composited and a single analysis conducted, but this would not allow the COV assumption to be confirmed, or the actual confidence range of the concentration to be determined. The use of stratified random sampling can usually be used to advantage by significantly reducing the COV of the sub-population in the strata, requiring fewer samples for characterization, as noted previously.

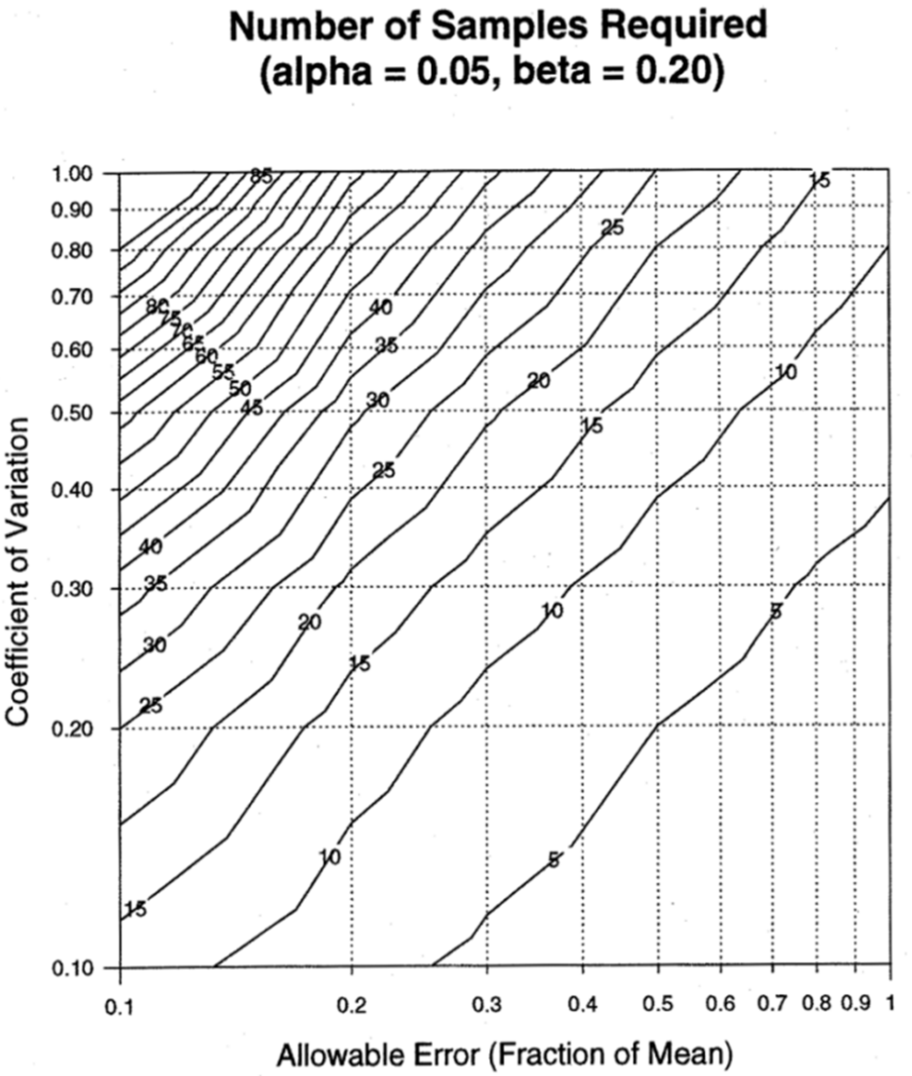


Figure 1. Sample Requirements for Confidence of 95% (α= 0.05) and Power of 80% (β= 0.20) (Pitt and Parmer 1995).

Gilbert (1987) presents variations of this basic equation that considers determining the number of samples needed to determine the probability of occurrence within a specified range (such as to calculate the frequency of standard violations). He also presents equations that consider correlated data, such as when the observations are not truly independent, as when very high pollutant concentrations affect values in close spatial or temporal proximity. As expected, correlated data results in needing more samples than indicated from the basic equations.

Types of Errors Associated with Sampling

Unfortunately, there are many errors associated with monitoring stormwater quality and quantity. Errors associated with too few (or too many) samples for a parameter of interest is only one category. Sampling and analytical errors may also be significant and would add to these other errors. Hopefully, the collective sum of all errors is known (through QA/QC activities and adequate experimental design) and manageable. An important aspect of a monitoring program is recognizing the levels of errors and considering the resulting uncertainties in developing recommendations and conclusions.

Generally, errors can be divided into precision and bias problems. Both of these errors, either together or separately, have dramatic effects on the final conclusions of a study. Bias is a measure of how close the measured median value is to the true median value, while precision is a measure of how "fuzzy" the median estimate is (the repeatability of the analyses and is used to determine the confidence of the measurements).

Errors in decision making are usually divided into type 1 (α: alpha) and type 2 (β: beta) errors:

> α (alpha) (type 1 error) - a false positive, or assuming something is true when it is actually false. An example would be concluding that a tested water was adversely contaminated, when it actually was clean. The most common value of α is 0.05 (accepting a 5% risk of having a type 1 error), although other values may be appropriate for specific project objectives and stages. Confidence is 1-α, or the confidence of not having a false positive.
>
> β (beta) (type 2 error) - a false negative, or assuming something is false when it is actually true. An example would be concluding that a tested water was clean when it actually was contaminated. If this was an effluent, it would therefore be an illegal discharge with the possible imposition of severe penalties from the regulatory agency. In most statistical tests, β is usually not directly considered (if ignored, β is 0.5), but is assumed to be considered during the experimental design phase with adequate samples collected to control the false negative rate. A typical value of β is 0.2, implying accepting a 20% risk of having a type 2 error. Power is 1-β, or the certainty of not having a false negative. Again, other levels of power may be appropriate for the specific project objectives.

It is important that power and confidence be balanced for an effective monitoring program. Most experimental designs ignore power, while providing a high value (typically 95%) for the level of confidence. This is an unrealistic approach as both false negatives and false positives are important. In many environmental programs, power (false negative problems) may actually be more critical than confidence. If a tested water had a type 2 error (false negative), inappropriate discharges would occur. Typical fines imposed by regulatory agencies are $10,000 per day for non-permitted discharges. Future liability for discharges of waste that were discharged due to an error in measurement or negligence can easily reach into millions of dollars for clean up and health effects. Clearly, one wants to minimize costs, yet have the assurance that the correct decision is being made. However, errors will always be present in any analysis, and some uncertainty in the conclusions must be accepted. Obviously, it can become prohibitively expensive to attempt to reduce monitoring errors to extremely low levels, especially when the monitoring program is affected by uncontrollable environmental factors.

Number of Samples Needed for Comparisons between Different Sites or Times

If a comparison of paired data sets is possible when measuring the benefits of the Cincinnati demonstration project control devices (such as influent and effluent samples collected simultaneously at a control device installation), then another statistical design approach is possible. A related equation to the one given previously can be used to estimate the needed samples for a paired comparison (Burton and Pitt 2002, after Cameron, undated):

$$n = 2 [(Z_{1-\alpha} + Z_{1-\beta})/(\mu_1 - \mu_2)]^2 \sigma^2$$

where α = false positive rate (1-α is the degree of confidence. A value of α of 0.05 is usually considered statistically significant, corresponding to a 1-α degree of confidence of 0.95, or 95%)

β = false negative rate (1-β is the power. If used, a value of β of 0.2 is common, but it is frequently ignored, corresponding to a β of 0.5.)

$Z_{1-\alpha}$ = Z score (associated with area under normal curve) corresponding to 1-α

$Z_{1-\beta}$ = Z score corresponding to 1-β value

μ_1 = mean of data set one

μ_2 = mean of data set two

σ = standard deviation (same for both data sets, same units as μ. Both data sets are also assumed to be normally distributed.)

This equation is also only approximate, as it requires that the two data sets be normally distributed and have the same standard deviations. As noted previously, most stormwater parameters of interest are likely closer to being log-normally distributed. Again, if the coefficient of variation (COV) values are low (less than about 0.4), then there is probably no real difference in the predicted sampling effort.

Figure 2 (Pitt and Parmer 1995) is a plot of this equation (normalized using COV and differences of sample means) showing the approximate number of sample pairs needed for an α of 0.05 (degree of confidence of 95%), and a β of 0.2 (power of 80%). As an example, twelve sample pairs will be sufficient to detect significant differences (with at least a 50% difference in the parameter value) for two locations, if the coefficient of variations are no more than about 0.5. Burton and Pitt 2001 contains similar plots for many combinations of other levels of power, confidence and expected differences.

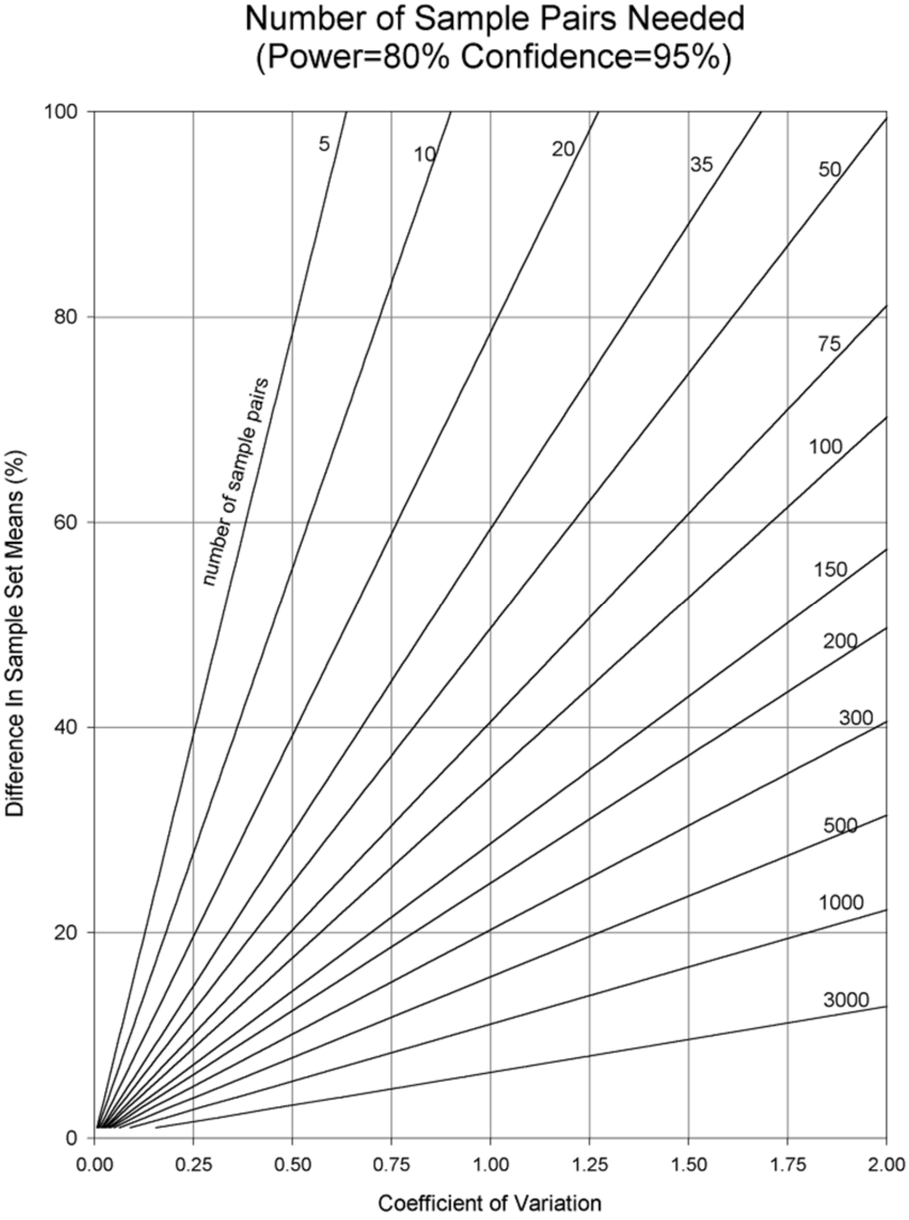


Figure 2. Sample Effort Needed for Paired Testing (Power of 80% and Confidence of 95%) (Pitt and Parmer 1995).

Project Sampling Description

The monitoring plan for Cincinnati will contain methods to determine the needed sampling effort, including the number of samples for the three monitoring areas. These procedures can be utilized for many different conditions and situations, but some prior knowledge of the conditions to be monitored is needed. A phased sampling approach is therefore recommended, allowing some information to be initially collected and used to make preliminary estimates of the sampling effort. Later sampling phases are then utilized to obtain the total amount of data expected to be needed.

Three types of sampling objectives exist for the Cincinnati demonstration projects. The following comments pertain to specific experimental design elements for these activities:

1) small scale monitoring to measure the benefits of infiltration devices. Several pairs of monitoring stations will be established to determine the direct benefits of infiltration devices (land use scale biofiltration devices in parking lots, along streets, institutional rain gardens, etc.). These will all be paired analyses with concurrent influent and effluent monitoring of flows and pollutants. Stratified random sampling will be used to separate the data into groups corresponding to different rain depths per season. Initial modeling of the area will be conducted to identify rain categories for the stratifications, but prior experience suggests the following rain depth strata: <0.5, 0.5 to 3, >3 inches. In addition, seasonal variations (relating to soil moisture and other antecedent period factors) will also be examined for appropriate strata. The desired number of events in each strata will depend on the expected variability of the factors being monitored, and the data quality objectives. Most stormwater constituent coefficients of variation range from about 0.5 to 1. If performance levels (treatment benefits) defined by percentage reductions of about 25% are desired to be statistically identified, with confidence levels of 0.95 and power of 0.8, then about 75 pairs of samples may be needed. With a multi-year project, about 30 plus events per year should be targeted for evaluation. Flows are relatively inexpensive to monitor, after the equipment is installed, so data should be collected for almost every rain event. Water quality evaluations are secondary for this project, so less demanding data quality objectives may be warranted. If 50% differences to be detected are a suitable goal, then about 25 pairs of samples will be needed. When the data are obtained, it will be separated into the different seasonal and rain depth strata for comparison tests. In the past, this approach has resulted in more complete understandings of device performance and better quality data than simply lumping all together. Of course, many more small events will be available for monitoring than the large category, so this initial plan may not be feasible, depending on the actual rains during the monitoring period.

2) large scale watershed monitoring to confirm benefits of multiple green infrastructure controls throughout the drainage areas. Monitoring stations will be located at the discharge of the large areas to quantify these benefits in combined sewage flows from the complete site. A control monitoring station is not likely to be available, as the land use areas being monitored are unique (only one zoo!). Therefore, pre- and post-installation monitoring will be compared, with independent (not paired) analyses. Flow (along with concurrent rainfall) is the primary parameter for monitoring at these locations and data should be collected for every event that occurs during the monitoring period. Large scale monitoring is much more challenging than small scale monitoring, as the benefits of the devices in the drainage area will have less of a benefit that the individual monitoring described above. It is expected that many small-scale controls will be installed throughout each area, with most of the runoff subjected to controls. With about 25 events each year that may produce measureable increased flows in the combined sewers, data from all of these events during the monitoring program may result in about 50 total events. With a larger COV expected (about 1.0), differences between the pre- and post-installation monitoring periods of about 60%, or larger, should be reliably detected.

3) monitoring to calibrate stormwater models. The three institutional land uses will have biofiltration devices installed along with some site beneficial uses, to reduce stormwater discharges to the combined sewers. The influent data from the monitored devices can be used to calibrate the stormwater models. In addition, the large watershed (pre- and post-installation periods) data can be used to verify the

calibration at a larger scale. Additional monitoring information for other commonly occurring land uses in the region will be needed to expand the model calibration for the whole city, as the data collected during this monitoring project only represents institutional land uses. These other data may be available from MS4 stormwater permit monitoring programs. Otherwise, it may be necessary to establish semi-permanent monitoring equipment at other areas. In order to obtain the necessary calibration information, data from at least 15 events for each area has been shown to usually be sufficient. Flow and rainfall data is the most critical need, along with detailed site descriptions.

Summary of Sampling and Monitoring Needs

The following is a summary of the expected amount of data to be collected as part of the monitoring programs in the three test areas:

Large-scale flow monitoring

Three study areas, each having at least one, and possibly up to five flow monitoring stations in the combined sewers downgradient (but close) to the test areas. About 25 events per year at each station, for one year of pre-installation and two years of post-installation monitoring is assumed. With three flow monitoring stations per site, then: Three study areas X three flow monitoring stations X 25 events per year X three years = 675 events for data collection. Each event may have about 12 hours of flow to be recorded, with data recorded every 5 minutes; with 144 flow data observations per event (double for about 3 rain gages at each study area for the precipitation data also). These data will need to be both graphically plotted and summarized per event, in addition to having the high-resolution data available for calibration of some models. No water sampling or water quality analyses are anticipated at the large-scale combined sewer locations.

Tables 1 and 2 are examples of these event-by-event summaries needed. The total combined flows will be compared initially. The full time series of flows will be examined by plotting the observed flows from the areas (normalized by area, showing cfs/acre). Statistical analyses will examine the differences to quantify infiltration and inflows for the pre- and post-installation conditions. Rain data will also be plotted on these time series.

In addition to these data collection efforts, detailed land development/characterization information will also be needed, along with disturbed soil characterization in the test areas. Appendices A and B are draft descriptions of these site and soil characterization methods.

Table 1. Example Observed Rainfall and Runoff Conditions (Hypothetical values shown)

site	area (acres)	event #	rain start date	rain start time	rain end data	rain end time	total rain (in) (1)	5-minute peak rain intensity (in/hr) (1)	pipeflow start date	pipeflow start time	pipeflow end data	pipeflow end time	total pipeflow discharge volume (ft^3) (2)	peak pipeflow discharge rate (cfs) (2)
Test Watershed	100	1	9/4/2009	10:30	9/5/2009	2:45	0.4	0.48	9/4/2009	10:30	9/5/2009	6:00	51050	7.51
Test Watershed	100	2	9/8/2009	16:00	9/9/2009	17:30	0.32	0.48	9/8/2009	16:30	9/10/2009	9:30	54665	4.1
Test Watershed	100	3	9/21/2009	10:00	9/22/2009	14:45	0.77	0.48	9/21/2009	10:15	9/23/2009	1:30	113380	5.25
Test Watershed	100	4	9/26/2009	0:30	9/26/2009	4:30	0.4	0.36	9/26/2009	0:45	9/27/2009	0:00	56550	8.94
Test Watershed	100	5	9/30/2009	16:15	10/1/2009	11:15	0.14	0.24	10/1/2009	5:00	10/1/2009	8:00	5586	1.04
Test Watershed	100	6	10/6/2009	2:15	10/9/2009	5:30	2.09	1.56	10/8/2009	2:30	10/11/2009	4:15	320319	16.77
Test Watershed	100	7	10/11/2009	23:30	10/15/2009	0:15	0.48	0.36	10/11/2009	23:30	10/15/2009	10:15	102782	6.02
Test Watershed	100	8	10/20/2009	5:30	10/22/2009	15:00	1.32	1.32	10/20/2009	5:45	10/25/2009	13:00	327772	11.57
Test Watershed	100	9	10/25/2009	14:00	10/27/2009	13:00	0.73	0.48	10/25/2009	14:00	10/29/2009	5:00	230809	12.67

Notes: 1) the rainfall data are obtained from a rain gauge at the site location; 2) the discharge volumes and flow rates have dry weather base flow value subtracted

Table 2. Example Calculated Rainfall and Runoff Conditions (based on observed conditions)

site	event #	rain start date	antecedent dry days	rain dur (hrs)	pipeflow duration (hrs)	avg rain int (in/hr)	total discharge (in)	Rv	pipeflow/rain duration ratio	peak/avg pipeflow rate ratio
Test Watershed	1	9/4/2009	n/a	16.25	19.5	0.024	0.14	0.35	1.2	10.46
Test Watershed	2	9/8/2009	3.55	25.5	41	0.0125	0.15	0.47	1.61	11
Test Watershed	3	9/21/2009	11.68	28.75	39.25	0.027	0.31	0.40	1.36	6.6
Test Watershed	4	9/26/2009	3.4	4	23.25	0.1	0.15	0.375	5.81	13.5
Test Watershed	5	9/30/2009	4.5	19	3	0.007	0.015	0.1	0.16	2.18
Test Watershed	6	10/6/2009	4.6	75.25	73.75	0.028	0.88	0.42	0.98	14.2
Test Watershed	7	10/11/2009	2.75	72.75	82.75	0.006	0.28	0.58	1.13	17.7
Test Watershed	8	10/20/2009	5.22	57.5	127.25	0.023	0.9	0.68	2.21	16.23
Test Watershed	9	10/25/2009	2.96	47	87	0.015	0.63	0.86	0.85	17.24

Small-scale flow monitoring

Numerous individual control practices will be monitored during this demonstration project. These will include small to large biofilters of differing designs, along with porous pavements, and beneficial use installations. As described previously, each type of device will require specialized monitoring locations and methods. In general, there are 2 to 4 monitoring locations per device (influent, overflow/effluent, underdrain, and subsurface percolating water). Each of these locations will require flow monitoring, and water sampling and analysis. If there are six devices for each of the three areas, three monitoring locations per device, and 30 events per device (spread over two years), a total of about 1600 samples will be collected representing about 500 separate events. Flow monitoring (and associated rainfall) are the priority analyses. Chemical analyses will be on flow-weighted composite samples (one per event per sampling location), although continuous water quality sondes can be very useful to supplement these data. Few constituents will be analyzed for each sample (TSS, turbidity will be most common, with particle size analyses on fewer samples, and bacteria (*E. coli* and enterococci), nutrients and copper and zinc on fewer samples). It may be possible to rotate sampling and monitoring equipment amongst the sampling locations. There would be about 54 separate sampling locations, and it may be possible to have about half that number of sampling and flow monitoring equipment, with the goal of about 30 events spread out over two years.

Sampling and Monitoring Equipment

Flow monitoring is critical for this project and accurate inflow and overflow rates will need to be continuously measured. Because of the closeness of the inlets to small bioretention devices, there may be insufficient distances to install many types of throated flow monitoring flumes at all locations. However, it is likely that small H flumes (available from Global Water at: http://www.globalw.com/products/h_flume.html) could be used for the small installations. The 0.50H flume requires an approach channel length of 2.5 ft. It is 0.95 ft wide and 0.675 ft tall. The flow range for this flume is 0.0004 to 0.35 cfs. For a drainage area of about 1 acre, this size flume can be used to monitor flows during rains having peak intensities of at least 1 inch per hour, while they can also measure flows during small rains down to 0.1 inches total, or less. This size flume can be located in a slightly modified inflow area to biofilters. The H flume must be installed level, with the approach length. The total length of the approach and H flume would be about 3 or 4 ft. A stilling well and level recorder will also be needed for the influent H flume, and one will also be needed in a standpipe in the biofilter to record the water depth. Overflow/bypass water volumes would be estimated from the rain garden/biofilter ponded water depth. This level will indicate when the flume is flooded and water is bypassing the entrance to the device. The effluent from the H flume can be directed into a forebay. The water sampler intake should also be located where the cascading water from the H flume can fall onto the inlet, in the forebay.

