Appendix 8 Low Impact Development Practices

United States
Environmental Protection Agency

Office of Water (4203)
Washington, DC 20460

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October 2000

Bioretention Applications

Inglewood Demonstration Project, Largo, Maryland
Florida Aquarium, Tampa, Florida

Key Concepts:

- Retrofits
- Structural Controls
- Source Controls

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Project Benefits:

- Retrofit Opportunity
- Pollutant Removal
- Volume Reduction
- Cost-Effectiveness

Introduction

Two case studies demonstrate the potential to use integrated management plans (IMPs) in the design of new parking facilities and as retrofits for existing parking facilities. The Inglewood study in Largo, Maryland, compared the pollutant removal efficiency of a bioretention cell in a laboratory setting to that of a comparable facility constructed in a parking lot. The Florida Aquarium study in Tampa, Florida, included monitoring of several storm events for volume and water quality control.

Inglewood Project Area

The project area is an existing 5-acre outdoor parking area located in a highly urbanized office park adjacent to Interstate 95. Runoff from adjacent areas does not flow across the lot. The slope of the parking area is approximately 3 percent. Parking stalls are aligned at 90-degree angles, and there are approximately 30 cars in each row of an aisle. At the end of each aisle are planting areas surrounded by curbs and gutters. Curb drainage inlets have been placed in some of the islands to intercept and collect runoff as sheet flow, which is piped to a downstream regional stormwater management facility.

Inglewood Project Description

The Inglewood project consisted of a laboratory segment and a field segment. The laboratory segment involved construction of a planter box filled with a typical bioretention facility soil mixture (50 percent construction sand, 20 to 30 percent topsoil, and 20 to 30 percent compost). This facility is approximately half the size in volume of the Inglewood facility. The box was planted with representative plants and mulched. A synthetic stormwater mixture was applied and the pollutant removal efficiency, temperature, and runoff volume rate were measured. The pollutant mix included metals (copper, lead, and zinc), phosphorus, organic nitrogen, and nitrate.

A landscaped island measuring approximately 38 feet by 12 feet was chosen as the retrofit area. The island contains a curb inlet that drains into the municipal storm drain system. Almost the entire drainage area is impervious. A 4-foot slot was cut into the curb immediately before the inlet. The landscaped island was then excavated to a depth of 4 feet. An underdrain was installed and tied into the bottom of the existing inlet to completely drain the planting soil to avoid oversaturation. The underdrain was covered with 8 inches of 1- to 2-inch gravel and backfilled with typical bioretention soil mix. The backfill extended to a depth of about 12 inches below the top of the curb, which allows for a ponding depth of approximately 6 inches of water in the island

Figure 1. Bioretention landscaping at the Inglewood demonstration project site.

Table 1. Summary of bioretention pollutant removal results for the Inglewood demonstration project.

Pollutant	Input mean ± standard deviation	Output mean ± standard deviation	Output range	Output percent removal mean ± standard deviation
Cu dissolved (μg/L)	120 ± 27	63 ± 6.5	55–75	48 ± 12
Cu total (μg/L)	120 ± 27	69 ± 9.4	55–85	43 ± 11
Pb dissolved (μg/L)	54 ± 9.4	11 ± 6	6.7–25	79 ± 26
Pb total (μg/L)	54 ± 9.4	16 ± 7	6.7–26	70 ± 23
Zn dissolved (mg/L)	1.1 ± 0.021	0.24 ± 0.44	0.11–0.56	78 ± 29
Zn total (mg/L)	1.1 ± 0.021	0.39 ± 0.44	0.12–1.4	64 ± 42
Ca (mg/L)	44 ± 6.4	32 ± 6.1	24–41	27 ± 14
Cl^- (mg/L)	5.1 ± 0.48	162 ± 80	74–228	3,000[a]
Na (mg/L)	3.1	359 ± 170	68–497	11,000[a]
P (mg/L)	0.83	0.11 ± 0.017	0.10–0.13	87 ± 2
TKN (mg/L as N)	6.9 ± 0.81	2.3 ± 0.64	1.7–3.0	67 ± 9
NO_3^- (mg/L as N)	1.3 ± 0.05	1.1 ± 0.15	0.94–1.2	15 ± 12

[a] Shows percent production.

before a backwater is created at the curb opening. Subsequently the area was planted and covered with 3 inches of shredded hardwood mulch. Figure 1 shows the bioretention area after vegetation was established.