ISCO water quality sampler (Teledyne Isco, Inc., Lincoln, NE) initiated by a rain gauge (Rainwise Inc, Bar Harbor, ME; Model RainWise Rainew^{TM} Wireless Rain Gauge with data acquisition, precision 1/100") or an ISCO sonic flow meter (Teledyne Isco, Inc., Lincoln, NE Model 2150 flow meter, range 0.033-10 ft; accuracy +/- 0.01 ft, for area; range -5 to +20 ft/sec, accuracy =/- 2%, for velocity). The ISCOs, when initiated, will take discrete samples on a determined time interval or as flow weighted samples.

Appendix A: Land Development Characterization in Test Areas

Introduction

Correct knowledge of local development characteristics helps improve the accuracy of stormwater quality and quantity modeling. Development characteristics of interest include impervious cover types and quantities, landscaping, roofing materials, areas of different surfaces, drainage system information, etc. Different surfaces in urban areas contribute flows and pollutants differently from other types of surfaces. As an example, pitched roofs are much more efficient in producing runoff than flat roofs. Treated wood, galvanized metals, and other coverings, all affect the concentrations of heavy metals from roofs. Similar differences exist for other types of urban surfaces. Obviously, the magnitude of "impervious" surfaces in each land use in an area has a large effect on runoff production. The ways these surfaces are connected to the drainage system also affects the amount of runoff produced. In addition, the types and extent of disturbed urban soils all affect runoff quality and quantity. It is therefore necessary to survey an area to determine these development characteristics in order to produce the most accurate runoff quality and quantity predictions, and to identify opportunities for retro-fitting stormwater management practices in existing areas. The data from these surveys can also be used to help identify public education programs and to identify changes in future development that can decrease runoff problems.

The first step in this process is to collect available land use information for the areas of study. Local planning agencies have very distinct land use descriptions and these categories should be the basis for the stormwater quality modeling. In some cases, these land use descriptions may be further subdivided, depending on age of development, etc. Aerial photographs of the study area are also needed in order to identify how the land use categories are located throughout the area, and to enable major differences in the main land use categories to be identified (amounts of mature vegetation, etc.). In major cities, from 10 to 20 land use categories and subcategories are usually sufficient to represent the range of conditions encountered. About 10 to 15 example homogeneous neighborhoods are selected in each of these categories for the site surveys. Each homogeneous area is relatively small, such as a single block area, a single school or church, a mall, a cemetery, a park, or up to about 5 or 10 acres of other areas. In the institutional areas being studied during this Cincinnati project, the complete areas need to be characterized using the methods described in this appendix. Additional information pertaining to other land uses is also provided, as those data are needed to extrapolate the test area results throughout the region. The selected homogeneous subareas/neighborhoods are then surveyed by visiting the areas and filling out a form containing basic site information, supplemented by photographs. Surfaces in each of the selected neighborhoods are also carefully measured using aerial photographs to determine the areas associated with the different surfaces. Relatively high resolution aerial photographs are of most use for this phase. Automatic image processing can be used for part of these analyses, but manual measurements are also usually needed. The following discussion describes these survey steps, after a description of typical land use categories.

Land Use Categories used during the Field Inventory Effort

A stormwater/watershed study should use the locally available land use data and definitions usually defined by the local planning agency. This section briefly describes the land use descriptions according to the documentation supplied with WinSLAMM (Pitt and Voorhees 2002), based on land use surveys mostly conducted in Wisconsin. Again, these definitions would need to be adjusted according to local planning agency definitions and available data, and may need to be further subdivided. As an example, it is common to subdivide the low and medium density residential areas according to when they were constructed, as major shifts in development characteristics have occurred over the years, and these areas usually make up the majority of the land uses in a community. During this inventory effort, all land covers are considered in each land use. These usually include streets, building roofs, parking lots, walkways, landscaped areas, undeveloped parcels, etc. Some planning agencies separate the streets from the land uses and consider these surfaces as part of a larger transportation land use. If that is the case, the areas need to be adjusted to include these surfaces as an integral part of each of the land uses.

Residential Land Uses

High Density Residential: Urban single family housing having a density greater than 6 units/acre. This land use includes the homes (roofs), driveways, yards, sidewalks, and streets, in addition to some minor surfaces.

Medium Density Residential*:* Urban single family housing at a density of 2 to 6 units/acre. The same as above, the homes, driveways, yards, sidewalks and streets adjacent to the house are included as the main surfaces.

Low Density Residential: Similar to the previous residential areas, except having a density of 0.7 to 2 units/acre.

Duplexes: Connected housing of two family units being 1 to 3 stories in height. Units may be adjoined up-and-down, side-by-side or front-and-rear. This land use includes the streets, buildings, yards, parking lots, and driveways as the main surfaces.

Multiple Families: Like duplexes, but housing containing three or more family units that are 1 to 3 stories in height.

Apartments: Multiple family units of 4 or more stories in height.

Trailer Parks: A mobile home or trailer park that includes all vehicle homes, yards, driveways, streets, walkways, and office area.

Medium Density Residential Area (no alleys)

Older Medium Density Residential Area (no alleys, but with more mature trees)

High Density Residential Area (no alleys)

High Rise Apartments

Example aerial photographs of different residential area categories (Pitt and McLean 1986).


Multi-family residential areas. Impervious areas (pitched roofs and parking areas) are all directly connected.
Small amounts of landscaped areas are also present.


Older medium density residential area.


Newer medium density residential area.

Commercial Land Uses

Strip Commercial: Includes buildings for which the primary function is the sale of goods or services. Some institutional land use such as post offices, fire and police stations, and court houses are also included in this category. The strip commercial land use includes the buildings, parking lots, and streets. This category does not include buildings used for the manufacturing of goods or warehouses, nurseries, tree farms, or lumber yards.

Shopping Centers: These are commercial areas where the related parking lot is at least 2.5 times the building roof area. The buildings in this category are usually surrounded by parking areas. This land use includes the buildings, parking areas, and the streets, plus any landscaping. This area also includes large regional shopping malls.

Office Parks: This is a land use containing non-retail businesses. The buildings are usually multi-story buildings surrounded by larger areas of lawn and other landscaping. This land use includes the buildings, the lawn, parking areas, and streets. The types of businesses found in this category may include: insurance offices, government buildings, company headquarters, etc.

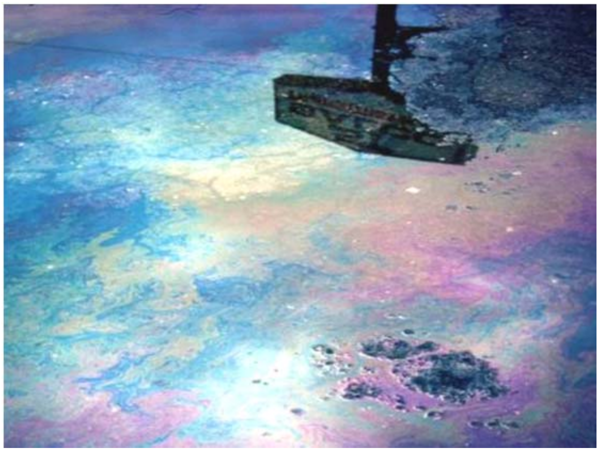
Downtown Central Business District: Highly impervious downtown areas of commercial and institutional land use. This land use also includes the buildings, parking areas, streets, but with minimal landscaping.

Example aerial photograph of strip commercial area surrounded by older high density residential area (Pitt and McLean 1986).

Paved parking area with frequent automobile movement

Contamination of paved parking areas due to commercial activities

Contamination of paved parking area due to inappropriate waste disposal



Parking area at automobile service area

Typical problem areas in commercial areas that should be documented during the field survey.

Typical strip commercial areas

Commercial shopping mall

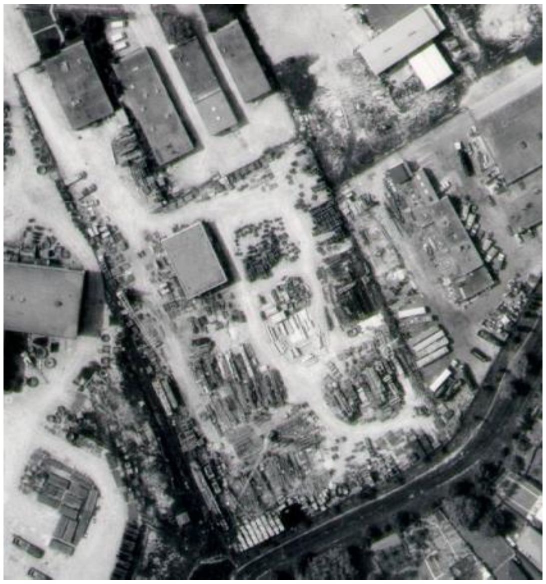
Industrial Land Uses

Manufacturing (Heavy) Industrial: Those buildings and premises which are devoted to the manufacture of products, with many of the operations conducted outside, such as power plants, steel mills, and cement plants.

Medium Industrial: This category includes businesses such as lumber yards, auto salvage yards, junk yards, grain elevators, agricultural coops, oil tank farms, coal and salt storage areas, slaughter houses, and areas for bulk storage of fertilizers. Municipal public works yards are also included in this category.

Non-Manufacturing (Light) Industrial: Those buildings which are used for the storage and/or distribution of goods awaiting further processing or sale to retailers. This category mostly includes warehouses and wholesalers where all operations are conducted indoors, but with truck loading and transfer operations conducted outside.


Non-manufacturing, light industrial area - warehousing


Medium industry - scrap yard/storage area

Example aerial photographs of industrial areas (Pitt and McLean 1986).


Contaminated paved storage area at vehicle junk yard


Contaminated unpaved storage area


Very large-scale metal recycling operation on unpaved surface


Heavy equipment storage area on concrete surface

Activities in industrial areas that contribute to stormwater pollutants that should be documented during field surveys.

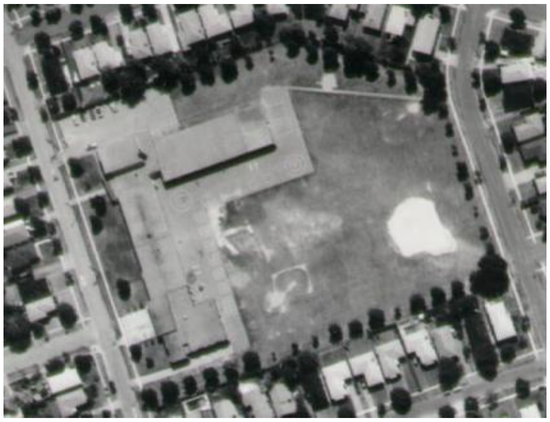
Light and medium industrial land use activities.

Institutional Land Uses

Hospitals: Medical facilities that provide patient overnight care. Includes nursing homes, state, county, or private facilities. This land use includes the buildings, grounds, parking lots, and driveways as the main surfaces.

Education (Schools): Includes any public or private primary, secondary, or college educational institutional grounds. The land use consists of the buildings, playgrounds, athletic fields, roads, parking lots, and lawn areas.

Miscellaneous Institutional: Churches and large areas of institutional property not part of strip commercial and downtown areas.


Example aerial photograph of educational land use area (Pitt and McLean 1986).



School



Church

Open Space Land Uses

Cemeteries: Includes cemetery grounds, roads, and buildings located on the grounds.

Parks: Outdoor recreational areas including municipal playgrounds, botanical gardens and arboretums, golf courses, and natural areas.

Undeveloped: Lands that are private or publicly owned with no structures and have an almost complete vegetative cover. This includes vacant lots, transformer stations, radio and TV transmission areas, water towers, and railroad rights-of-way.

Example aerial photograph of open space land use area, a cemetery (Pitt and McLean 1986).

Freeway Land Uses

Freeways: These are limited access highways and the interchange areas, including any vegetated rights-of-ways.

Example aerial photograph of freeway land use area (Pitt and McLean 1986).

Suburban freeway with large shoulders and grass swales
at median

Urban freeway with minimal grass area, almost completely paved right-of-way

Depressed downtown freeway with eroding embankment

Homogeneous Neighborhood Surveys

An “Area Description” field sheet is used to record important characteristics of the homogeneous land use areas during the field surveys (Figure A-1). In addition, aerial photographs, such as from TerraServer USA http://terraservice.net/ (Figure A-2) or preferably higher resolution satellite images (Figure A-3) are used to measure the actual coverage of each type of surface in each neighborhood studied. The following discussion describes the field sheet and the information requested.

Location: Site number:
Date: Time:
Photo numbers:
<u>Land-use and industrial activity</u>:
Residential: low medium high density single family
multiple family
trailer parks
high rise apartments
Income level: low medium high
Age of development: <1960 1960-1980 1980-2000 >2000
Institutional: school church hospital other (type):
Commercial: strip shopping center/mall downtown hotel offices
Industrial: light medium heavy (manufacturing) describe:
Open space: undeveloped park golf cemetery
Other: freeway utility ROW railroad ROW other:
<u>Maintenance of building</u>: excellent moderate poor
<u>Heights of buildings</u>: 1 2 3 4+ stories
<u>Roof drains</u>: % underground % gutter % impervious % pervious
<u>Roof types</u>: flat composition shingle wood shingle metal other:
<u>Sediment source nearby</u>? No Yes (describe):
<u>Treated wood near drainage system or directly connected pavement</u>? No telephone poles fence other:
<u>Landscaping near road or directly connected impervious surfaces</u>:
Quantity: none some much
Type: deciduous evergreen lawn
Maintenance: excessive adequate poor
Leafs on street: none some much
<u>Topography</u>:
Street slope: flat (<2%) medium (2-5%) steep (>5%)
Land slope (next to street): flat (<2%) medium (2-5%) steep (>5%)
<u>Traffic speed</u>: <25mph 25-40mph >40mph
<u>Traffic density</u>: light moderate heavy
<u>Parking density</u>: none light (20 to 50%) moderate (50 to 80%) heavy (>80%)
<u>Width of street</u>: number of parking lanes:
number of driving lanes:
<u>Condition of street</u>: good fair poor
<u>Texture of street</u>: smooth intermediate rough very rough
<u>Pavement material</u>: asphalt concrete unpaved
<u>Driveways:</u> paved unpaved
Condition: good fair poor
Texture: smooth intermediate rough
<u>Gutter material</u>: grass swale lined ditch concrete asphalt
Condition: good fair poor
Street/gutter interface: smooth fair uneven
<u>Litter loadings near street</u>: clean fair dirty
<u>Parking/storage areas</u> (describe):
Condition of pavement: good fair poor
Texture of pavement: smooth intermediate rough unpaved

Directly connected to drainage: yes no

Other paved areas (such as alleys and playgrounds), describe:

Condition: good fair poor

Texture: smooth intermediate rough

Directly connected to drainage: yes no

Other notes/comments:

Figure A-1. Area description field sheet.

Figure A-2. Example of 1 m monochromatic aerial photograph (USGS photo).

Figure A-3. Example of sub meter color satellite image (Google).

Detailed Instructions for Field Inventory Sheet

- *Location*:

The block address number range and the street name are noted. A sub-area name can also be used to describe the drainage area, or portion of town. A field sheet is filled out for each homogeneous land use area being investigated in the study area. Specific blocks to be surveyed are selected based on maps and aerial photographs before the survey is conducted. Each site needs at least two photographs taken: one is a general scene and the other is a close-up showing about 25 by 40 centimeters of pavement. Additional photographs are usually taken to record unusual conditions. A photograph is also taken of the completed field sheet at the end of each neighborhood survey to separate and label the images. These photographs are very important to confirm the descriptions recorded on the data sheets and to verify the consistency of information for the different areas within each category. The photographs are also very important when additional site information is needed, but not specifically recorded on the data sheets.

- *Land-use*:

The land-use type that best describe the block is circled. The previous land use descriptions are one scheme that has been used with WinSLAMM. However, these definitions may need to be modified based on local practice and information. Also, some of the homogeneous areas may need to be re-categorized after the data is obtained. As an example, the housing density initial estimates may be incorrect for some areas and the surveyed areas may need to be moved to another category after the accurate measurements are available. If more than one land-use is present in an area being studies (would happen if conducting a survey in a monitored area), then a separate form should be used for each homogeneous land use subarea. The approximate income level for the residential areas is also circled. The specific types of industrial activities (warehouses, metal plating, bottling, electronics, gas station, etc.) for industrial and commercial areas are also noted on the form. Also, the approximate age of development is circled.

- *Roof drainage*:

The discharge location of the roof drains is also noted on the form. The approximate distribution of the discharge locations is noted if more than one location is evident. This is determined by driving around the complete area and tallying the roof drain locations. It is assumed that all backyard drains are disconnected, unless alleys are present. In that case, drive the alleys and note the back drain connections. Obviously, do not trespass to view all the drains. The “underground” location may be to storm sewers, sanitary sewers, or dry wells. Some areas have the roof drains apparently directed underground but are actually discharged to the roadside gutter or drainage ditch. If they lead to the gutter (discharge locations are usually seen along the gutter), then the “to gutter” category is circled. Additionally, if the flow path length is less than about five feet over pervious ground for a typical house, it is functionally directly connected to impervious areas, requiring circling the “to impervious” category. The roof types and building heights are also indicated (again, the approximate distributions are noted if more than one type is present in the “homogeneous” subarea). It is necessary to take an inventory of all visible roof drains in the study block by keeping tallies of each type of drain connection. The distribution of the percentage per connection type was put on the sheet. If other categories of characteristics vary in the study block (paved or unpaved driveway categories is another common variation), then these are also tallied.


A directly connected roof drain


A disconnected roof drain (drains to pervious area)


Pitched metal roof


Flat commercial roofs

- *Sediment sources*:

Sediment sources near the drainage (street, drainage way, or gutter), such as construction sites, unpaved driveways, unpaved parking areas or storage lots, or eroding vacant land, are described and photographed.

Soil erosion from landscaped areas having fine-grained soils during periods of high rain intensities

Scoured drain from paved area.

Utility work near street.

Unprotected slope.

- *Treat wood near drainage system or directly connected impervious area:*

Circle or describe any treated wood that is located near any directly connected impervious area. Most wood treatment chemicals (heavy metals or organic compounds) are effectively captured if drained to landscaped areas. If drain to pavement, much of the toxicants can directly enter the drainage system. Also describe the type of wood preservative, if possible (Copper-chromium-arsenic, CCA, creosote, etc.).

Treated wood near drainage system or directly connected impervious areas can contribute toxicants to the storm drainage system.

- *Landscaping near road or directly connected impervious surfaces:*

Describe the type of landscaping near the road and other directly connected impervious surfaces. Large amounts of trees near these surfaces can add nutrients to the stormwater. Deciduous vegetation can add large amounts of leaf litter in the fall that requires special cleanup operations to prevent clogging of the drainage system. Excessive maintenance (total absence of weeds, for example) implies an excess amount of chemical use (fertilizers, herbicides, and pesticides) that also contribute to stormwater degradation.

Wide arterial street with little roadside vegetation.

Narrow residential street with substantial adjacent vegetation (Bannerman photo).

• *Parking density:*

Vehicles parked along a street cleaning route reduce the length of curb that may be cleaned by municipal street cleaning operations. Since most of the street surface pollutants are found close to the curb on smooth streets with little parking, parked vehicles can drastically reduce the cleaning effectiveness of normal cleaning programs on these streets. Extensively parked cars block the migration of particulates towards the curb, resulting in higher “middle of the street" loading values than for streets with little or no parking. The percentage of curb length occupied by parked vehicles is close to the percentage of parking spaces occupied, but is usually smaller due to parking restrictions such as driveways and fire hydrants. As the number of parked cars increases, the percentage of' curb left uncleaned by street cleaning operations increases proportionally, especially as the street cleaning equipment must also maneuver around the parked cars.

If a smooth street has extensive on-street parking 24 hours a day (such as in a high density residential neighborhood), most of the street surface particulates would not be within the 8 ft. strip next to the curb that is usually cleaned by street cleaning equipment. If the percentage of curb length occupied by parked cars exceeds about 80 percent for extensive 24 hour parking conditions, it would be best if the parked cars remained and the street cleaner swept around the cars (in the 8 to 16 ft. strip from the curb). Of course, all of the cars should be removed periodically to allow the street cleaner to operate next to the curb to remove litter caught under the cars. In an area with extensive daytime parking only (such as in downtown commercial areas), the parked cars should remain parked during cleaning (daytime cleaning) if the percentage of curb length occupied exceeds about 95 percent.

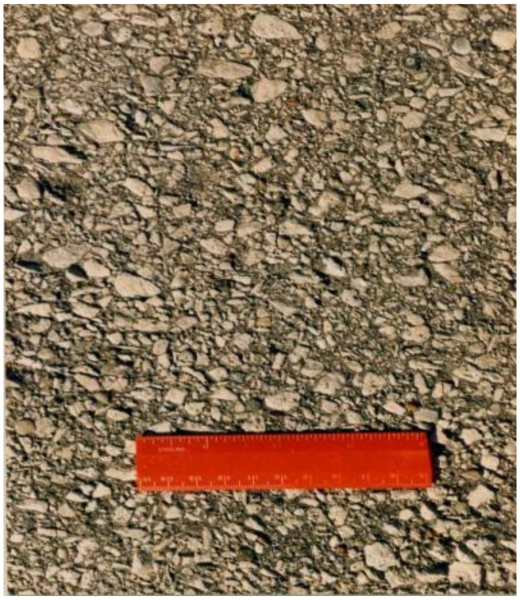
• *Street and Pavement*:

The numbers of traffic and parking lanes are also noted on the field sheet. Pavement condition and texture are different characteristics and are noted separately. Condition implies the state of repair, specifically relating to cracks and holes in the pavement. Texture implies roughness. A rough street may be in excellent condition: many new street overlays result in very rough streets. Some much worn streets may also be quite smooth, but with many cracks. Rough or streets in poor condition have much greater street dirt loadings and are much more difficult to clean with street cleaning equipment. They also produce less washoff of the street dirt during rains. Smooth streets are cleaned by both street cleaning equipment and rains more effectively.

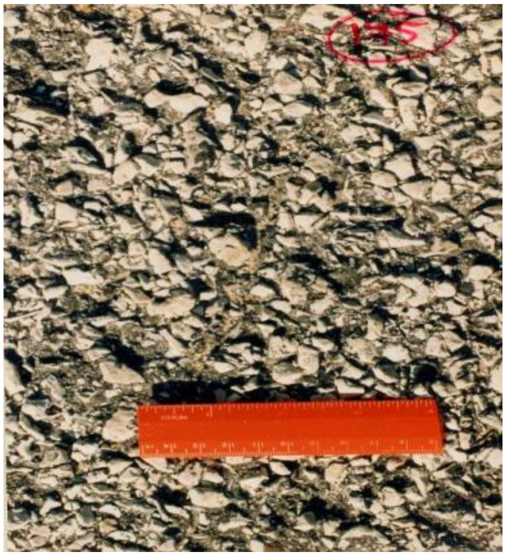
A close-up photograph of the street surface is used to make final determinations of street texture by comparing with reference photographs. An overview photograph of the street is also taken to make the final determination of the street condition. The gutter/street interface condition is an indication of how well the street pavement and the gutter material join. Many new streets overly jobs are uneven, resulting in a several centimeter ridge along the gutter/street interface. If the street interface has poor condition or is uneven, an additional photograph is taken to show the interface close-up. The litter perception is also indicated on the field sheet and another photograph is taken of heavily littered areas.


Smooth textured street.


Intermediate textured street.



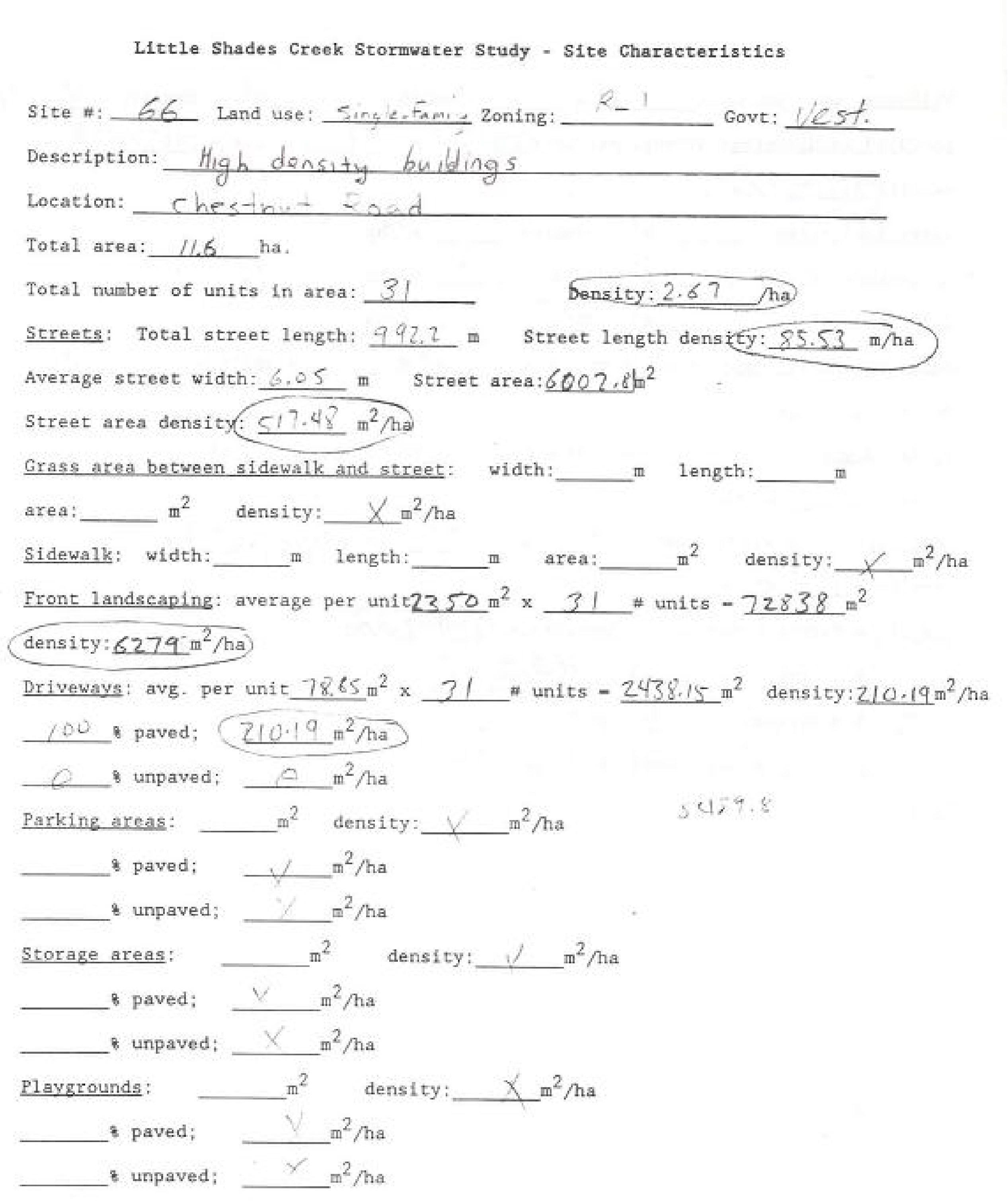
Rough textured street



Very rough textured street.

Aerial Photographic Measurements of Source Areas

The measurements of the source areas from aerial photographs are also needed. After the field data description sheets are filled out during each neighborhood survey, the corresponding aerial photographs from TerraServer USA and/or satellite images are examined, and the individual elements (roofs, parking areas, street areas, sidewalks, landscaping, etc) are measured using. This can be done manually or by using automated tools, such as GIS Tools (ArcGIS 9.0). The aerial photograph area measurements are tabulated and summarized in Excel spreadsheets. These data are then used to build the modeling files, such as used by WinSLAMM to describe each land use area. This information can be manually measured from aerial photographs and recorded on data sheets, using one sheet for each site surveyed. An example of this manual measurement data sheet is shown below.



Little Shades Creek Stormwater Study - Site Characteristics

Site #: 66 Land use: Single-Family Zoning: R-1 Govt: Vest.

Description: High density buildings

Location: Chestnut Road

Total area: 11.6 ha.

Total number of units in area: 31 Density: 2.67 /ha

Streets: Total street length: 992.2 m Street length density: 85.53 m/ha

Average street width: 6.05 m Street area: 6002.8 m^2

Street area density: 517.48 m^2/ha

Grass area between sidewalk and street: width: ____ m length: ____ m

area: ____ m^2 density: X m^2/ha

Sidewalk: width: ____ m length: ____ m area: ____ m^2 density: X m^2/ha

Front landscaping: average per unit 2350 m^2 x 31 # units = 72838 m^2

density: 6279 m^2/ha

Driveways: avg. per unit 78.65 m^2 x 31 # units = 2438.15 m^2 density: 210.19 m^2/ha

100 % paved; 210.19 m^2/ha

0 % unpaved; 0 m^2/ha

5479.8

Parking areas: ____ m^2 density: X m^2/ha

____ % paved; X m^2/ha

____ % unpaved; X m^2/ha

Storage areas: ____ m^2 density: X m^2/ha

____ % paved; X m^2/ha

____ % unpaved; X m^2/ha

Playgrounds: ____ m^2 density: X m^2/ha

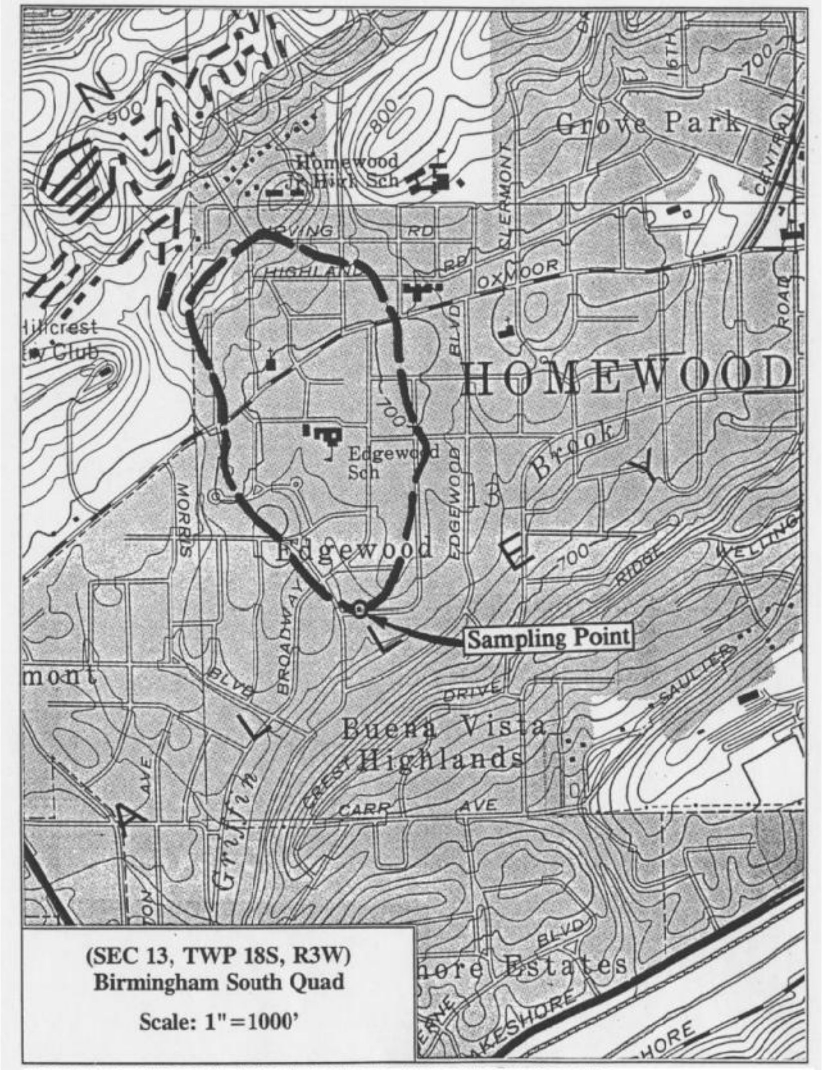
____ % paved; X m^2/ha

____ % unpaved; X m^2/ha

Example of first page of the area measurement sheets.

Bochis (2007) and Bochis, *et al*. (2008) recently examined several different approaches using automated methods to acquire the source area data as part of a stormwater study in Jefferson County, AL. The first step was to obtain satellite imagery taken during 2001 and 2003, plus watersheds paper maps from the Storm Water Management Authority of Jefferson County (SWMA). All images were originally purchased from Space Imaging and acquired by IKONOS Satellite imagery which is a high-resolution satellite operated by Space Imaging LLC. IKONOS produces 1-meter black-and-white (panchromatic) and 4-meter multi-spectral (red, blue, green, near infrared) imagery that can be combined in a variety of ways to accommodate a wide range of high-resolution imagery applications. The satellite was launched on September 24, 1999 and has been delivering commercial data since early 2000.

The second step was the electronic delineation of the study watersheds using map digitizing and GIS tools. The multi-spectral image of Jefferson County and the paper maps of the watersheds were used to manually digitize and then cut each of the watersheds using ArcGIS 9 (ArcMap). Each watershed was saved separately as a shape file (.SHP). The following are examples of a high density residential shape file, showing the location on the USGSA quad map and the cut out shape aerial image. Since these were monitored watersheds, they usually included a mixture of land uses, although each was predominately a single land use. Therefore, several homogeneous land use neighborhoods were inventoried in each watershed to represent each of the land uses present. The areas of these land uses were also determined and the characteristics of the complete watershed were therefore known.



ALJC009: HIGH DENSITY RESIDENTIAL- SHADES CREEK BASIN

Mixed High Density Residential Area - Site Satellite Image (Bochis 2007).

The multi-spectral Jefferson.sid aerial images were obtained from the National Aerial Photography Program (NAPP) which were further processed by SWMA. Film negatives were purchased by SWMA from the USGS and were scanned and saved into digital format, orthorectified and sid'ed into USGS quad arrangements (one singular layer). They were not scanned by a metric scanner (which would have resulted in sharper and more precise output image).

The National Aerial Photography Program was initiated in 1980 and coordinated by the USGS. The purpose is to acquire aerial photography of each of the 48 lower states every five years. They are acquired at 20,000 feet elevation and centered on 1:24,000 scale USGS maps, with eight frames making up one USGS quadrangle map. Each frame represents 32.3 sq.mi. at 2-ft pixels. Final output are digital ortho quarter quads (DOQQ) and revised approximately every five years. For more information about NAPP, see: http://eros.usgs.gov/products/aerial/napp.php. The next step used the two 1-meter panchromatic satellite images ("Leafoff.img" flown December 2000 and "Leaffon.img", flown summer 2001; raster format "ERDAS IMAGE", number of raster bands: 1) of Jefferson County. These images were purchased by SWMA from Space Imaging and were assembled into mosaics using a PLSS-Township arrangements. It is complete for the entire county area, but with cloud obstructions in some areas. The overlapping/cutting process made use of GIS Tools: ArcInfo, ArcToolbox and ArcMap 8.9. Each image was saved separately (.IMG extension) having the equivalent name of the watershed.

The satellite image measurement process was initially used to describe the different land uses within the watersheds. For residential land uses, the most visible neighborhoods (having minimal tree cover) were selected and their individual elements were electronically measured. However, for industrial, commercial, and institutional areas, it was necessary to take account of all the elements incorporated into the land use due to greater variabilities of the different surface cover areas. The areas of the individual elements were calculated using ArcGIS and stored in the shape file attribute table.

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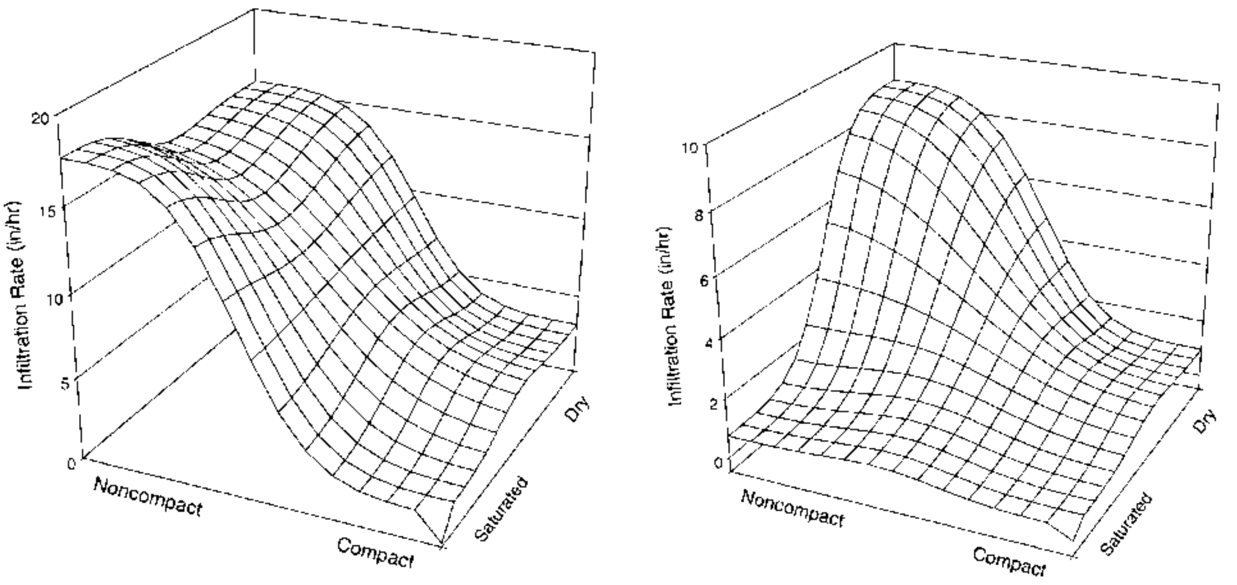
Appendix B: Soil Sampling and Characterization in Test Areas

Introduction

Hydrologic models must contain a process to address the infiltration of rain water into the soil. The infiltration process in most models is usually dependent on the porosity and moisture content of the soil: in an unsaturated soil, infiltration usually is initially rapid but then declines to a constant value as the soil becomes saturated. Soil infiltration is an issue in urban watershed management due to concerns of groundwater contamination and because poor infiltration conditions after land development, which is one of the causes of increased surface runoff (in addition to increased amounts of impervious surfaces) (Pitt, *et al.* 1994 and 1995). It has been well documented that during urbanization, soils are greatly modified, especially related to soil density. Increased soil compaction results in soils that do not behave in a manner predicted by traditional infiltration models. It is crucial, therefore, that stormwater engineers better understand infiltration in disturbed urban soils. Laboratory and field tests can be used to determine expected infiltration behavior of disturbed urban soils for a specific area. This standard operating procedure (SOP) describes these tests that can be used to determine the behavior of disturbed urban soils.

Since the early 1990s, a series of laboratory and field tests have been developed and conducted on soils covering a wide range of soil textures, densities and stiffness (Pitt, *et al.* 1999). Selected results from these tests are summarized in a recent paper (Pitt, *et al*. 2008). As shown in the following figures, these field tests highlighted the importance of compaction on the infiltration rate of soils. For sandy soils, minimal effects are seen associated antecedent moisture conditions compared to soil compaction. For the clayey soils, both the compaction level and antecedent moisture conditions are likely important in determining the infiltration rate.



Three dimensional plot of infiltration rates for sandy soil conditions.

Three dimensional plot of infiltration rates for clayey soil conditions.

Effects of soil moisture and soil compaction on infiltration rates (Pitt, *et al.* 1999).

Methodology

Site soil evaluations have several components, including infiltration measurements, along with soil density, texture, and moisture determinations. The following describe these tests, with appropriate references to standard protocols.

Infiltration Measurements

Small-scale infiltrometers have been used to measure infiltration rates in disturbed urban soils and in other locations. Using several of these units simultaneously, and in relatively close proximity, enables measurements of variability to be determined. These tests are also relatively rapid, enabling several sites to be investigated in one day, if 6 units are used. This is substantially faster, and results in better measurements of infiltration variability, than is possible if using traditional double-ring infiltrometers. However, any standard or small double-ring infiltrometer likely over-estimates the actual infiltration rates for a specific site. The relatively small areas being tested, even with the larger traditional units, have substantial edge effects, especially if the area's soils are not saturated. The most precise measurements of infiltration, and which should be used in areas where large infiltration units are being designed, should rely on full-scale tests. These are typically large trenches, constructed to penetrate the depths of soil that the final units will use for infiltration, and use large volumes of water over extended periods of time. For small stormwater biofiltration units, this approach is usually not warranted, while it would be for infiltration galleries that are critical for drainage in enclosed areas.

The procedure described here uses three TURF-TEC Infiltrometers (Turf-Tec, Coral Springs, FL, http://www.turf-tec.com/IN2lit.html) for each area. A small crew of two field personnel can usually conduct two sets simultaneously, if six infiltrometers are available, and if the sites are in relatively close proximity. Three of these units are used, usually within a meter or so of each other, to indicate the infiltration rate variability of soils in close proximity, such as for a single biofiltration facility. Readings are taken about every five minutes over a duration of two hours, or at least until a sustained period of constant infiltration is observed. The incremental infiltration rates are calculated by noting the drop of water level in the inner compartment of each infiltrometer over each five minute time period. In the following example, infiltration was measured at two locations having natural grass covers, and a third measure was for the infiltration after the grass sod was removed. This was done to investigate the influence of the surface vegetation on the infiltration rates. The tests should be done using the surface cover of interest. If measuring the infiltration rates for rainfall on typical turf landscaped areas, then the sod should remain in place (though trimmed in height) for the tests. For biofiltration devices that will be planted with discrete plants and shrubs, the sod should probably be removed to better represent the absence of surface grass thatch.

For tests with sod in place, the grass is cut to a height of several inches to facilitate work. The infiltrometers are then gently driven into the ground up to their "Saturn" ring (ensuring that the infiltrometers are 1 to 2 inches in the ground). After the soil and seal are inspected and ensured to be even and smooth, tap water is then carefully poured into the inner chamber and allowed to overflow into the outer ring. Measurements of water loss are then immediately started. These measurements can be taken every few minutes at the beginning of the test, and less frequently later in the test, or at a constant frequency of about every 5 minutes. The following are photographs of the test setups, along with a filled-out field sheet that was used for recording the water losses in the units.

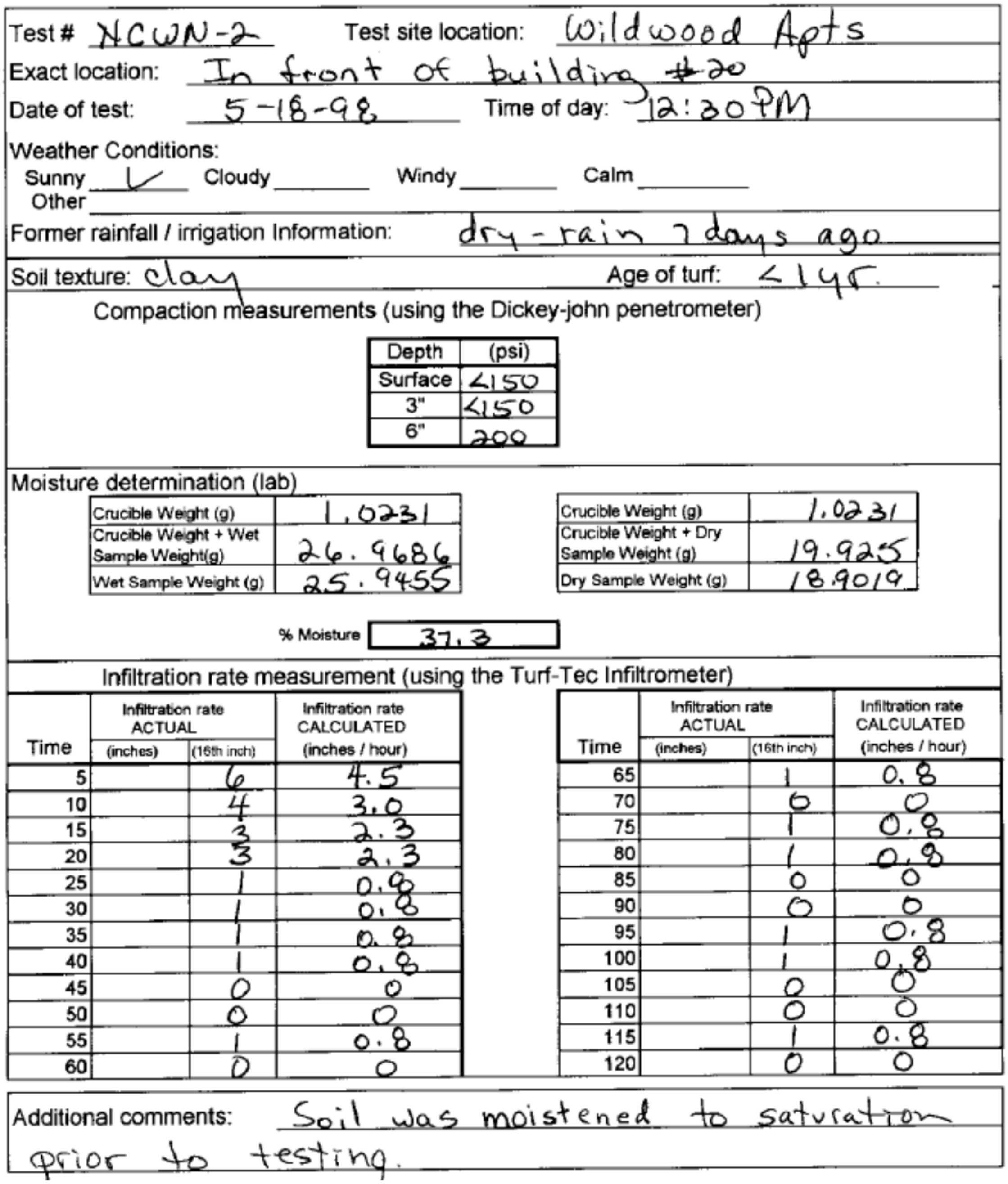
Set of three Turf-Tec infiltrometers for infiltration measurements in pre-development soils.