The stormwater mixture was applied to a 50-square-foot area in the field facility at a rate of 1.6 inches per hour for 6 hours. The removal rates for several pollutants are shown in Table 1. In addition to pollutant removal, the runoff temperature was lowered approximately 12 °C as the runoff was processed and filtered through the soil mixture. Most of the pollutant removal process occurred in the mulch layer.

A similar field investigation was conducted on an 8-year-old facility, and the metals removal rate was much higher (Davis et al., 1998). This effect might be attributed to slower flow rates through the soil, which has higher clay content, as well as greater pollutant uptake by vegetation.

Inglewood Project Summary and Benefits

This study showed the feasibility of retrofitting an existing parking facility and demonstrated the consistency of laboratory and field pollutant removal performance. The retrofit cost approximately $4,500 to construct and treats approximately one-half acre of impervious surface. The bioretention retrofit was a more cost-effective way to filter pollutants than many proprietary devices designed to treat the same volume of runoff. These proprietary devices could cost $15,000 to $20,000, would be more expensive to maintain, and would not significantly decrease runoff volume or temperature. Also, bioretention areas offer the ancillary benefit of aesthetic enhancement. It is interesting to note that a drought occurred after the installation of the plants, and although many of the other plants in the parking lot died or experienced severe drought stress, the plants in the bioretention facility survived because of the retained water supply.

Florida Aquarium Project Area

The Florida Aquarium site is an 11.5-acre, asphalt and concrete parking area that serves approximately 700,000 visitors per year. Runoff was controlled using the following IMPs:

- End-of-island bioretention cells
- Bioretention swales located around the parking perimeter
- Permeable paving
- Bioretention strips between parking stalls
- A small pond to supplement storage and pollutant removal

Figure 2 is an illustration of the site that details the type and location of runoff controls.

Florida Aquarium Project Description

A total of 30 storm events were monitored for one year at the Florida Aquarium site during 1998-1999. The Southwest Florida Water Management

District measured rainfall and flow from eight of the subcatchments in the parking area and collected water quality samples on a flow-weighted basis. Comparisons between pavement areas controlled by IMPs and uncontrolled asphalt areas were made for peak runoff rate, runoff volume, runoff coefficients, and water quality. Sediment cores from swales also were collected and analyzed.

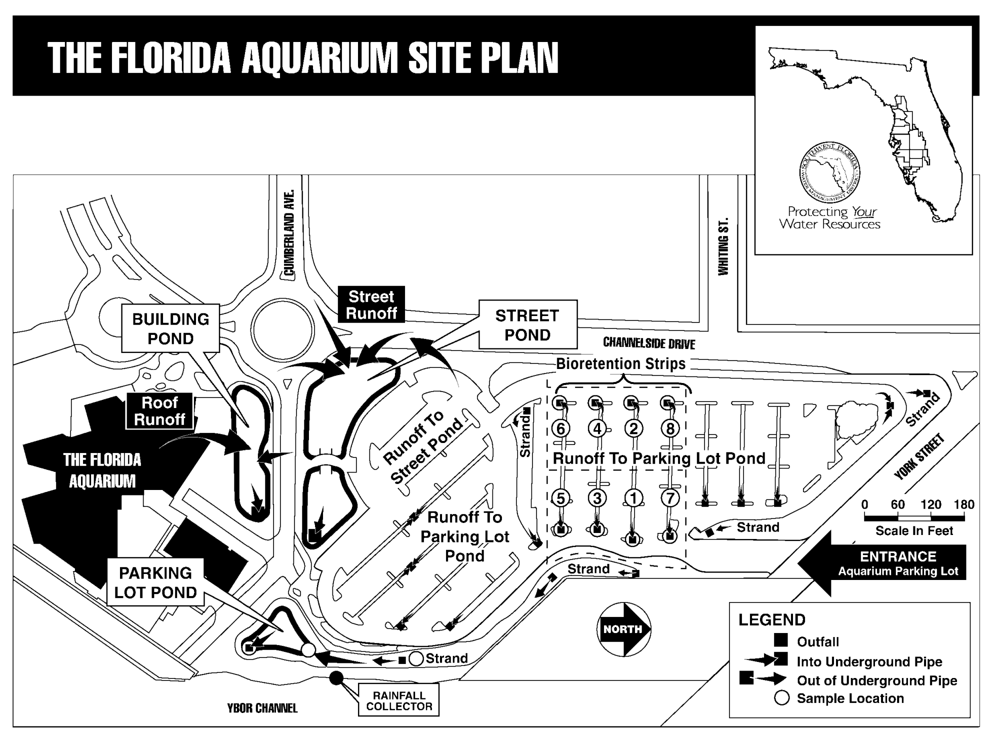

Figure 2. Layout of the Florida Aquarium site with IMPs. The eight basins outlined with dotted lines were evaluated in this part of the study.