Turf-Tec infiltrometer at bare soil location.

Infiltrometer at site with grass.

Turf-Tec infiltrometers

Traditional ASCE double-ring infiltrometer.



Test # NCWN-2 Test site location: Wildwood Apts

Exact location: In front of building #20

Date of test: 5-18-98 Time of day: 12:30PM

Weather Conditions:

Sunny ✓ Cloudy ____ Windy ____ Calm ____

Other ____

Former rainfall / irrigation Information: dry - rain 7 days ago

Soil texture: clay Age of turf: <1yr.

Compaction measurements (using the Dickey-john penetrometer)

Depth	(psi)
Surface	<150
3"	<150
6"	200

Moisture determination (lab)

Crucible Weight (g)	1.0231
Crucible Weight + Wet Sample Weight(g)	26.9686
Wet Sample Weight (g)	25.9455

Crucible Weight (g)	1.0231
Crucible Weight + Dry Sample Weight (g)	19.925
Dry Sample Weight (g)	18.9019

% Moisture 37.3

Infiltration rate measurement (using the Turf-Tec Infiltrometer)

Time	Infiltration rate ACTUAL (inches)	(16th inch)	Infiltration rate CALCULATED (inches / hour)
5		6	4.5
10		4	3.0
15		3	2.3
20		3	2.3
25		1	0.8
30		1	0.8
35		1	0.8
40		1	0.8
45		0	0
50		0	0
55		1	0.8
60		0	0

Time	Infiltration rate ACTUAL (inches)	(16th inch)	Infiltration rate CALCULATED (inches / hour)
65		1	0.8
70		0	0
75		1	0.8
80		1	0.8
85		0	0
90		0	0
95		1	0.8
100		1	0.8
105		0	0
110		0	0
115		1	0.8
120		0	0

Additional comments: Soil was moistened to saturation prior to testing.

Calculation of Infiltration Rates

One of the oldest and most widely used infiltration equations was developed by Horton (1939). This equation can be used to compare the measured equation parameters with published literature values. The equation is as follows:

$$f = f_c + (f_o - f_c)e^{-kt}$$

where:

f = infiltration rate at time t (in/hr),

f_o = initial infiltration rate (in/hr),

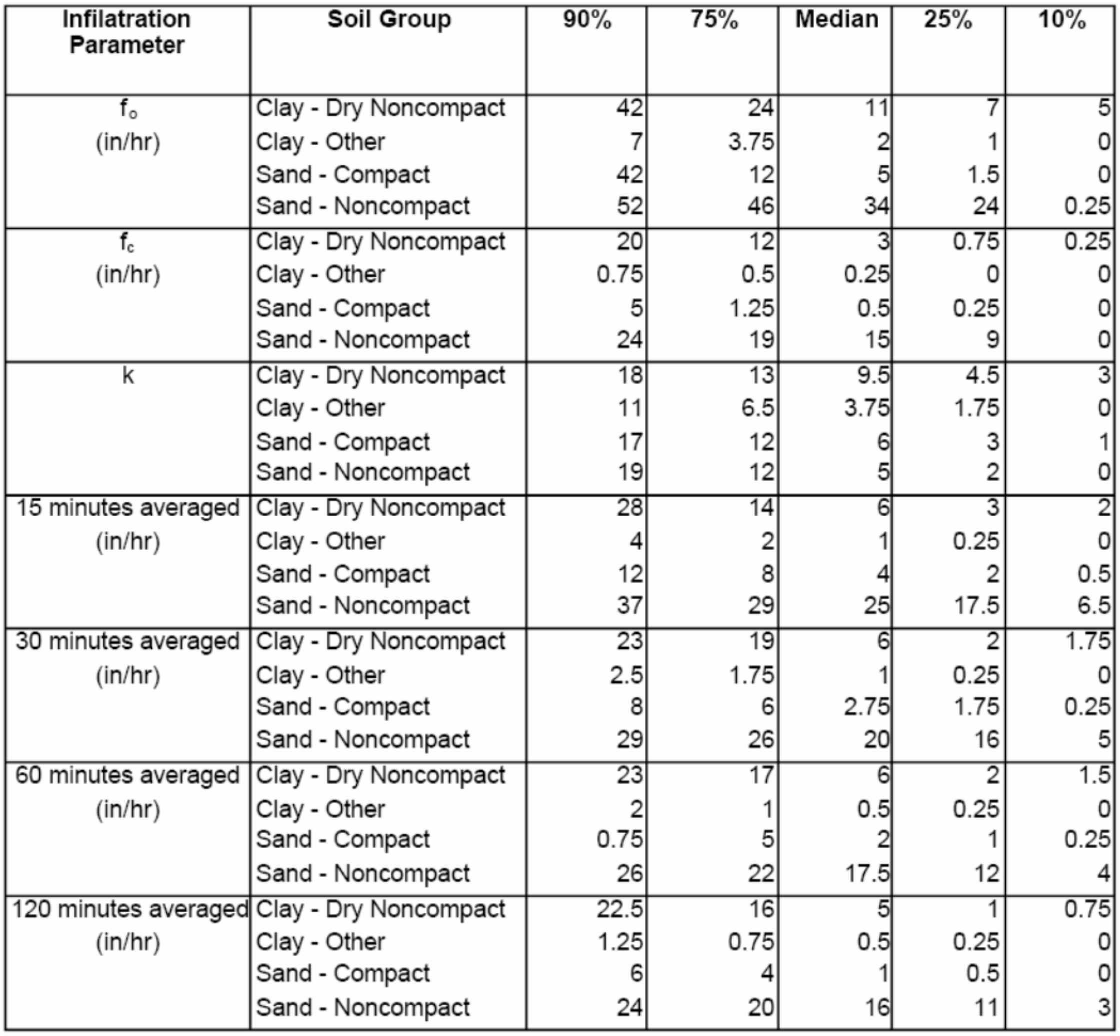
f_c = final infiltration rate (in/hr),
k = first-order rate constant (hr^{-1})

This equation assumes that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time (Bedient and Huber 1992). The capacity of the soil to hold additional water decreases as the time of the storm increases because the pores in the soil become saturated with water. The Horton equation’s major drawback is that it does not consider the soil storage availability after varying amounts of infiltration have occurred, but only considers infiltration as a function of time (Akan 1993). However, integrated forms of the equation can be used that do consider the amount of water added to the soil.

It is recommended that f_c, f_o, and k all be obtained through field data, but they are rarely measured locally. More commonly, they are determined through calibration of relatively complex stormwater drainage models (such as SWMM), or by using values published in the literature. The use of published values in place of reliable field data is the cause of much concern by many (Akan 1993). The following lists shows commonly used Horton infiltration parameter values, as summarized by Akan (1993):

Soil Type	**f_o (in/hr)**
Dry sandy soils with little to no vegetation	5
Dry loam soils with little to no vegetation	3
Dry clay soils with little to no vegetation	1
Dry sandy soils with dense vegetation	10
Dry loam soils with dense vegetation	6
Dry clay soils with dense vegetation	2
Moist sandy soils with little to no vegetation	1.7
Moist loam soils with little to no vegetation	1
Moist clay soils with little to no vegetation	0.3
Moist sandy soils with dense vegetation	3.3
Moist loam. soils with dense vegetation	2
Moist clay soils with dense vegetation	0.7

The following table summarizes the Horton equation coefficients as measured by Pitt, *et al.* 1999 for different urban soils, showing the dramatic effect soil density has on the infiltration characteristics:

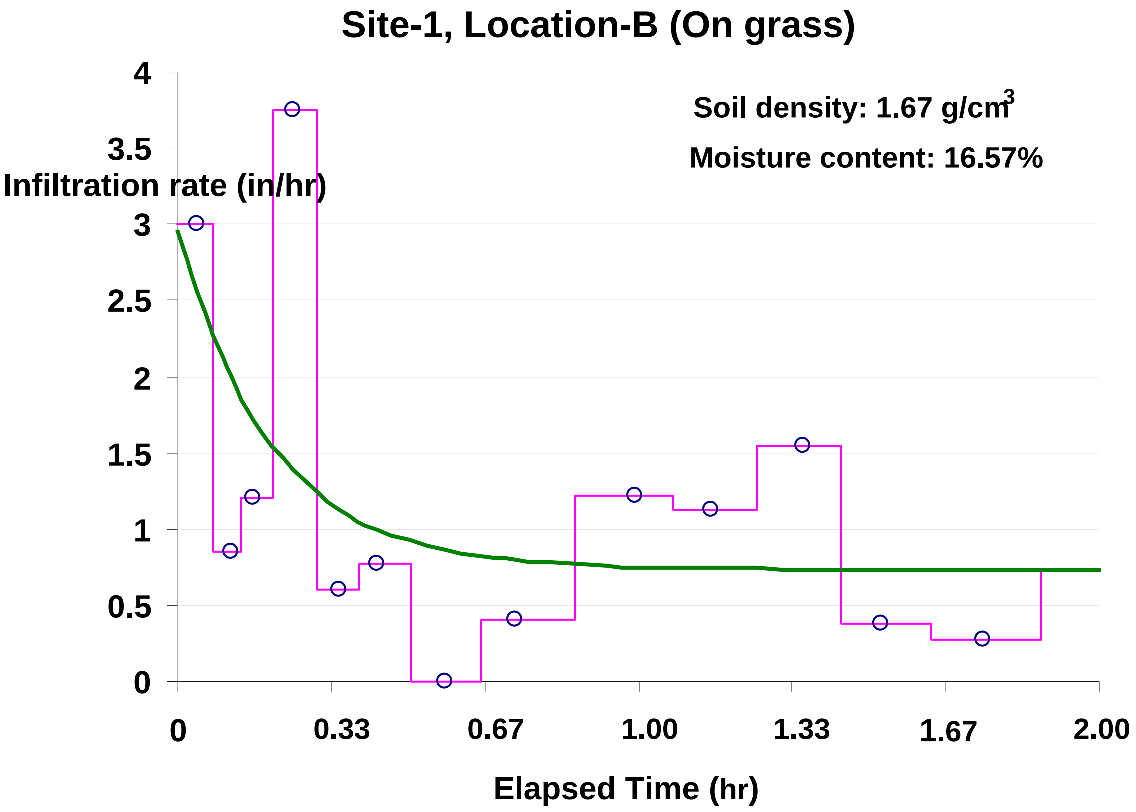


Infilatration Parameter	Soil Group	90%	75%	Median	25%	10%
f_o	Clay - Dry Noncompact	42	24	11	7	5
(in/hr)	Clay - Other	7	3.75	2	1	0
	Sand - Compact	42	12	5	1.5	0
	Sand - Noncompact	52	46	34	24	0.25
f_c	Clay - Dry Noncompact	20	12	3	0.75	0.25
(in/hr)	Clay - Other	0.75	0.5	0.25	0	0
	Sand - Compact	5	1.25	0.5	0.25	0
	Sand - Noncompact	24	19	15	9	0
k	Clay - Dry Noncompact	18	13	9.5	4.5	3
	Clay - Other	11	6.5	3.75	1.75	0
	Sand - Compact	17	12	6	3	1
	Sand - Noncompact	19	12	5	2	0
15 minutes averaged	Clay - Dry Noncompact	28	14	6	3	2
(in/hr)	Clay - Other	4	2	1	0.25	0
	Sand - Compact	12	8	4	2	0.5
	Sand - Noncompact	37	29	25	17.5	6.5
30 minutes averaged	Clay - Dry Noncompact	23	19	6	2	1.75
(in/hr)	Clay - Other	2.5	1.75	1	0.25	0
	Sand - Compact	8	6	2.75	1.75	0.25
	Sand - Noncompact	29	26	20	16	5
60 minutes averaged	Clay - Dry Noncompact	23	17	6	2	1.5
(in/hr)	Clay - Other	2	1	0.5	0.25	0
	Sand - Compact	0.75	5	2	1	0.25
	Sand - Noncompact	26	22	17.5	12	4
120 minutes averaged	Clay - Dry Noncompact	22.5	16	5	1	0.75
(in/hr)	Clay - Other	1.25	0.75	0.5	0.25	0
	Sand - Compact	6	4	1	0.5	0
	Sand - Noncompact	24	20	16	11	3

The following is an example of infiltration measurements, showing the spreadsheet summary and the resulting plot of infiltration. It is important that the units be consistent during these analyses. Even though the time was noted in minutes and the water loss readings in 16th of an inch, these were both converted to elapsed time in hours and depth in decimal inches. The incremental infiltration rate is therefore expressed as in/hr and the plot shows these infiltration rates with time, in hours. In this example for one infiltrometer, the resulting rates do not decrease very smoothly, but show the common irregularity common for disturbed urban soils. The early rates are larger than the final rates, as expected, but that may not always be true. The use of at least 3 infiltrometers in an area helps determine the variability of infiltration in an area of interest. Also, due to the highly variable nature of the measured infiltration values, it probably does not matter which infiltration “model” is used to predict infiltration. In our work, we use a probability distribution of the infiltration rates and random rates described by these probability plots. The preceding table shows some of the probability values for the equation parameters, and also shows the actual infiltration rates averaged for different rain durations and soil conditions.

Site 1, Location-B (on Grass)

Time (Reading)	Total Elapsed Time (min)	Total Elapsed Time (hr)	Reading (inch)	Reading (inch)	Incremental Infiltration rate (in/min)	Incremental Infiltration rate (in/hour)
0" (water added)	**0**	**0**	**-2/16**	**-0.125**	0.05	3.00
2' 30"	2.5	0.042	0/16	0	0.05	3.00
5' 54"	6.9	0.115	1/16	0.0625	0.01	0.85
10' 00"	10.0	0.167	2/16	0.125	0.02	1.21
10' 00" (water added)	**10.0**	**0.167**	**-2/16**	**-0.125**	0.06	3.75
15' 00"	15.0	0.250	3/16	0.1875	0.06	3.75
21' 13"	21.2	0.353	4/16	0.25	0.01	0.60
26' 05"	26.1	0.435	5/16	0.3125	0.01	0.77
35' 02"	35.0	0.583	5/16	0.3125	0.00	0.00
35' 02" (water added)	**35.0**	**0.583**	**-2/16**	**-0.125**	0.01	0.41
44' 07"	44.1	0.735	-1/16	-0.0625	0.01	0.41
59' 30"	59.5	0.992	4/16	0.25	0.02	1.22
1, 09' 30"	69.5	1.158	7/16	0.4375	0.02	1.13
1, 09' 30" (water added)	**69.5**	**1.158**	**-2/16**	**-0.125**	0.03	1.55
1, 21' 35"	81.6	1.360	3/16	0.1875	0.03	1.55
1, 31' 30"	91.5	1.525	4/16	0.25	0.01	0.38
1, 44' 55"	104.9	1.748	5/16	0.3125	0.00	0.28
1, 44' 55" (water added)	**104.9**	**1.748**	**-2/16**	**-0.125**	0.01	0.74
2, 00' 09"	120.2	2.003	1/16	0.0625	0.01	0.74



Soil Density and Moisture Measurements

As noted above, infiltration is strongly affected by the soil density. In fact, for sandy soils, Pitt, *et al.* (1999 and 2008) shows that soil density has a greater effect on infiltration rates than soil moisture, while for clayey soils, soil density has about the same effect on infiltration as does soil moisture. Unfortunately, most stormwater models effectively track soil moisture, but they ignore soil density. It is important to also measure soil density, along with the infiltration rates. The following table shows the effects of soil bulk densities on root growth and typical soil density values:

Bulk Densities and Root Growth (NRCS 2001)

	Ideal bulk density (g/cc)	Bulk densities that may affect root growth (g/cc)	Bulk densities that restrict root growth (g/cc)
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams	<1.40	1.60	>1.75
Loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.10	1.55	>1.65
Sandy clays, silty clays, clay loams (35 to 45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Most of the measured densities of disturbed urban soils are in the range of values having likely effects on root growth.

Direct Measurements of Soil Density and Moisture
Precise measurements of soil density (and simultaneous soil moisture determinations) are needed for urban soil investigations. It is possible to directly measure the soil moisture and soil density at the same time as the infiltration tests using a modification of the historical "sand and balloon" test method. In this procedure, the surface vegetation is removed from the test area and a small hole is carefully excavated with a hand trowel. The excavated soil (not including the removed sod) is placed in a zip lock plastic bag to seal in the moisture and is then transported to the laboratory. The preferred sizes of the holes range from about 1 to 2 L in volume (about 6 inches deep and wide), and have smooth sides. After the hole is dug and the soil carefully placed in the zip lock bag, the hole is then filled with clean laboratory Ottawa test sand (or other free-flowing sand) from a graduated cylinder up to the level of the excavated soil. The volume of sand added to fill the hole to the excavated depth is carefully determined and noted. The soil sample is then brought to the laboratory and weighed. It is then dried in a drying oven at 105^{o}C and weighed again to determine the moisture content. The density of the soil is determined by dividing the dry soil mass by the sand volume used to re-fill the hole. The soil moisture content is also determined through the soil drying process. The dried soil can also be used in a sieve analysis to determine the soil texture.


Direct soil density measurement; filling excavated hole with sand.

The laboratory soil moisture is obtained using ASTM method D 2974-87 (*Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils*), while the soil texture is determined by sieve analyses. The samples were prepared based on ASTM 421 *Practice for Dry Preparation of Soil Samples for Particle Size Analysis and Determination of Soil Constants.* The sieve analysis used was the ASTM D 422-63 *Standard Test Method For Particle Size Analysis of Soils* for the particles larger than the No. 200 sieve, along with ASTM D 2488-93 *Standard Practice for Description and Identification of Soils (Visual - Manual Procedure).*

Soil Chemical Measurements

A portion of the dried soil sample should also be sent to the state horticultural lab for further analyses to supplement the above described physical tests. As an example, we use the Auburn University Soil Testing Laboratory where soil texture (% sand, % silt, and % clay), organic matter, cation exchange capacity (CEC), and general nutrients (and fertilizer recommendations) can be analyzed at a very good price. Since this was a southern soil lab, they did not routinely do SAR analyses that are critical in areas having irrigation or snowmelt influences. It is critical that Na, Ca, and Mg are all evaluated for the soils, besides the other constituents noted. It would have been beneficial to also have organic carbon content measured to supplement the CEC and the organic matter results, if available. Other state agricultural schools offer similar services.

The following tables show an example summary of all of the soil test data for a series of recent samples from an agricultural area that is being developed as an industrial park. These analyses were conducted to accurately predict pre-development conditions, and to identify locations where post-development biofiltration controls may be most efficient. These results were also used to predict the performance of regional drainage system components that were built in undisturbed soil areas. A brief example narrative of these results is also provided. These tables also include volatile solids results which were also analyzed in-house.

All of the soils are silt loam, with an average of 72% silt, 23% sand, and 5% clay, with little variation in texture over the test site. The sustained infiltration rates (final constant values) for all the sites averaged about 2.8 inches/hr, with an overall range of 0.3 to 7.4 in/hr. Sites 1 and 2 are lower than the other sites, and are both located on the upper end of the western main drainage, in a grass field that has not been cultivated for some time, but is harvested for hay. Sites 7, 8, and 11 all have larger sustained infiltration rates than the others and are located in the central drainage area, also in harvested hay fields, but near the edges of the field. Site 9 has the highest rate, and was in the cultivated area of the corn field. The soil densities are inversely related to the sustained infiltration rate, in general, except for the corn field site that had the highest density and the highest infiltration rate. Site 11, the other high infiltration rate site, had the lowest soil density observed. The areas having the highest sustained infiltration rates also had the highest initial infiltration rates, some being as high as 25 inches/hour. The sustained final infiltration rate was observed from 10 to 60 minutes after the start of the tests, with an average of about 24 minutes.

The organic matter content of the soils averaged 5.6% (ranged from 2.4 to 7.3), and the associated volatile solids content averaged 131g/kg (ranged from 67 to 238g/kg). These values are consistent with a silt loam soil. For comparison, soils in the Central Great Plains have organic contents ranging between 1 and 2% for cultivated soils, and about 1.5 to 3.0% for native grasslands. Agricultural yield is usually regarded as sustainable at organic contents of about 2%. Soils with large amounts of clay generally require large amounts or organic matter. Soils with a higher organic matter content will have a higher cation exchange capacity (CEC), higher water holding capacity, and better tilth than soils with a lower organic matter content. Generally, healthy soil has between 3% and 5% organic material. Only site 9 (located in the cultivated portion of the corn field) had less than this amount (at 2.4%).

The cation exchange capacity is the sum of exchangeable bases plus total soil acidity at a specific pH value, usually 7.0 or 8.0. The cation exchange capacity of a soil is a measure of its ability to bind or hold exchangeable cations. It is a measure of the number of negatively-charged binding sites in the soil. It is expressed here in centimoles of charge per kilogram of exchanger (cmolckg-1). These units are equivalent to the more commonly reported meq/100g units. These soils had CEC values ranging from about 4.9 to 7.2 meq/100g (average of 5.7) and fall in the range of sands. Loam soils have CEC values in the 10 to 15 meq/100g range, while organic soils have CEC values in the high range of 50 to 100 meq/100g.

The pH of the soil ranged from 5.1 to 6.3 (average of 5.9) and had recommended limestone additions (from 0 to 3.5 tons per acre) to increase the pH to at least 6. The eastern half of the site required more neutralization than soils in the western half.

The phosphorus, potassium, magnesium, and calcium levels averaged 14, 21, 33, and 411 lbs/acre, respectively. There were no specific fertilizer recommendations provided with the soil report for these nutrients. The phosphorus is in a typical range for other silt loam soils, while the potassium may be lower than some silt loam soils. As noted previously, it is critical that sodium also be analyzed in soils subjected to snowmelt.