Florida Aquarium Project Summary and Benefits

The parking areas controlled by IMPs showed a significant reduction in runoff volume and peak runoff rate. Table 2 shows pollutant load reductions for three pavement types; reduction is compared to pollutant loads in runoff from a basin without a swale. Much of the pollutant reduction is attributed to the reduced runoff in basins with swales. Because the swales are only the first element in the treatment train, even better removal efficiencies should be seen when data are analyzed for the entire system.

Table 2. Load efficiency of pollutants expressed as percent reduction for three types of pavement at the Florida Aquarium site.

Constituents	Percent pollutant reduction[a]		
	Asphalt w/swale	Cement w/swale	Porous w/swale
Ammonia	45	73	85
Nitrate	44	41	66
Total Nitrogen	9	16	42
Orthophosphorus	-180	-180	-74
Total Phosphorus	-94	-62	3
Suspended Solids	46	78	91
Copper	23	72	81
Iron	52	84	92
Lead	59	78	85
Manganese	40	68	92
Zinc	46	62	75

[a] The basins with swales were compared to a basin without a swale to determine the amount of reduction in pollutant loads possible using these small alterations. Notice that the efficiencies for phosphorus are negative, indicating an increase in phosphorus load in the basins with a swale.

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Field Evaluation of Permeable Pavements for Stormwater Management

Olympia, Washington

Key Concepts:

- Structural Controls
- Volume Reduction
- Space Savings

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Project Benefits:

- Elimination of Stormwater Ponds
- Demonstration of Water Quality Benefits
- Lower Maintenance

Introduction

This study demonstrates the potential of permeable pavement systems to restore soil infiltration functions in the urban landscape. It is based on the results of a project that included installing and monitoring several porous pavement systems in a parking area. The project's objectives were to

- Review existing information on permeable pavements
- Construct full-scale test sites
- Evaluate the long-term performance of these systems

The report outlines the difficulties encountered, costs of installing and maintaining the systems, performance based on existing soil systems, special benefits of filling the open cells with grass as opposed to gravel, and other water quality benefits.

Project Area

The demonstration site was in an office parking lot in Olympia, Washington. Two adjacent parking stalls were constructed using four types of permeable pavement systems that consisted of a combination of grass and gravel, as shown in Figure 1. The designs were

1. A flexible system consisting of a plastic network of cells with grass infill and virtually no impervious area coverage.
2. A flexible system consisting of a plastic network of cells similar to design 1 but filled with gravel.
3. A system consisting of impervious blocks with the space between the blocks filled with grass. (Total surface area is 60 percent impervious).
4. A system consisting of impervious blocks with the space between the blocks filled with gravel. (Total surface area is 90 percent impervious).

A control stall was constructed out of traditional asphalt. A system of pipes, gutters, and automatic sampling gauges was installed to collect and measure the quantity and chemistry of surface runoff and subsurface infiltrate. Figure 2 shows a schematic of the test facility.

Figure 1. Different types of permeable pavement. From top left: reinforced gravel and grass pavement, reinforced grass pavement, 60% impervious concrete blocks with grass, 90% impervious blocks with gravel.

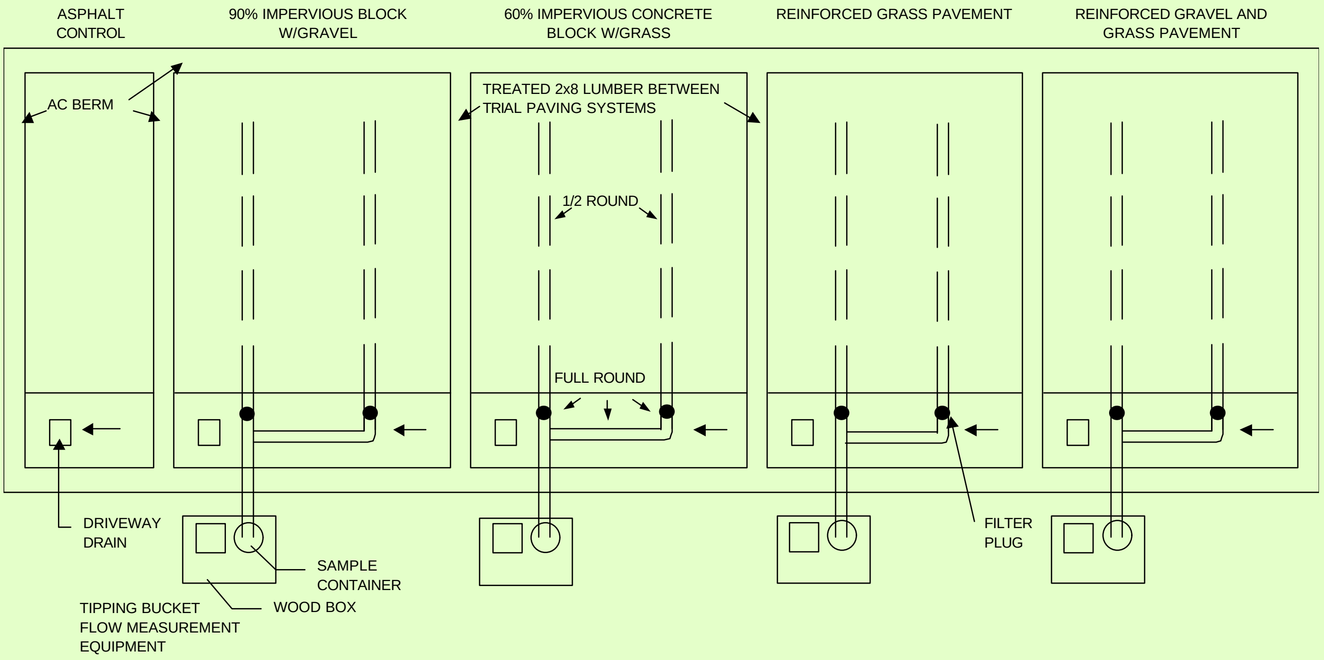

Figure 2. Schematic of the test facility showing treatments and runoff collection devices.

Project Summary and Benefits

The results of this study showed the following relationships:

- The use of permeable pavement systems dramatically reduced surface runoff volume and attenuated the peak discharge, as shown in Figure 3.
- Although there were significant structural differences between the systems, the hydrologic benefits were consistent.
- Storm characteristics and weather conditions influenced the hydrologic responses of the systems.
- Permeable pavement system types vary widely in cost and are more expensive than typical asphalt pavements. Cost comparisons between permeable pavement installations and conventional ponds or underground vaults are limited. However, the elimination of conventional systems and reduced life cycle and maintenance costs can result in significant cost savings over the long term.
- A significant contribution of permeable pavements is the ability to reduce *effective impervious area*, which has a direct connection with downstream drainage systems. This strategy of hydrologic and hydraulic disconnectivity can be used to control runoff timing, reduce runoff volume, and provide water quality benefits.

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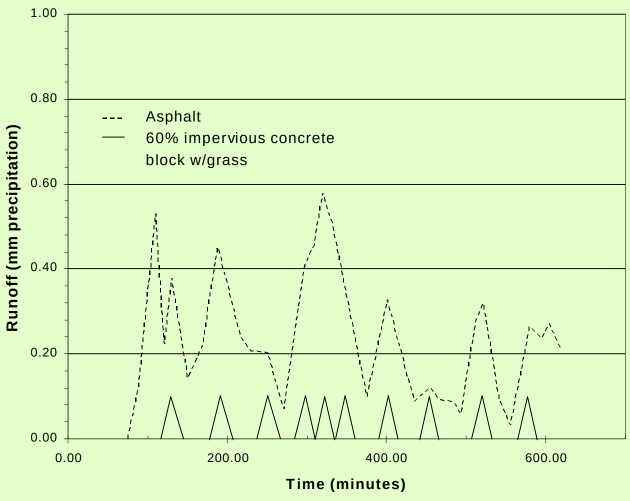

Figure 3. Runoff volumes from asphalt and permeable pavements.

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Vegetated Roof Cover

Philadelphia, Pennsylvania

Key Concepts:

- Structural Control
- Retrofit Opportunity
- Volume Reduction
- Life Cycle Costs

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Project Benefits:

- Runoff Reduction
- Air & Water Quality Improvement
- Aesthetics
- Energy Conservation

Introduction

Vegetated roof covers on industrial and office buildings have been used in Europe for more than 25 years to control runoff volume, improve air and water quality, and promote energy conservation. These systems, known as "green roofs" or "extensive roof gardens," also have aesthetic benefits. They typically include layers of drainage material and planting media on a high-quality waterproof membrane. These systems use foliage and a lightweight soil mixture to absorb, filter, and detain rainfall. Some of the conditions responsible for the promotion and acceptance of green roofs in Europe, which many American cities face as well, are