Site ID	Location	Surface	Test duration (hour)	initial infilt. rate (in/hr)	final (constant) infiltr. rate (in/hr)	Time to constant rate (hr)	Soil density (g/cm^3)	Initial soil moisture (%)
Site-1	Location-A	grass	2	3.01	1.56	1.00	1.67	16.6
Site-1	Location-B	grass	2.00	3	0.73	0.67		
Site-1	Location-C	soil	1.99	4.66	0.89	0.33		
Site-2	Location-A	grass	2.00	11.40	1.9	0.15	1.59	13.8
Site-2	Location-B	grass	2.00	7.20	1.86	0.33		
Site-2	Location-C	soil	1.98	6.10	0.34	0.15		
Site-3	Location-A	grass	2.02	8.25	3.18	0.50	1.39	12.9
Site-3	Location-B	grass	2.01	8.23	2.97	0.50		
Site-3	Location-C	soil	2.00	4.99	0.54	0.15		
Site-4	Location-A	grass	1.77	9.66	4.24	0.33	1.52	12.6
Site-4	Location-B	grass	1.48	8.8	2.07	0.67		
Site-4	Location-C	soil	1.48	7.19	2.67	0.33		
Site-5	Location-A	soil	1.49	11.35	2.32	0.15	n/a	17.0
Site-5	Location-B	grass	1.48	19.10	5.31	0.33		
Site-5	Location-C	grass	1.49	5.46	1.7	0.83		
Site-7	Location-A	grass	1.34	8.63	3.6	0.15	1.37	13.5
Site-7	Location-B	grass	1.33	12.59	4.88	0.50		
Site-7	Location-C	soil	1.32	11.56	2.8	0.33		
Site-8	Location-A	soil	1.27	16.10	2.52	0.33	1.42	14.6
Site-8	Location-B	grass	1.26	14.20	2.86	0.33		
Site-8	Location-C	grass	1.25	14.10	4.43	0.33		
Site-9	Location-A	grass	1.85	25.00	7.22	1.00	1.66	10.8
Site-9	Location-B	soil	1.85	24.60	7.39	0.50		
Site-10	Location-A	grass	2.03	5.88	0.76	0.50	1.40	10.8
Site-10	Location-B	grass	1.85	1.57	1.00	0		
Site-10	Location-C	soil	1.65	7.42	0.86	0.15		
Site-11	Location-A	grass	0.99	16.80	6.82	0.15	1.21	12.1
Site-11	Location-B	soil	0.97	13.60	3.19	0.15		
Site-11	Location-C	grass	0.96	9.10	1.75	0.50		
Site-12	Location-A	grass	1.00	5.88	2.51	0.33	1.53	11.9
Site-12	Location-B	grass	0.99	5.81	0.85	0.33		
Site-12	Location-C	soil	0.98	8.36	1.11	0.33		

	initial infilt. rate (in/hr)	**final (constant) infilt. rate (in/hr)**	**Time to constant rate (hr)**	**Soil density (g/cm^3)**	**Initial soil moisture (%)**
average	9.99	2.77	0.39	1.47	13.41
min	1.57	0.34	0.00	1.21	10.80
max	25.00	7.39	1.00	1.66	17.00
standard deviation	5.76	1.95	0.23	0.14	1.99
COV	0.57	0.70	0.61	0.09	0.15

Sample ID	Sand (%)	Silt (%)	Clay (%)	Textural Class	H_2O avail (cm/cm)	Organic Matter (%)	Volatile Solids (g/kg)
Site 1	21.25	76.25	2.5	Silt Loam	0.19	5.5	153.7
Site 2	18.75	76.25	5	Silt Loam	0.20	4.1	99.0
Site 3	23.75	71.25	5	Silt Loam	0.19	5.9	112.5
Site 4	25	70	5	Silt Loam	0.18	5.5	145.9
Site 5	26.25	71.25	2.5	Silt Loam	0.18	5.9	73.8
Site 7	21.25	73.75	5	Silt Loam	0.19	7.0	162.5
Site 8	26.25	66.25	7.5	Silt Loam	0.18	6.9	91.4
Site 9	23.75	66.25	10	Silt Loam	0.19	2.4	67.4
Site 10	22.5	72.5	5	Silt Loam	0.19	4.6	117.1
Site 11	21.25	73.75	5	Silt Loam	0.19	6.3	237.6
Site 12	26.25	71.25	2.5	Silt Loam	0.18	7.3	178.6
average	23.30	71.70	5.0		0.19	5.6	130.9
min	18.75	66.25	2.5		0.18	2.4	67.4
max	26.25	76.25	10.0		0.20	7.3	237.6
standard deviation	2.52	3.37	2.2		0.01	1.4	50.8
COV	0.11	0.05	0.4		0.03	0.3	0.4

Sample Name	pH	Phosphorus (lbs/acre)	Potassium (lbs/acre)	Magnesium (lbs/acre)	Calcium (lbs/acre)	Recommended Limestone (tons/acre)	CEC ($cmol_c kg^{-1}$)
Site 1	6.1	17	16	35	478	0.0	5.84
Site 2	5.9	21	10	25	358	1.5	4.93
Site 3	6.2	10	13	33	497	0.0	5.55
Site 4	6.3	7	14	31	453	0.0	5.2
Site 5	6.2	12	16	47	453	0.0	5.75
Site 7	6.2	11	24	34	583	0.0	5.07
Site 8	5.6	7	18	38	381	2.0	5.69
Site 9	5.1	45	45	17	267	3.0	5.6
Site 10	5.4	8	31	26	249	3.0	6.69
Site 11	6	9	23	45	459	0.0	5.6
Site 12	5.4	9	18	31	340	3.5	7.24
average	5.9	14	21	33	411	1	5.74
min	5.1	7	10	17	249	0	4.93
max	6.3	45	45	47	583	3.5	7.24
standard deviation	0.4	11	10	9	102	1.45	0.68
COV	0.07	0.78	0.48	0.26	0.25	1.23	0.12

Loams and Light clays (CEC = 4.6-9.0 cmolckg-1)

References

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Appendix C: Statistical Analyses for Biofiltration Devices

Introduction

This short document illustrates some of the basic data evaluation and presentation suggestions for the bioretention, and possibly other, stormwater controls that will be examined and tested as part of the National Demonstration of Green Infrastructure for the Control of Combined Sewerage Overflow project being conducted in Kansas City. This is not intended to be a comprehensive discussion of all statistical methods that will likely be used during the project and stresses basic exploratory data analysis and comparison tests and plots. The following material is summarized from the lengthier discussion at:
http://unix.eng.ua.edu/~rpitt/Class/ExperimentalDesignFieldSampling/MainEDFS.html

Exploratory Data Analysis

Exploratory data analysis (EDA) is an important tool to quickly review available data before a specific data collection effort is initiated. A summary of the data's variations, and differences between different sampling locations, is most important and can be presented using several simple graphical tools. An important reference for basic exploratory analyses is *Exploratory Data Analysis* (Tukey 1977) which is the classic book on this subject and presents many simple ways to examine data to find patterns and relationships. Besides plotting of the data, exploratory data analyses should always include corresponding statistical test results.

Basic Data Plots

There are several basic data plots that need to be prepared as data is being collected and when all of the data is available. These plots are basically for QA/QC purposes and to demonstrate basic data behavior. These basic plots include: time series plots (data observations as a function of time), control plots (generally the same as time series plots, but using control samples and with standard deviation bands), probability plots (described below), scatter plots (described below), and residual plots (needed for any model building activity, especially for regression analyses).

Probability Plots

The most basic exploratory data analysis method is to prepare a probability plot of the available data. The plots indicate the possible range of the values expected, their likely probability distribution type, and the data variation. It is difficult to recommend another method that results in so much information using the data available. Histograms, for example, cannot accurately indicate the probability distribution type very accurately, but they more clearly indicate multi-modal distributions.

The values and corresponding probability positions are plotted on special normal-probability paper. This paper has a y-axis whose values are spread out for the extreme small and large probability values. When plotted on this paper, the values form a straight line if they are Normally distributed (Gaussian). If the points do not form an acceptably straight line, they can then be plotted on log-normal probability paper (or the data observations can be log transformed and plotted on normal probability paper). If they form a straight line on the log-normal plot, then the data is log-normally distributed. Other data transformations are also possible for plotting on normal-probability paper, but these two (normal and log-normal) usually are sufficient for most receiving water analyses.

Figures C-1 and C-2 are probability plots of stormwater data from the National Stormwater Quality Database (NSQD) (Maestre and Pitt 2005). These plots are for all conditions combined and represent several thousand observations. In most cases, it is obvious that normal probability plots do not indicate normal distributions, except for pH (which is already log-transformed). However, Figure C-2 plots are log-normal probability plots and generally show much better normal distributions, as is common for stormwater data. However, some extreme values are still obviously not represented by log-normal probability distributions.

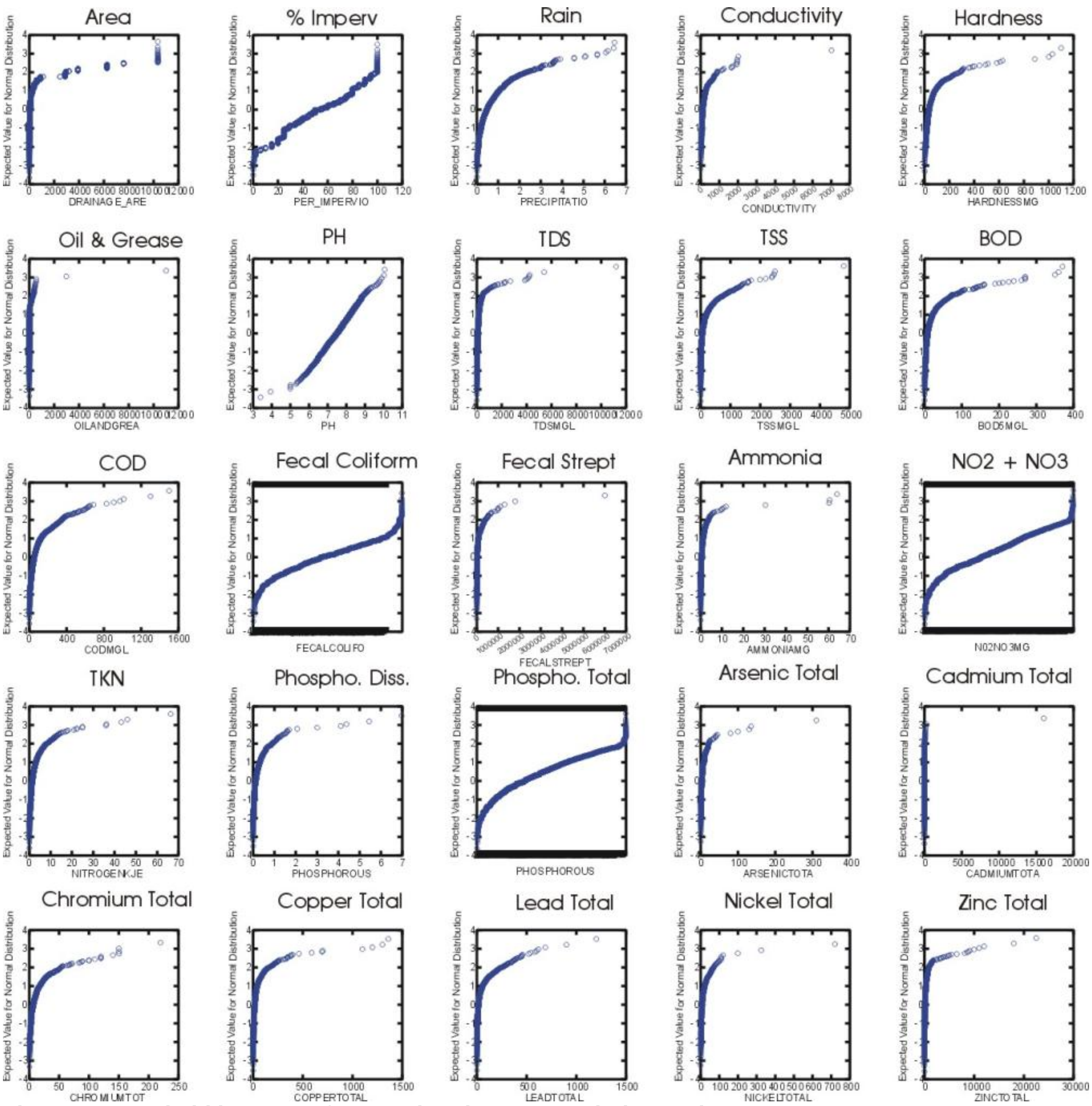


Figure C-1. Probability plots of NSQD data (Maestre and Pitt 2005).

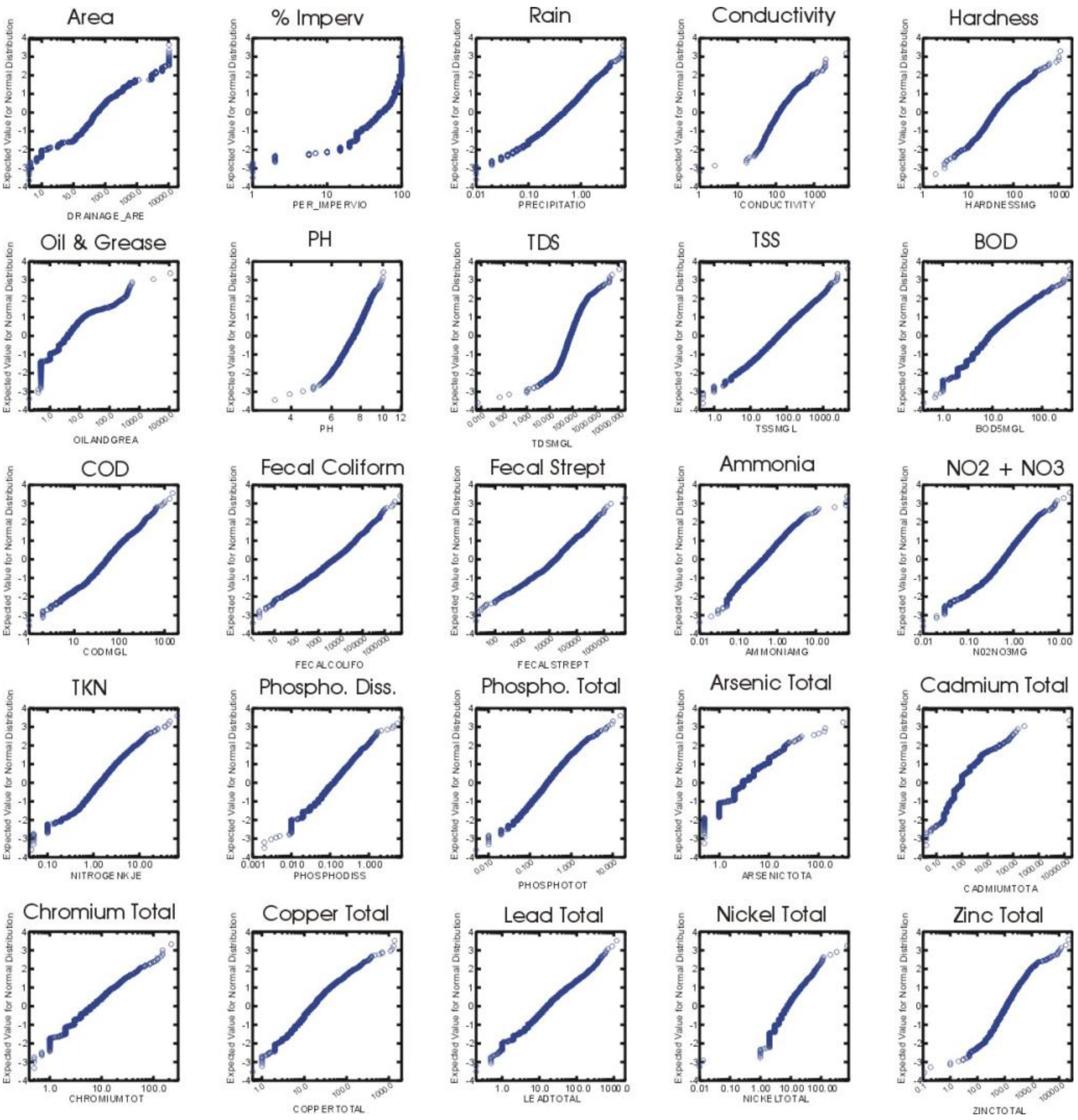


Figure C-2. Log-probability plots of NSQD data (Maestre and Pitt 2005).

Figure C-3 shows three types of results that can be observed when plotting pollutant reduction observations on probability plots, using data collected at the Monroe St. wet detention pond in Madison, WI, by the USGS and the WI DNR. Figure 3a for suspended solids (particulate residue) shows that SS are highly removed over a wide range of influent concentrations, ranging from 20 to over 1,000 mg/L. A simple calculation of percentage reduction would not show this consistent removal over the wide range. In contrast, Figure 3b for total dissolved solids (filtered residue) shows poor removal of TDS for all concentration conditions, as expected for this wet detention pond. The percentage removal for TDS would be close to zero and no additional surprises are indicated on this plot. Figure 3c, however, shows a wealth of information that would not be available from simple statistical numerical summaries. In this plot, filtered COD is seen to be poorly removed for low concentrations (less than about 20 mg/L, but the removal increases substantially for higher concentrations. Although not indicated on these plots, the rank order of concentrations were similar for both influent and effluent distributions for all three pollutants.

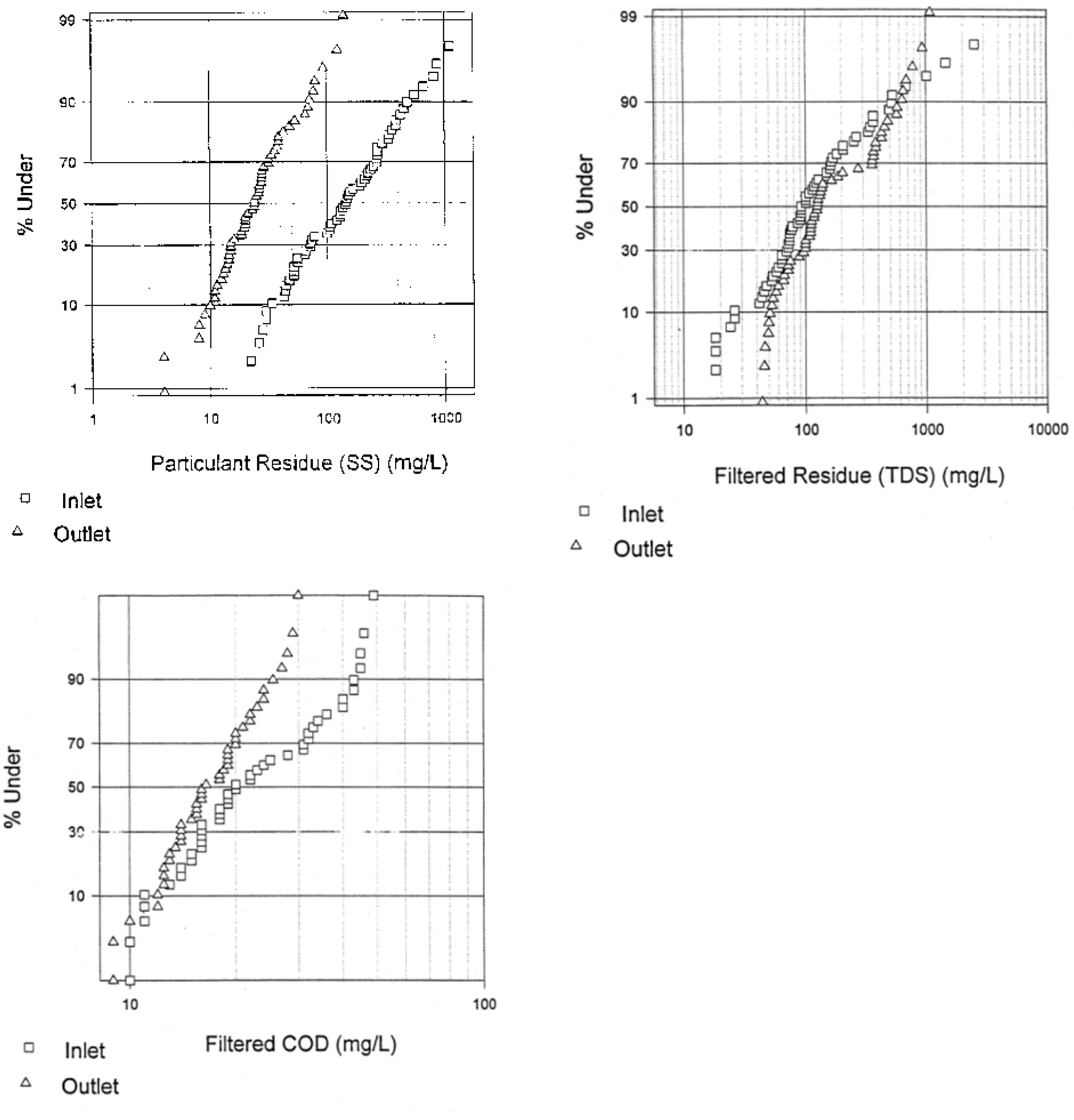


Figure C-3. Influent and effluent observations for suspended solids, dissolved solids, and filtered COD at the Monroe St., Madison, WI, stormwater detention pond.

Generally, water quality observations do not form a straight line on normal probability paper, but do (at least from about the 10 to 90 percentile points) on log-normal probability paper. This indicates that the samples generally have a log-normal distribution and many parametric statistical tests can probably be used, but only after the data is log-transformed. These plots indicate the central tendency (median) of the data, along with their possible distribution type and variance (the steeper the plot, the smaller the COV and the flatter the slope of the plot, the larger the COV for the data). Multiple data sets can also be plotted on the same plot (such as for different sites, different seasons, different habitats, etc.) to indicate obvious similarities (or differences) in the data sets. Most statistical methods used to compare different data sets require that the sets have the same variances, and many require normal distributions. Similar variances would be indicated by generally parallel plots of the data on the probability paper, while normal distributions would be reflected by the data plotted in a straight line of normal probability paper.

Probability plots should be supplemented with standard statistical tests that determine if the data is normally distributed. These tests, at least some available in most software packages, include the Kolmogorov-Smirnov one-sample test, the chi-square goodness of fit test, and the Lilliefors variation of the Kolmogorov-Smironov test. They basically are paired tests comparing data points from the best-fitted normal curve to the observed data. The statistical tests may be visualized by imagining the best-fitted normal curve data and the observed data plotted on normal probability paper. If the observed data crosses the fitted curve data numerous times, it is much likely to be normally distributed than if it only crossed the fitted curve a few times.

Digidot Plot

Berthouex and Brown (1994) point out that since the best way to display data is with a plot, it makes little sense to present the data in a table. They highly recommend a digidot plot, developed by Hunter (1988) based on Tukey (1977), as a basic presentation of characterization data. This plot indicates the basic distribution of the data, shows changes with time, and presents the actual values, all in one plot. A data table is therefore not needed in addition to the digidot plot. A stem and leaf plot of the data is presented as the y-axis and the data are presented in a time series (in the order of collection) along the x-axis. Figure C-4 is an example of a digidot plot, as presented by Berthouex and Brown (1994). The stem and leaf plot is constructed by placing the last digit of the value on the y-axis between the appropriate tic marks. In this example, the value 47 is represented with a 7 placed in the division between 45 and 50. Similarly, 33 is represented with a 3 placed in the division between 30 and 35. Values from 30 to 34 are placed between the 30 and 35 tic marks, while values from 35 to 39 are placed between the 35 and 40 tic marks. Simultaneously, the values are plotted in a time series in the order of collection. This plot can therefore be constructed in real time as the data is collected and obvious trends with time can be noted. This plot also presents the actual numerical data that can also be used in later statistical analyses.