- Widespread implementation of stormwater-related fees or taxes
- Laws requiring mitigation or compensation for the elimination of open space
- Densely populated areas with high real estate values
- Requirements to reduce loads on combined sewer systems (CSSs)

Project Area

The demonstration project was installed on the roof of the Fencing Academy of Philadelphia (Figure 1). Like many urban areas on the East Coast, Philadelphia experiences frequent, small, high-intensity storm events. These short-duration events frequently overload and surcharge sewer systems. In the Philadelphia region, storms with 24-hour volumes of 2 inches or less contribute 90 percent of all rainfall. Vegetated roof covers are designed to control these high-intensity storms by intercepting and retaining water until the rainfall peak has passed, while also allowing larger storm events to be safely conveyed away from the building.

Vegetated roofs are complex structures that require consideration of the load-bearing capacity of roof decks, the moisture and root penetration resistance of the roof membrane, hydraulics, and wind shear.

The plants help recreate the hydrologic function of open space in the following ways:

- Capturing and holding precipitation in the plant foliage
- Absorbing water in the root zone

Figure 1. Fencing Academy of Philadelphia vegetated roof cover.

- Slowing the velocity of direct runoff by extending the flow path through the vegetation
- Cooling the temperature of the air and runoff. (Green roofs can be very effective measures for reducing the “thermal shock” caused by flash runoff from hot roof surfaces.)

Project Description

The vegetated rooftop project at the Fencing Academy of Philadelphia is a 3,000-square-foot vegetated cover installed and monitored by Roofscapes, Inc., on top of an existing structure (Figure 1). The roof system was intended to mimic the natural hydrologic processes of interception, storage, and detention to control the 2-year, 24-hour storm event. The distinguishing features of this system include

- Synthetic under-drain layer that promotes rapid drainage of water from the surface of the roof deck
- Thin, lightweight growth media that permits installation on existing conventional roofs without the need for structural reinforcement
- Meadow-like setting of perennial *Sedum* varieties that have been selected to withstand the range of seasonal conditions typical of the Mid-Atlantic region without the need for irrigation or regular maintenance

The installed vegetated roof cover is only 2.74 inches thick including the drainage layer. The system weighs less than 5 pounds per square foot when dry and less than 17 pounds per square foot when saturated. The saturated moisture content of the media is 45 percent by volume. The saturated infiltration capacity is 3.5 inches per hour. Figure 2 shows the components of the roof system.

The runoff characteristics of the roof were simulated using rainfall records for 1994 from eastern Pennsylvania. The model predicted a 54 percent reduction in annual runoff volume. The model also predicted attenuation of 54 percent of the 24-hour, 2-year Type II storm event and 38 percent of the 24-hour, 10-year Type II storm event. Additionally, monitoring at a pilot-sized project for real and synthetic storm events was conducted for a period of 9 months at 14- and 28-square-foot trays. The most intense storm monitored was a 0.4-inch, 20-minute thunderstorm. The storm event occurred after an extended period of rainfall had fully saturated the system. Figure 3 shows the runoff attenuation effectiveness for this event. Although 44 inches of rainfall was recorded during this period, only 15.5 inches of runoff was generated from the trays. Runoff was negligible for storm events with less than 0.6 inch of rainfall.

Project Summary and Benefits

This project showed that vegetated rooftop covers can help to reduce peak runoff rates for a wide range of storm events. The project also demonstrated that existing structures can be successfully retrofitted to help prevent CSS surcharging in urban areas. Significant energy