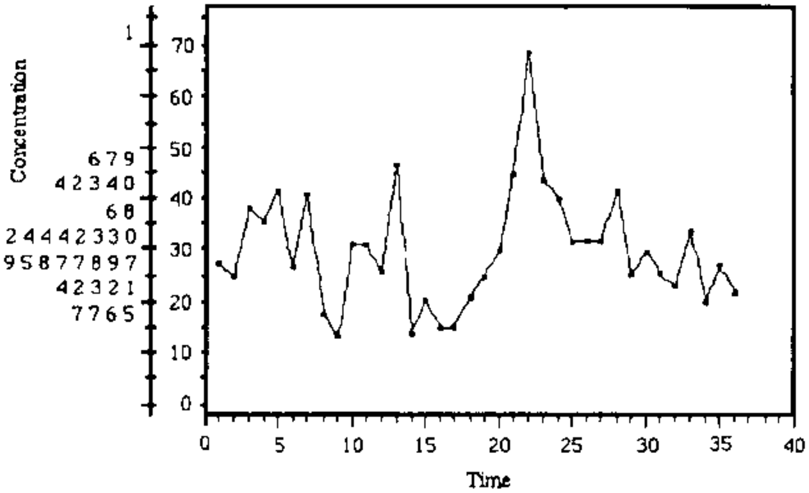


Figure C-4. Digidot Plot (Berthouex and Brown 1994).

Scatterplots

According to Berthouex and Brown (1994), the majority of the graphs used in science are scatterplots. They stated that these plots should be made before any other analyses of the data are performed. Scatterplots are typically made by plotting the primary variable (such as a water quality constituent) against a factor that may influence its value (such as time, season, flow, another constituent like suspended solids, etc.). Figure C-5 is a scatterplot showing COD values plotted against rain depth to investigate the possibility of a "first-flush," where higher concentrations are assumed to be associated with small runoff events (Pitt 1985). In this example, the smallest rains appear to have the highest COD concentrations associated with them, but the distribution of values is very wide. This may simply be associated with the much greater number of events observed having small rains and an increased likelihood of events having unusual observations to occur when more observations are made. When many data are observed for many sites, generally smaller rains do seem to be associated with the highest concentrations observed, but it is not a consistent pattern.

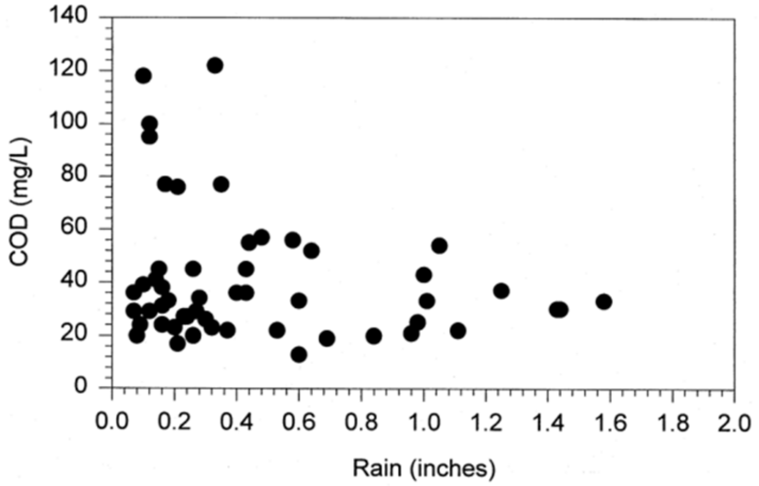


Figure C-5. Scatterplot for Bellevue, Washington, COD stormwater concentrations, by rain depth (Pitt 1985).

Grouped scatterplots (miniatures) of all possible combinations of constituents can be organized as in a correlation matrix (Figure C-6, Cleveland 1994). This arrangement allows obvious relationships to be easily seen, and even indicates if the relationships are straight-lined, or are curvilinear. In this example, the highest ozone values occur on days having the highest temperatures, and the lowest ozone concentrations occur on days having brisk winds and low temperatures. Figure C-7 contains several scatterplots of NSQD data showing poor correlation of residential area stormwater concentration with rain depth (Maestre and Pitt 2005). Figure C-8 are scatterplots used in QA/QC analyses of NSQD data showing reasonable relationships between constituents. In these cases, most of the dissolved copper and zinc concentrations are less than the concurrent total concentrations, as expected. Similarly, BOD5 is smaller than COD and ammonia is less than total Kjeldahl nitrogen values. Initially, several data sets were plotted with unreasonable relationships and review of the data indicated transcription errors that were corrected, for example.

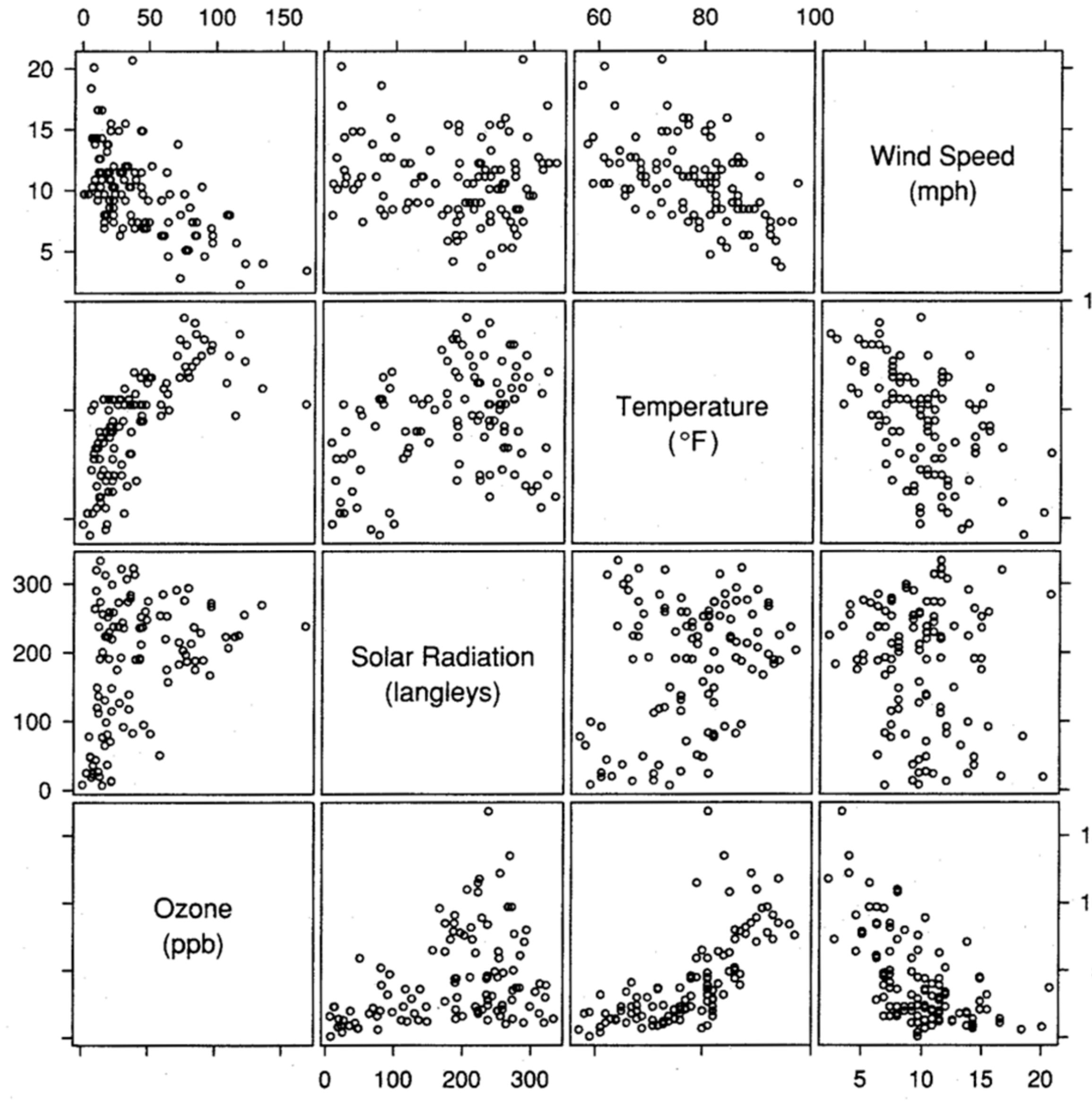


Figure C-6. Grouped scatterplot for ozone, solar radiation, temperature, and wind speed (Cleveland 1994).

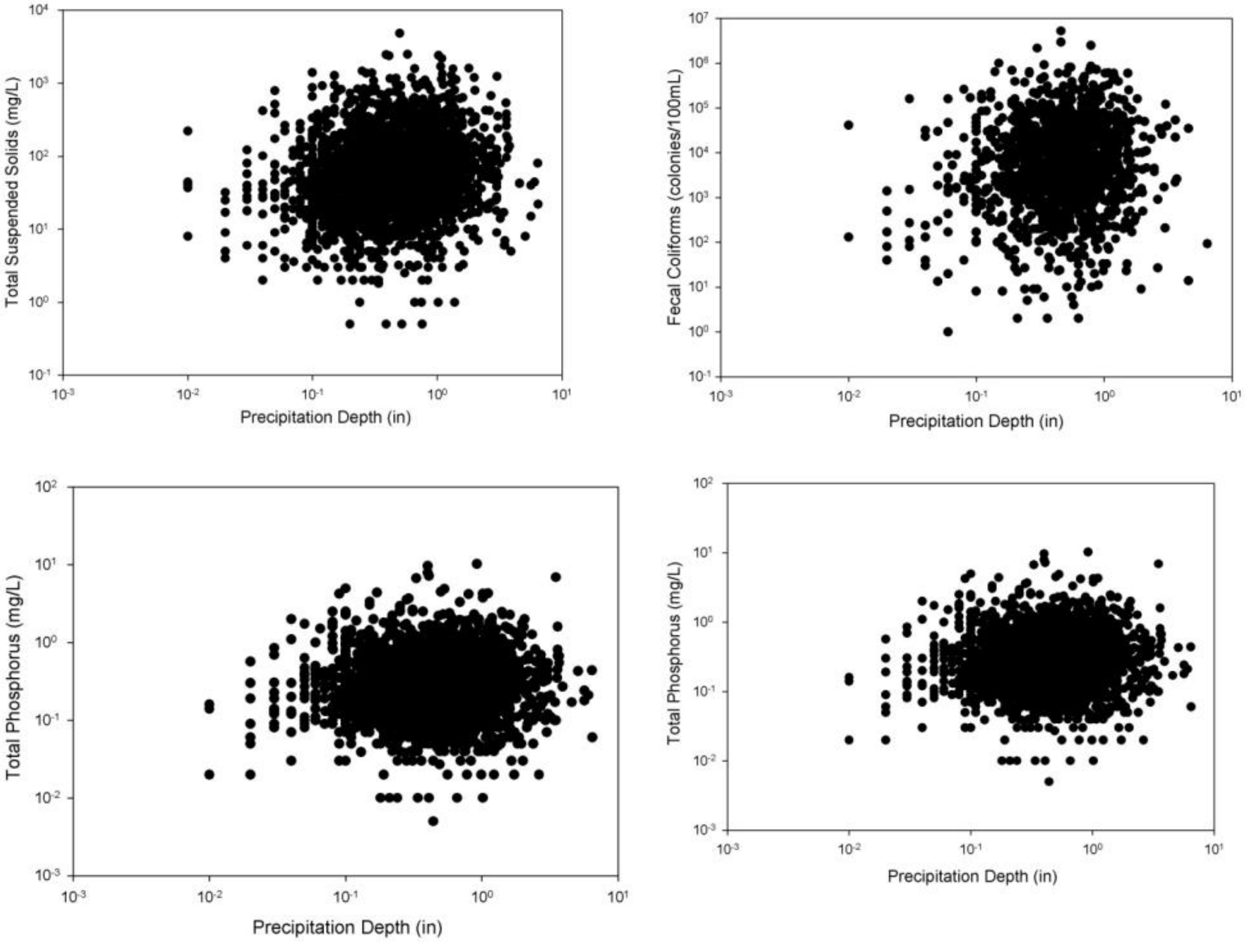
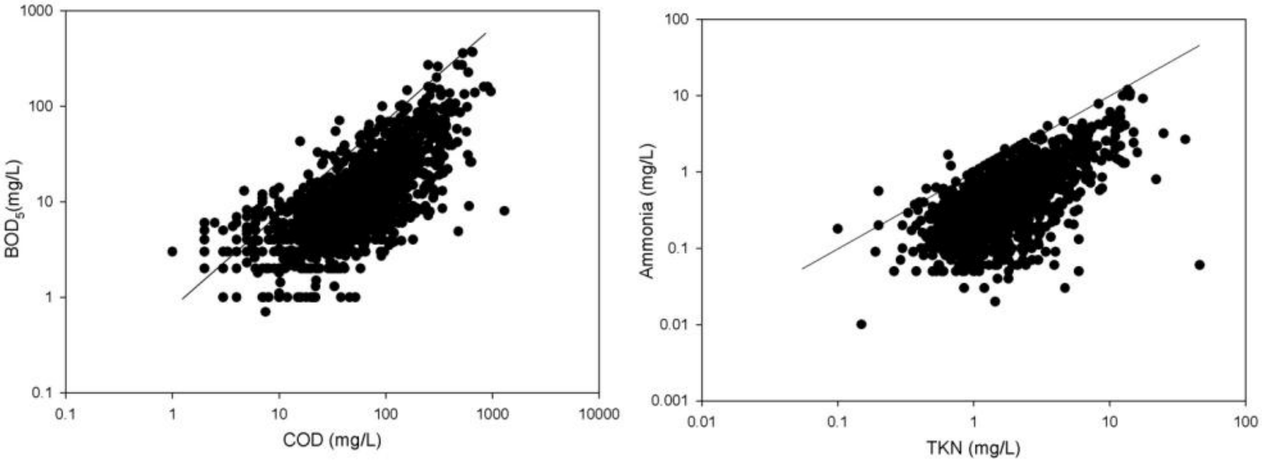


Figure C-7. Scatterplots of NSQD data showing poor correlation of residential area stormwater concentration with rain depth (Maestre and Pitt 2005).



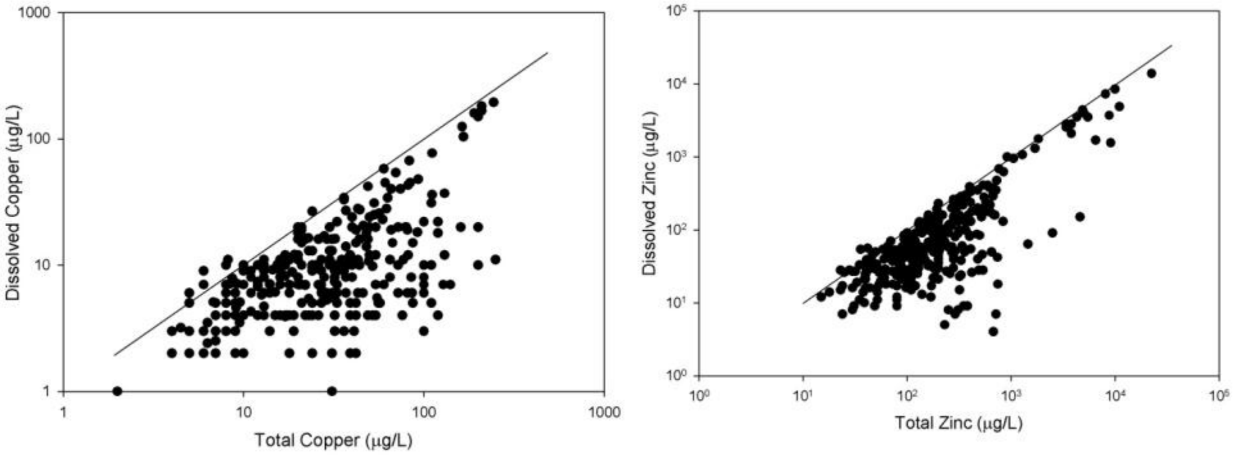


Figure C-8. Scatterplots used in QA/QC analyses of NSQD data showing reasonable relationships between constituents (Maestre and Pitt 2005).

Grouped Box and Whisker Plots

Another primary exploratory data analysis tool, especially when differences between sample groups are of interest, is the use of grouped box and whisker plots. Examples of their use include examining different sampling locations (such as above and below a discharge), influent and effluent of a treatment process, different seasons, etc. These plots indicate the range and major percentile locations of the data, as shown on Figure C-9 (Pitt 1985). In this example, seasonal groupings of stormwater quality observations for COD (Chemical Oxygen Demand) from Bellevue, Washington, were plotted to indicate obvious differences in the values. If the 75 and 25 percentile lines of the boxes do not overlap on different box and whisker plots, then the data groupings are likely significantly different (at least at the 95% level). When large numbers of data sets are plotted using box and whisker plots, the relative overlapping (or separation) of the plots can be used to identify possible groupings of the separate sets. In this case, there are no clear significant differences, but the summer season appears to have most of the highest concentrations observed.

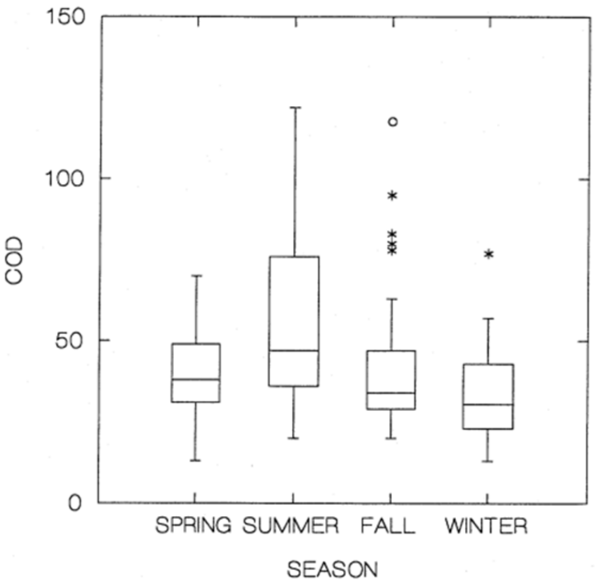


Figure C-9. Grouped box and whisker plot for Bellevue, Washington, COD stormwater concentrations, by season (Pitt 1985).

To supplement the visual presentation with the grouped box and whisker plots, a one-way ANOVA test (or the Kurskal-Wallis ANOVA on ranks test) should be conducted to determine if there is any statistically significant difference between the different boxes on the plot. ANOVA doesn't specifically identify which sets of data are different from any other, however. A multiple comparison procedure (such as the Bonferroni *t*-test) can be used to identify significant differences between all cells if the ANOVA finds that a significance difference exists. Both of these tests (ANOVA and Bonferroni *t*-test) are parametric tests and require that the data be normally distributed. It may therefore be necessary to perform a log-transformation on the raw data. These tests will identify differences in sample groupings, but similarities (to combine data) are probably also important to know.

Figure C-10 is a grouped box and whisker plot that shows significant differences in fluorescence values for groups of source waters. This was used in the inappropriate discharge study conducted by the Center for Watershed Protection and Pitt (2004) to distinguish groups of contaminated waters from clean water sources.

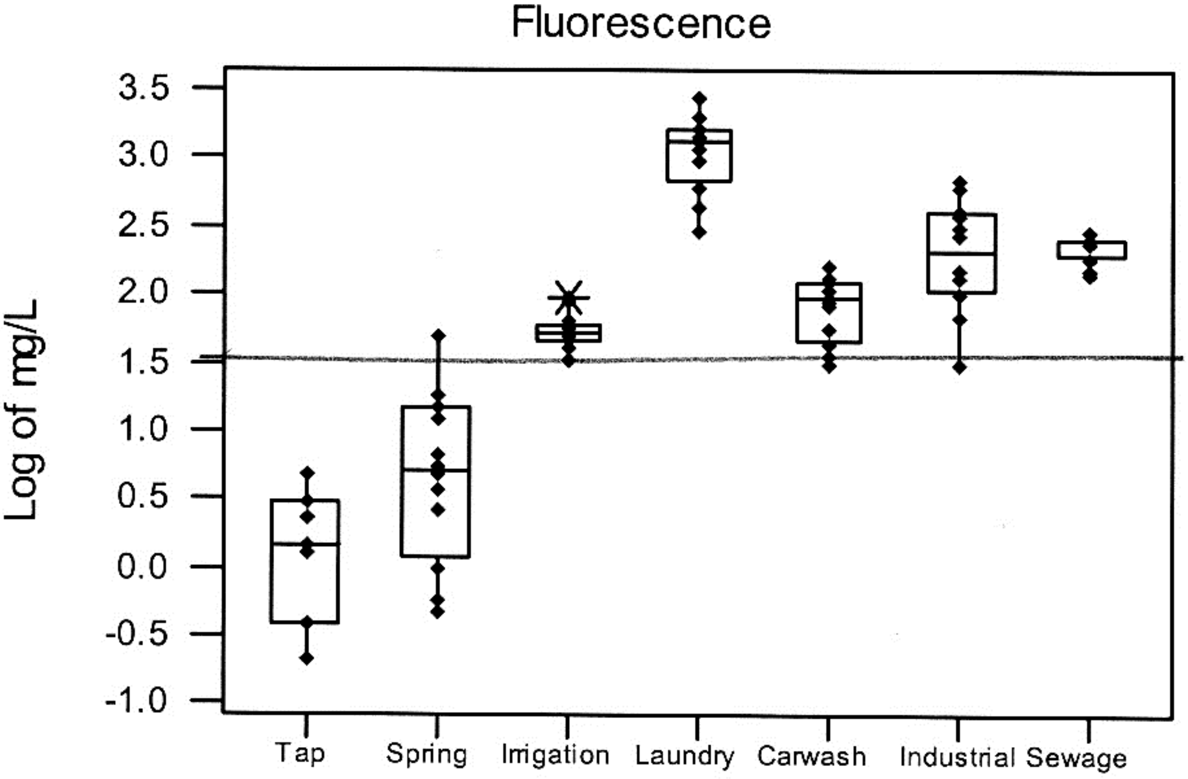


Figure C-10. Grouped box and whisker plot indicating significant differences in fluorescence values for groups of source waters (CWP and Pitt 2004).

Statistical Evaluation of a Water Treatment Control Device

The following example illustrates some graphical and statistical analysis methods used recently to evaluate a stormwater control device. This was for a media filter, but similar approaches could be used for biofilters and the other demonstration devices for the Cincinnati demonstration projects.

Controlled sediment removal tests were conducted for several media, different flow rates, and influent sediment concentrations. As shown in Figure C-11, the percentage reductions for suspended solids for the mixed media tests and high influent concentrations (485 to 492 mg/L) were 84 to 94%, with effluent concentrations ranging from 31 to 79 mg/L for flows ranging from 15 to 30 gal/min. During the low concentration tests (54 to 76 mg/L), the reductions ranged from 68 to 86 mg/L, with effluent concentrations ranging from 11 to 19 mg/L. The coarser bone char and activated carbon media tests had slightly poorer solids removal rates (62 to 79% during the highest flow tests), but with much higher flow rates (46 to 50 gal/min). At flows similar to the mixed media (21 to 28 gal/min), these coarser materials provided similar removals (about 79 to 88% for suspended solids). The flow rates therefore seemed to be more important in determining particulate solids capture than the media type.

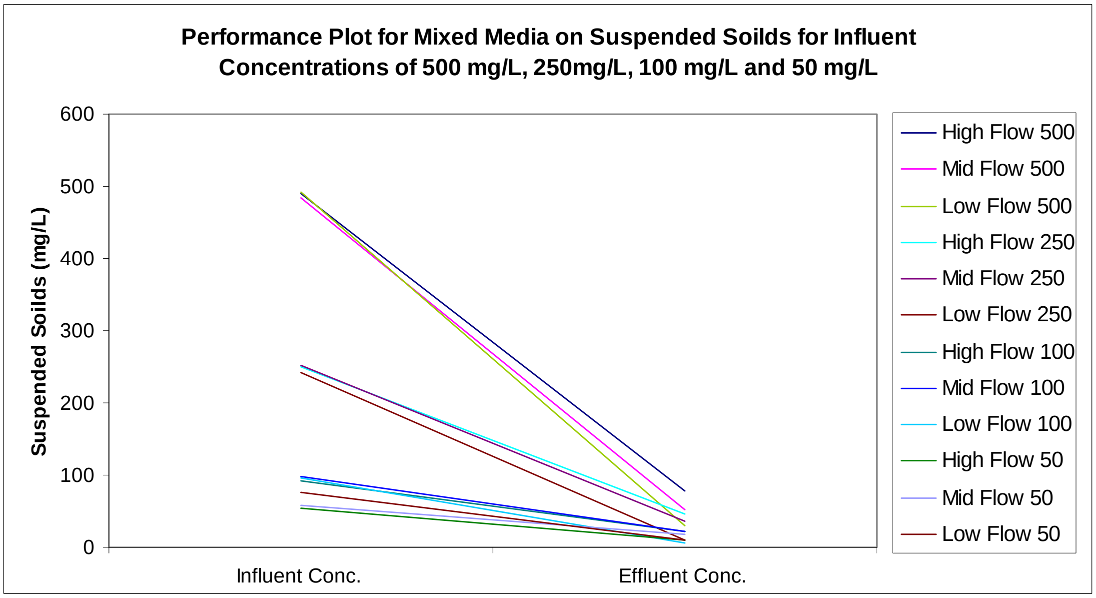


Figure C-11. Performance plot for mixed media for suspended solids at influent concentrations of 500 mg/L, 250 mg/L, 100 mg/L and 50 mg/L.

Every storm evaluated had a hyetograph (rainfall pattern) and hydrograph (runoff pattern) prepared with the treatment flow capacity marked for that particular event. An example is shown in Figure C-12.

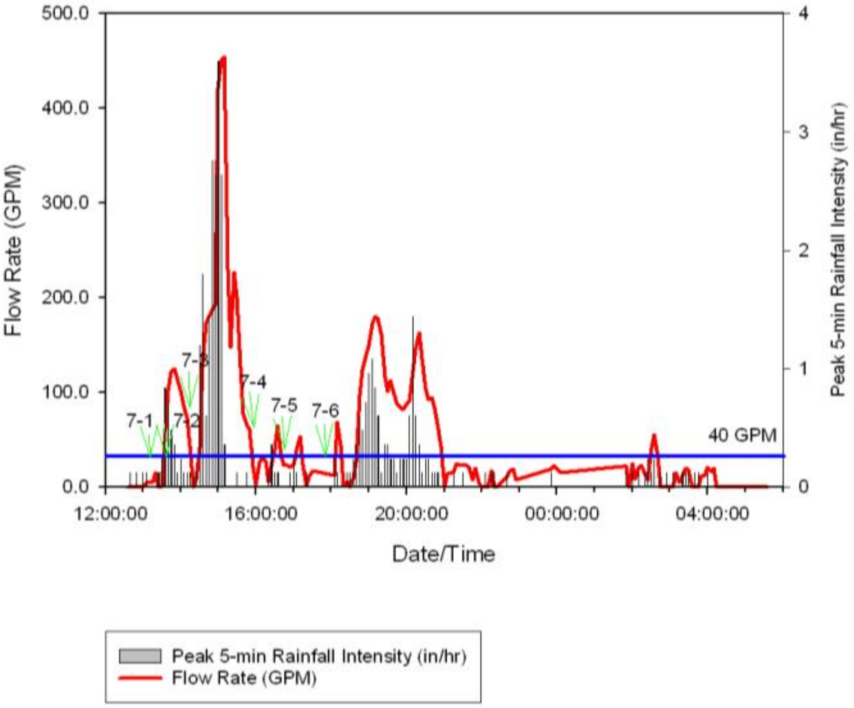


Figure C-12. Hydrograph and hyetograph for Hurricane Katrina (August 29, 2005).

Thirty-one separate rains occurred during the 10 month monitoring period from February 2 to November 21, 2005. The monitoring period started off unusually dry in the late winter to early summer months. However, the mid-summer was notable for severe thunderstorms having peak rain intensities (5-min) of up to 4 inches per hour. The late summer was also notable for several hurricanes, including Hurricane Katrina on August 29, 2005 that delivered about 3 inches of rain over a 15 hour period, having peak rain intensities as high as 1 in/hr in the Tuscaloosa area. During the monitoring period, the treatment flow rates were observed to decrease with time, as expected. Figure C-13 relates the decreasing flow rate with rain depth. The filter was always greater than the specified 25 gpm treatment flow rate during the 10 month period. It is estimated that the 25 gpm treatment flow would be reached after about 30 inches of rainfall (in an area having 0.9 acre of impervious surfaces), or after about 45,000 ft^3 of runoff, or after about 160 lbs of suspended solids, was treated by the filter.

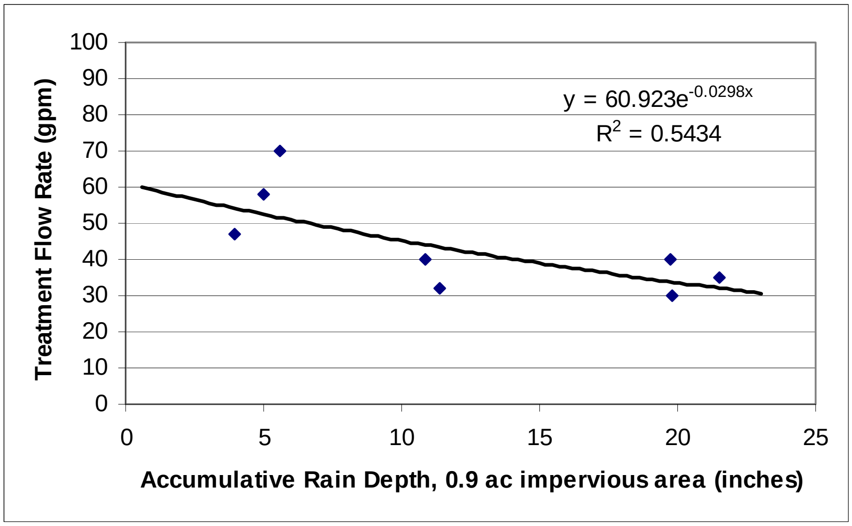


Figure C-13. UpFlo^{TM} filter treatment rate with rain depth.

These data indicate that the performance of the UpFlo^{TM} filter is dependent on influent concentrations. As an example, the following figures show the analyses for suspended solids. Figure C-14 is a scatterplot of the observed influent concentrations vs. the effluent concentrations, while Figure C-15 is a line plot that connects paired influent and effluent concentrations. These plots show generally large reductions in TSS concentrations for most events.

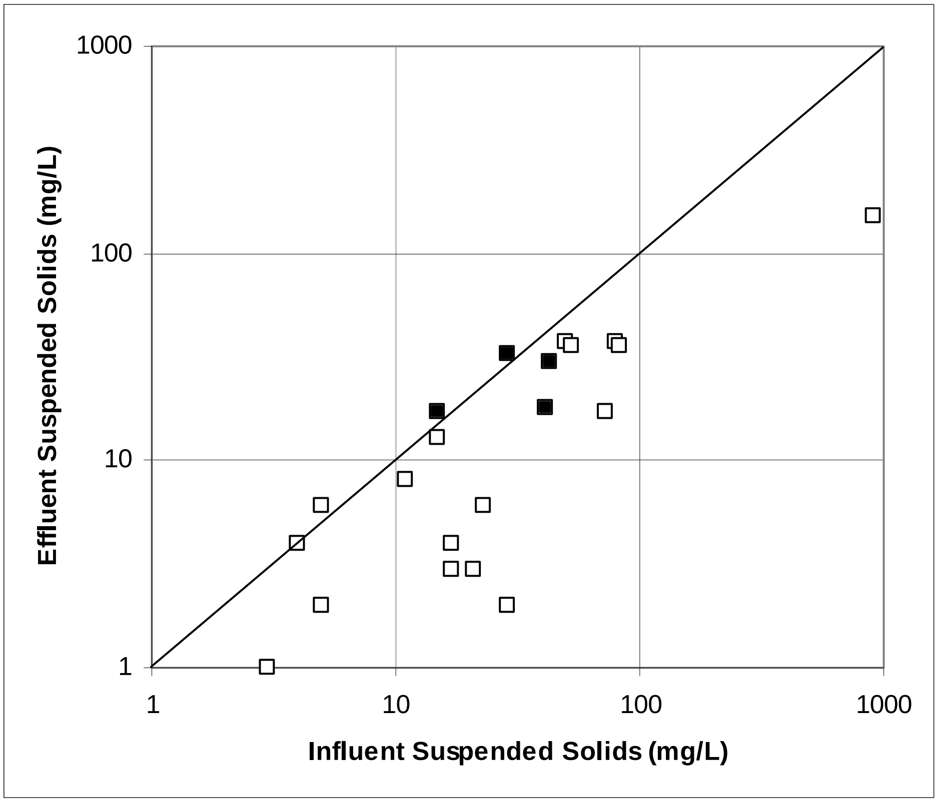


Figure C-14. Scatterplot of observed influent and effluent suspended solids concentrations (filled symbols are events that had minor filter bypasses).

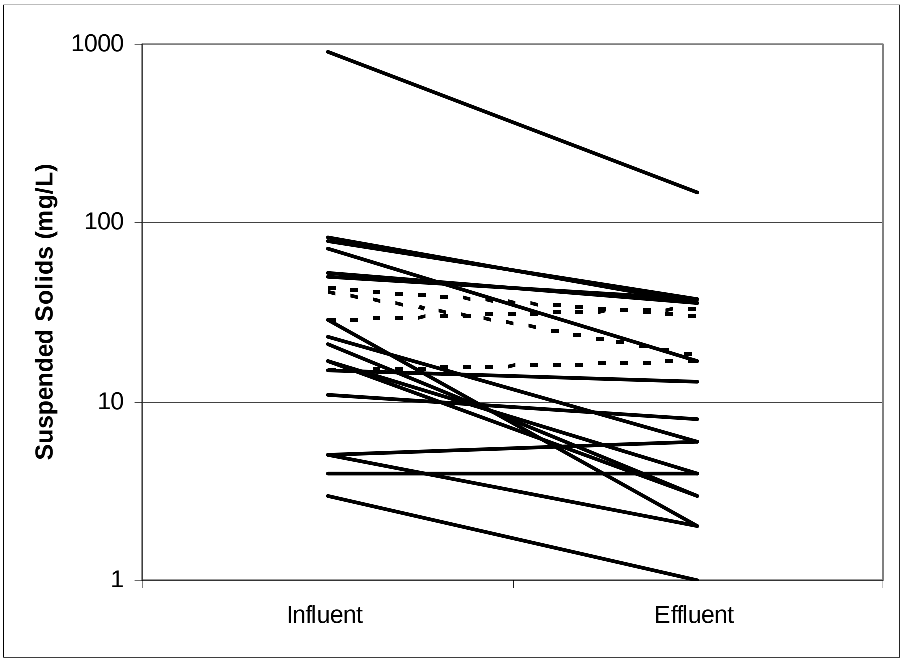


Figure C-15. Paired influent and effluent suspended solids concentrations.

The nonparametric sign test was also used to calculate the probability that the influent equals the effluent concentrations. For the TSS data, P < 0.01, indicating with >99% confidence that the influent does not equal the effluent concentrations. Therefore, the test was statistically significant at least at the α 0.05 level.

These data were fitted to regression equations to predict the effluent concentrations from the influent conditions. In all cases, the data needed to be log-transformed in order to obtain proper residual behavior. For TSS, the following equation was found to be very significant, according to the ANOVA analyses:

Effluent Suspended Solids, log mg/L = 0.730 * (Influent Suspended Solids, log mg/L)

Regression Statistics on Observed Influent vs. Effluent Suspended Solids, log mg/L

Multiple R	0.94
R Square	0.89
Adjusted R Square	0.85
Standard Error	0.37
Observations	24

ANOVA

	df	SS	MS	F	Significance F
Regression	1	25.4	25.4	187	3.11E-12
Residual	23	3.12	0.136		
Total	24	28.55			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
X Variable 1*	0.730	0.053	13.7	1.56E-12	0.620	0.841

* the intercept term was determined to be not significant during the initial analyses and was therefore eliminated from the model and the regression and ANOVA reanalyzed.

As indicated on the ANOVA analyses above, the intercept term was not significant when included in the model, so that term was removed, and the statistical test conducted again. The overall significance of the model is very good (F<<0.001), and the adjusted R^2 term is 0.85. The P-value for the slope term of the equation is also highly significant (P<<0.001) and the 95% confidence limit of the calculated coefficient is relatively narrow (0.62 to 0.84). Figure C-16 is a plot of the fitted equation along with the observed data, while Figure C-17 contains the residual plots, all showing acceptable patterns.

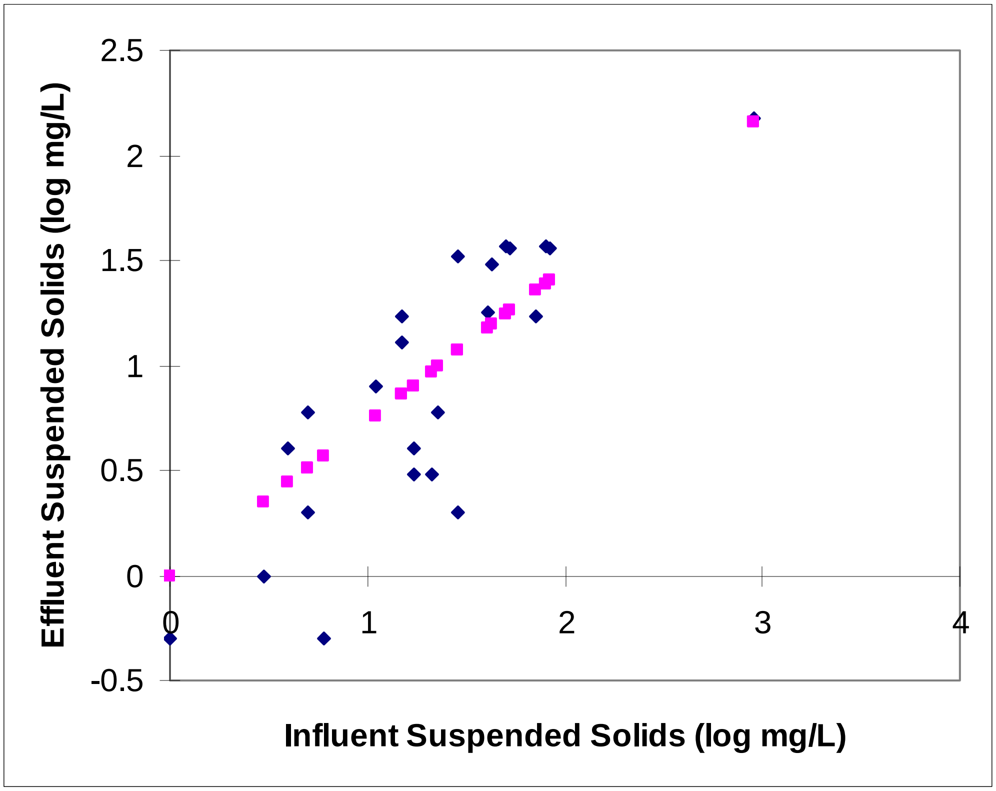


Figure C-16. Fitted equation and data points for influent and effluent suspended solids.

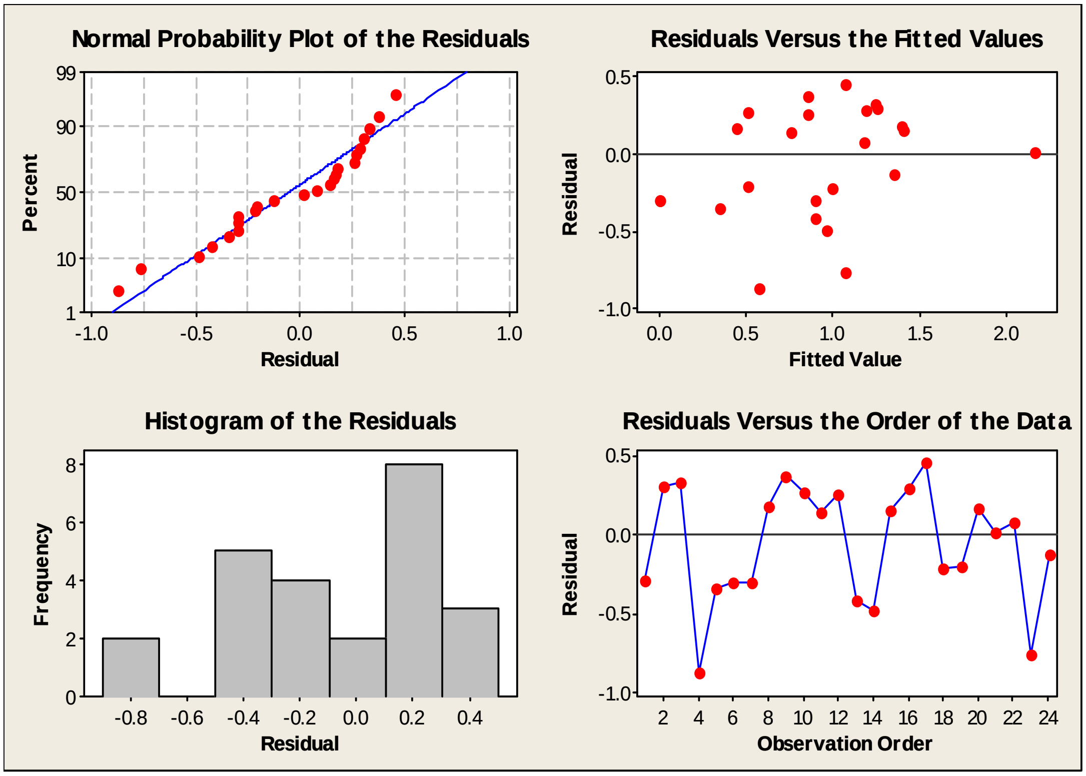


Figure C-17. Residual analyses of fitted equation for suspended solids influent vs. effluent.

Confidence intervals of the influent vs. effluent plots are shown in Figure C-18, while Figure C-19 shows the confidence intervals for calculated percentage reduction values. As indicated in Figure C-19, the TSS reductions would be >70% when influent concentrations exceeded about 80 mg/L, >80% when influent concentrations exceeded about 300 mg/L, and >90% when influent concentrations exceeded about 1000 mg/L.

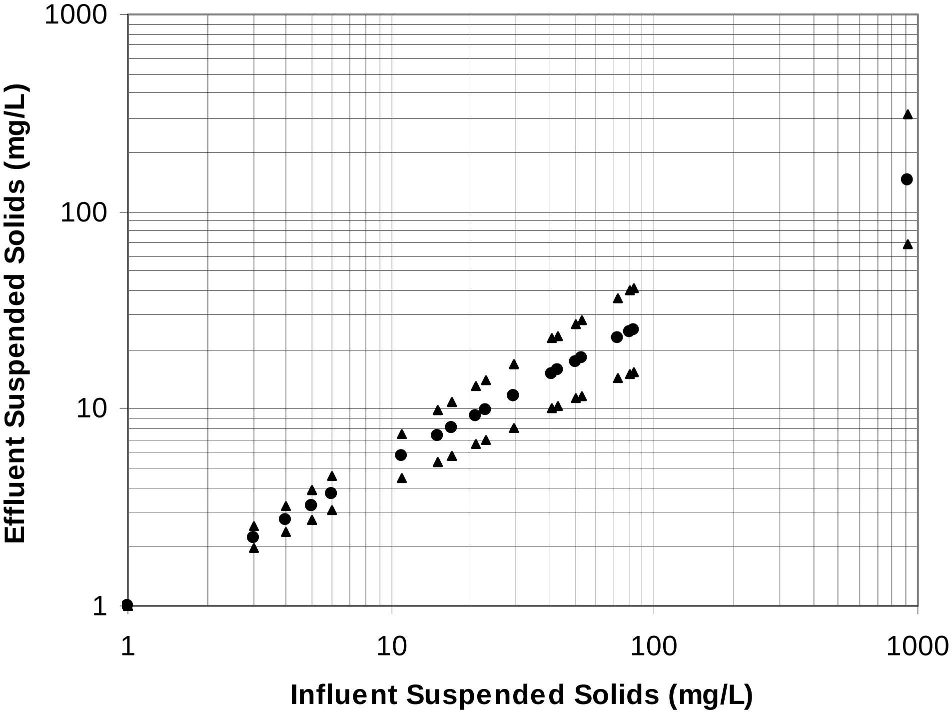


Figure C-18. Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.

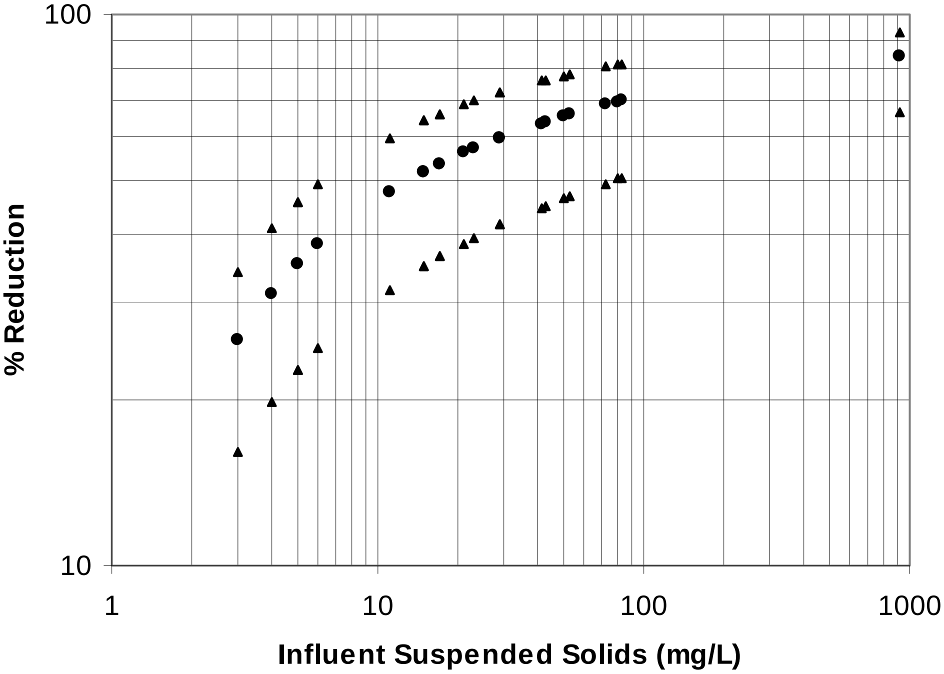


Figure C-19. Percentage reductions as a function of influent concentrations, with 95% confidence limits.

Tables C-1 summarizes the expected mass balance of particulate material removed by the UpFlow^{TM} filter during the sampling period, considering both the measurements from the automatic samplers (for suspended material <150 µm in size) and the larger material retained in the sump, assuming all the runoff was treated by the filter, with no bypass, and all material greater than about 250 µm would be retained in the filter and sump. The suspended solids removal rate is expected to be about 80%, while the removal rates for the other monitored constituents are expected to be about 72 to 84%, depending on their associations with the different particle sizes.

Table C-1. Calculated Mass Balance of Particulate Solids for Monitoring Period

particle size range (µm)	SS influent mass (kg)	SS effluent mass (kg)	SS removed (kg)	% reduction
0.45-3	9.3	2.8	6.6	70
3-12	18.7	6.4	12.3	66
12-30	22.4	7.7	14.7	66
30-60	26.7	6.8	19.9	74
60-120	4.6	1.8	2.9	61
120-250	19.8	4.3	15.5	78
250-425	11.5	0.0	11.5	100
425-850	17.1	0.0	17.1	100
850-2,000	10.5	0.0	10.5	100
2,000-4,750	4.8	0.0	4.8	100
>4,750	3.5	0.0	3.5	100
sum	148.9	29.8	119.2	80

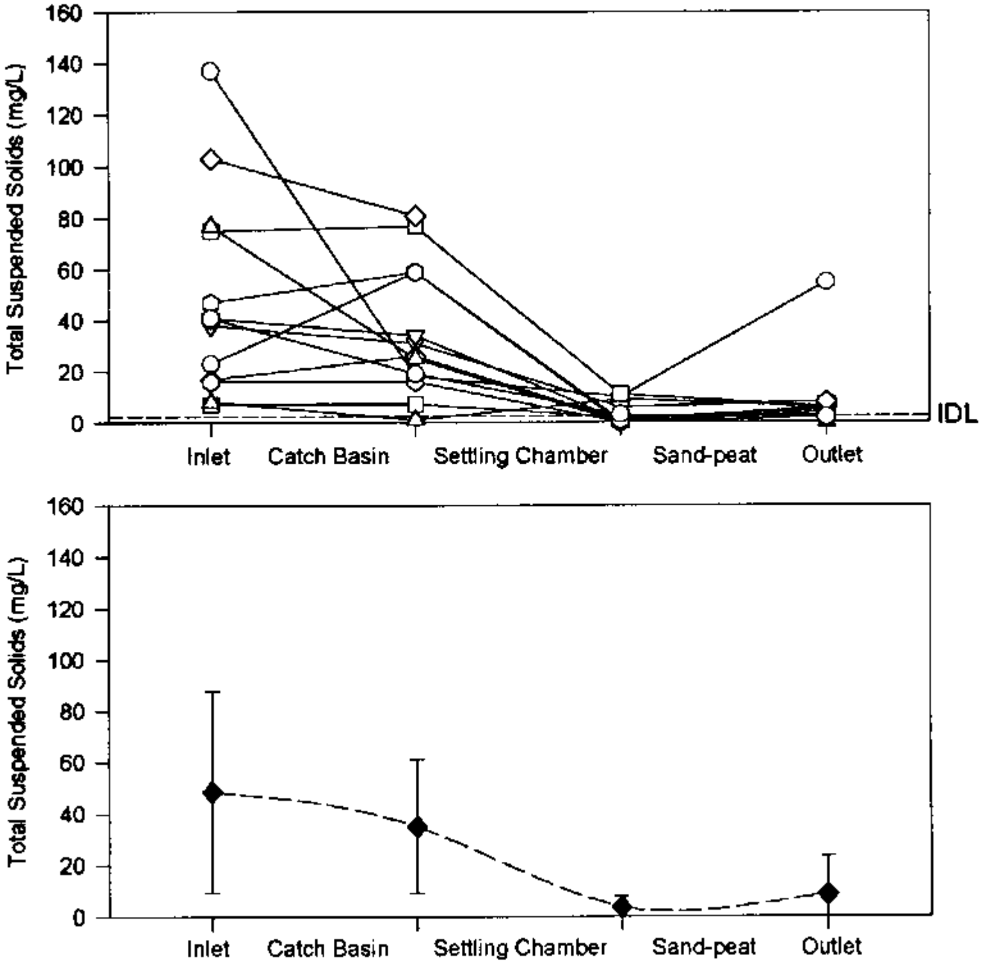
Other Exploratory Data Methods used to Evaluate Stormwater Controls

There are many other ways to present data from stormwater control practices. Several of these are shown in the following discussion.

Figure C-20 is a plot showing the TSS concentrations of influent water and after several stages of treatment in the multi-chambered treatment train (MCTT) (Pitt, *et al.* 1999). Even though the influent quality was highly variable, the effluent was quite consistent. The first event, with a high effluent, was associated with rinsing fine media that hadn't been adequately cleaned. Table C-2 is a listing of the TSS data for these MCTT tests (mg/L) for each of the 12 events. The following discussion outlines a simple analysis protocol that examined this data.

The first step in any analyses is to prepare several simple data plots. Figure C-20 is a scatterplot of influent and effluent TSS observations. Except for the one high effluent observation, most of the effluent appears to be relatively constant and not affected by the influent conditions. If this was the case, a regression analysis with ANOVA would result in the slope term being insignificant and the intercept being significant. This would imply that there is no relationship between the influent and effluent TSS quality, and the effluent quality is constant for all conditions, a very favorable outcome. Figure C-21 is the same plot, but with log transformations. In this case, there appears to be a positive trend between the influent and effluent, although slight. Figure C-22 contains box and whisker plots of the influent and effluent TSS data, in actual and log space. Normal and log-normal probability plots of the influent and effluent MCTT TSS data are shown in Figure C-23. These plots show reasonable parallel probability lines for the log-normal plot. Figure C-24 shows a log-normal probability plot of the influent TSS data and Anderson-Darling test results, indicating a good fit (after the one large effluent data value was removed as that was an unusual observation associated with the first test and media that was not completely washed).

Figure C-25 shows the data and the fitted regression line, with the 95% significance limits. The limits are very wide due to the few data observations (11 sets shown here). Table C-3 shows the ANOVA results for the fitted regression line of this TSS MCTT data. This shows that the regression is not significant and that there is no significant relationship between the influent and effluent TSS observations. The effluent TSS can therefore best be described using a probability plot, as the little variability present cannot be adequately explained by the changing influent conditions. Far from being a problem with statistical analyses, this is the desired result from a control device: the effluent quality is consistent and not related to influent conditions. Of course, the excellent quality of the effluent is also very important!



	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1543	0.0010	-0.1191	0.0002
Min. Percent Reduction	-157	-800	-500	25
Max. Percent Reduction	88	100	45	100
Median Percent Reduction	17	91	-400	83
Std. Dev. of Percent Reduction	65	257	240	22
COV of Percent Reduction	7.4	19	-1.5	0.28

Figure C-20. Line plot and statistical summaries showing performance of MCTT for different treatment components (Pitt, *et al.* 1999).

Table C-2. Total Suspended Solids Data for MCTT tests (mg/L) (Pitt, *et al.* 1999).

STORM	INLET	OUTLET
1	137	55
2	7	3

3	8	6
4	38	8
5	17	6
6	16	4
7	23	<2.5
8	75	6
9	77	<2.5
10	41	5
11	103	8
12	41	<2.5

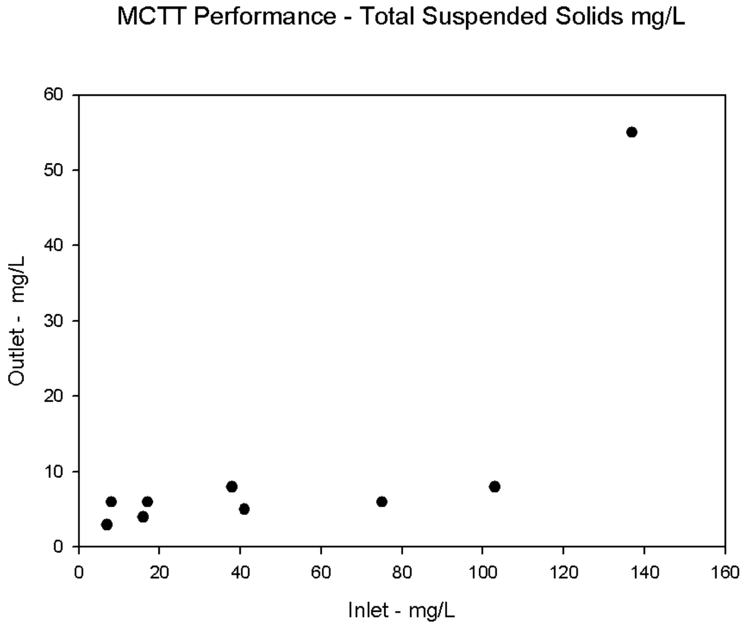


Figure C-20. Plot of influent and effluent MCTT TSS data (Pitt, *et al.* 1999).

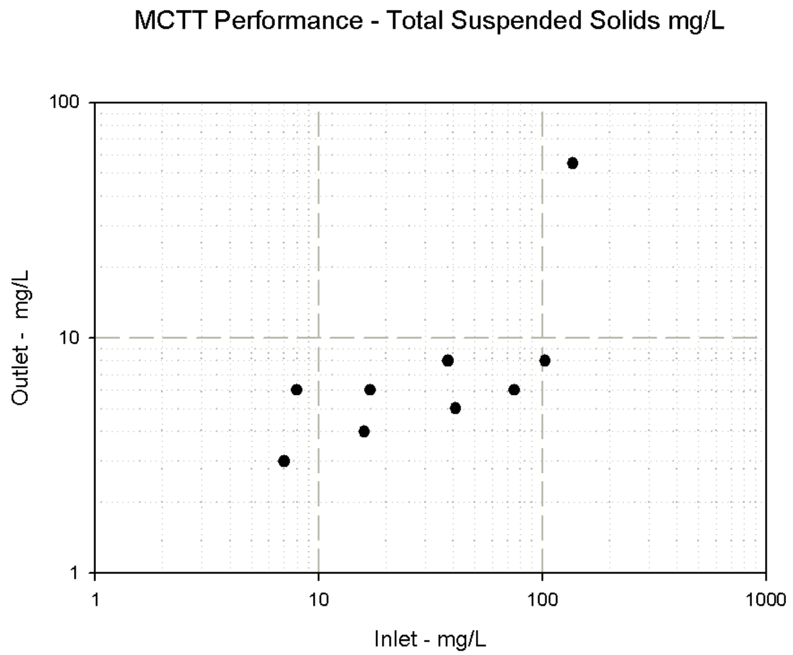


Figure C-21. Plot of influent and effluent MCTT TSS data, log transformed data (Pitt, *et al.* 1999).

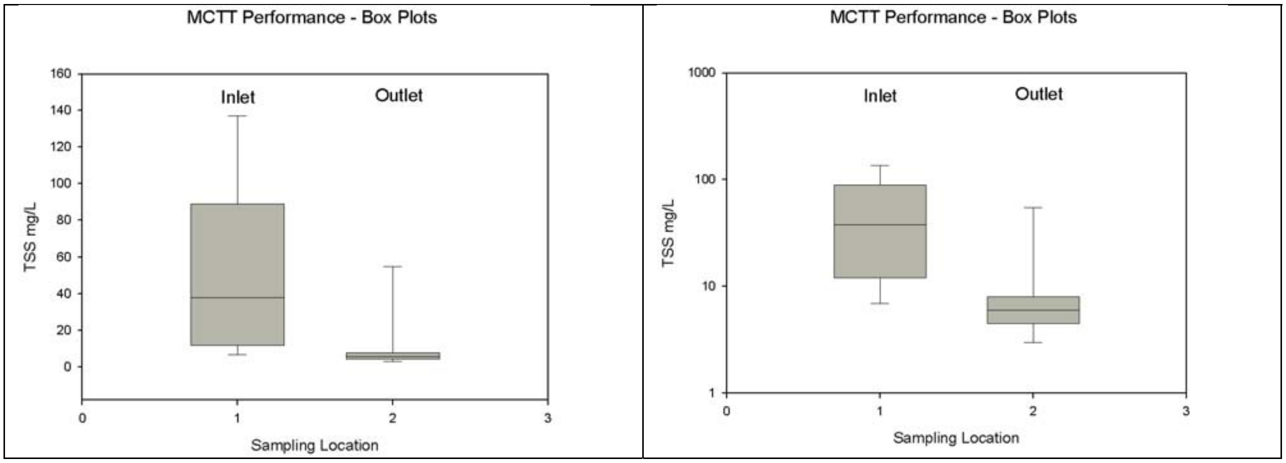


Figure C-22. Box and whisker plots of influent and effluent TSS data for MCTT, in actual and log space.

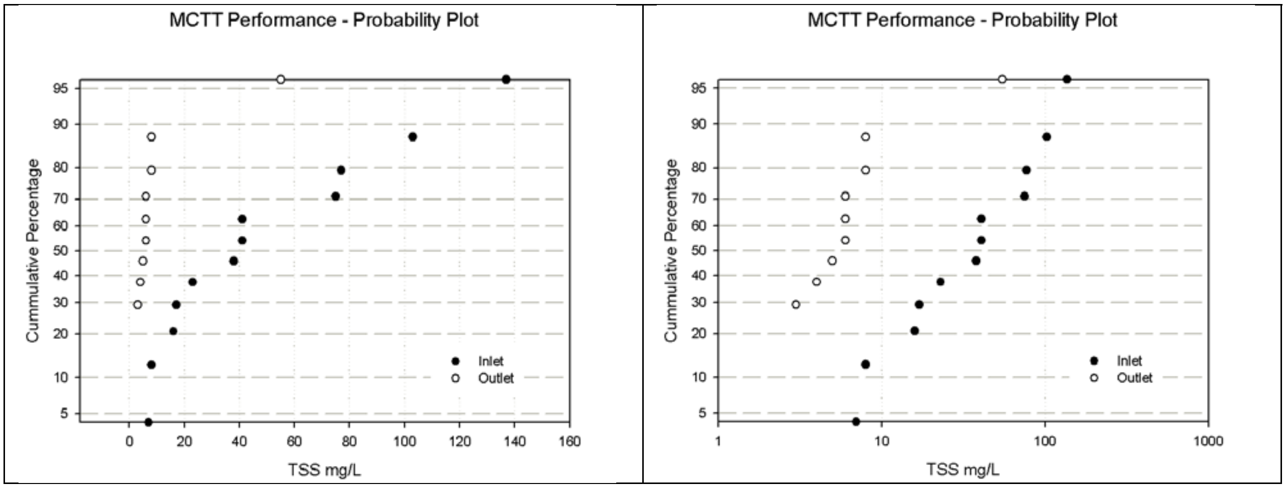


Figure C-23. Normal and log-normal probability plots of influent and effluent MCTT TSS data.

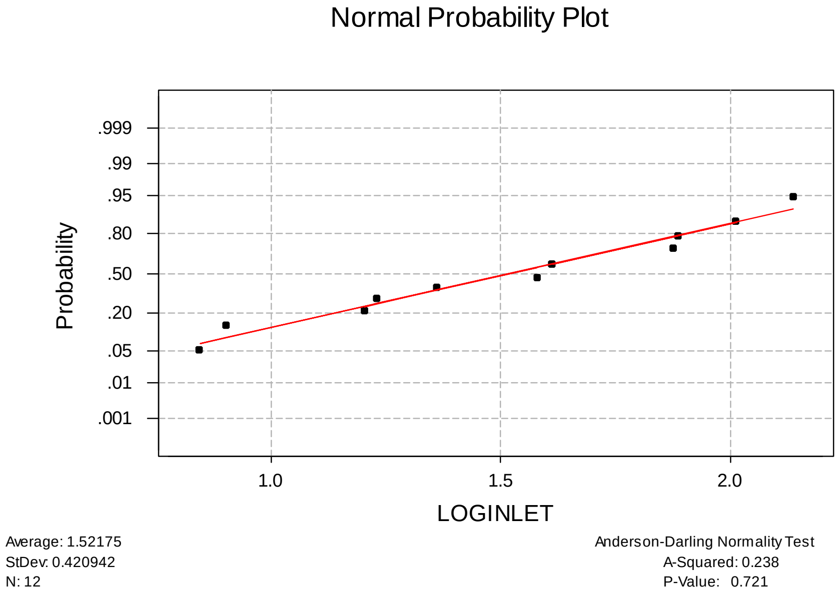


Figure C-24. Log probability plot of influent TSS data and Anderson-Darling test results.

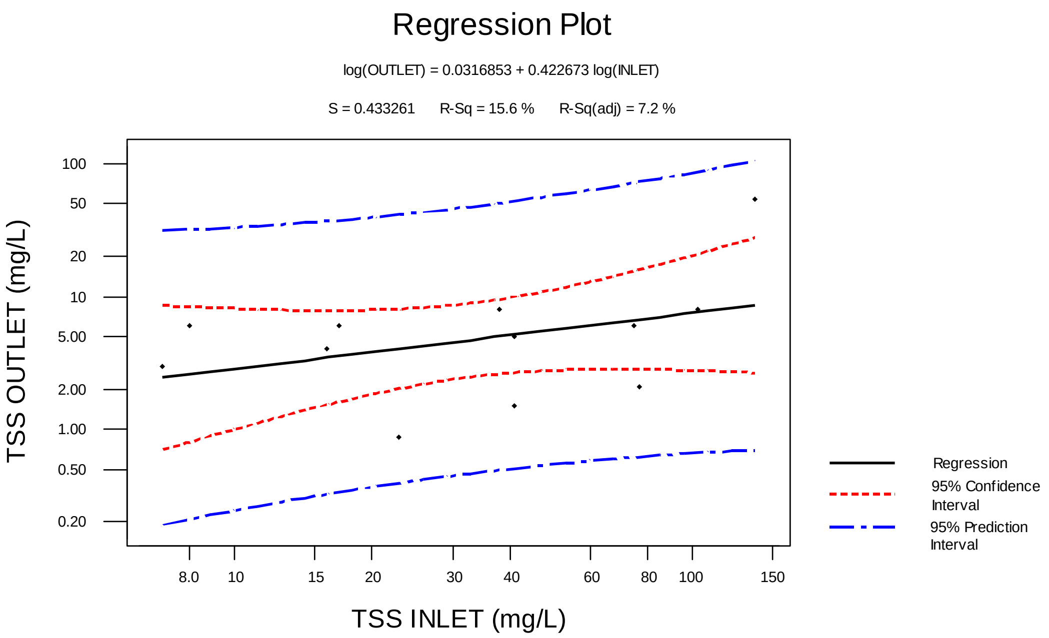


Figure C-25. Data and regression line, with 95% significance limits.

Table C-3. ANOVA Results for Regression Analysis of TSS MCTT Data.

```
Dependent variable is:    LOGOUTLET
No Selector
R squared = 15.6%     R squared (adjusted) = 7.2%
s =  0.4332  with  12 - 2 = 10  degrees of freedom

Source        Sum of Squares    df    Mean Square    F-ratio
Regression    0.347854           1       0.347854     1.85
Residual      1.87625           10       0.187625

Variable      Coefficient    s.e. of Coeff    t-ratio    prob
Constant      0.0333252      0.4876           0.0683     0.9469
LOGINLET      0.421692       0.3097           1.36       0.2032
```

Figure C-26 is a comparison of two alternative upflow treatment schemes, comparing the benefits of a suitable sump (Johnson, *et al*. 2003). The benefit of the sump was much more obvious for turbidity than for total solids, although it still provided a significant improvement for all constituents.

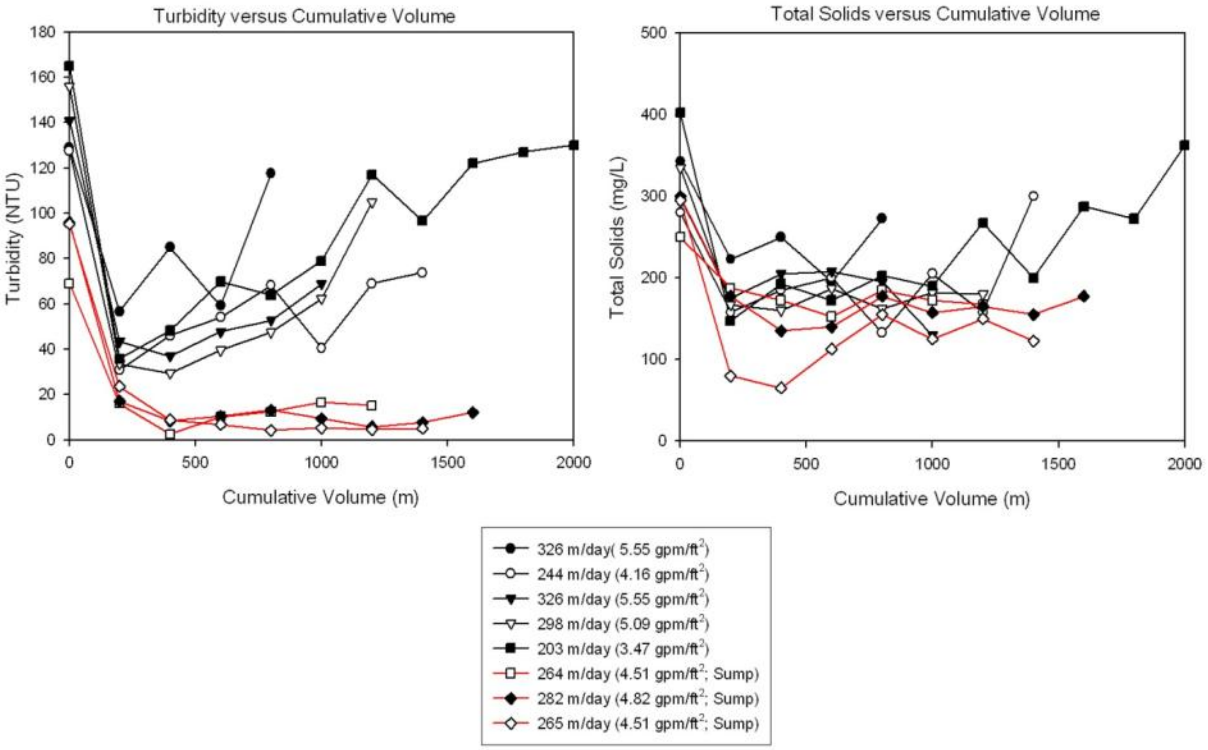


Figure C-26. Comparisons of two alternative upflow treatment schemes (Johnson, *et al.* 2003).

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