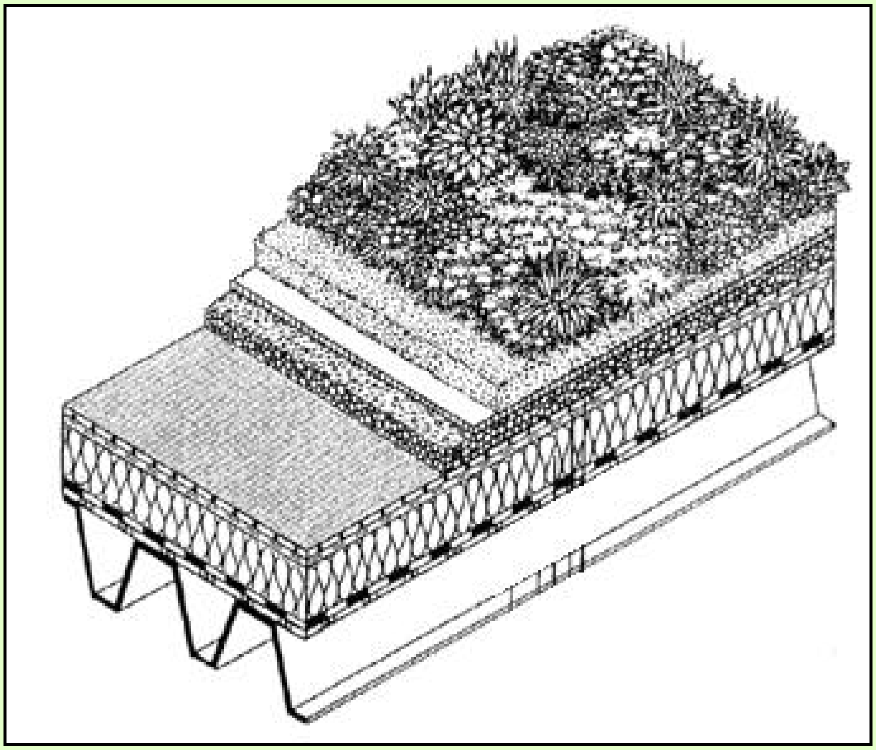

Figure 2. Components of the vegetated roof cover.

conservation benefits also are associated with vegetated rooftop covers. During the spring and summer, temperatures on a neighboring black tar roof varied by as much as 90 °F, while the variation under the 2.74-inch vegetated cover was only 18 °F. The vegetated cover also insulates the roof in winter, and the vegetation protects the roof membrane from the elements. Vegetated rooftop covers can potentially extend the life of a roof by 20 years or more.

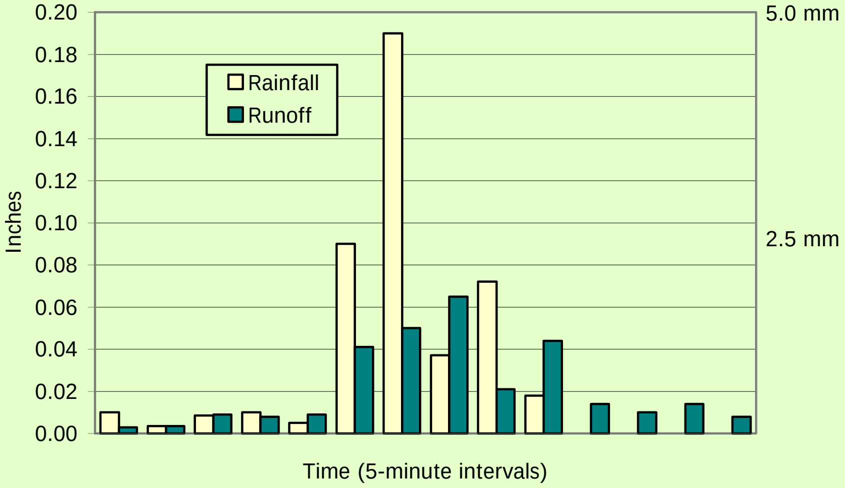

Figure 3. Runoff attenuation efficiency for a 0.4-inch rainfall event with saturated media.

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Street Storage for Combined Sewer Surcharge Control

Skokie and Wilmette, Illinois

Key Concepts:

- Street Storage
- Flow Regulation
- Street & Inlet Modifications
- Source Control

Project Benefits:

- Elimination of Surcharge
- Community Acceptance
- Cost Savings

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Introduction

This case study describes the use of street storage and catch basin modifications to reduce the rate of runoff entering combined sewer systems (CSSs). These modifications help alleviate residential basement flooding that results from CSS surcharging during rainfall events. Because building relief sewers would be both expensive and disruptive, the communities of Skokie and Wilmette, Illinois, were willing to try alternative approaches. The communities decided to modify street cross sections and storm drain inlets so the street surfaces could store and convey runoff during peak storm events and reduce hydraulic loading to the combined sewer. This process required extensive coordination with regional, state, and local officials and residents to ensure that safety and community acceptance concerns were satisfied.

Project Area

The street surface storage projects were conducted in the towns of Skokie and Wilmette, Illinois, suburbs of Chicago. The entire 8.6 square miles of Skokie and a 2-square-mile section of Wilmette are urban areas served by a CSS. Skokie has approximately 23,000 households (65 percent of which occupy single-family homes) and Wilmette has approximately 9,000.

Figure 1. Runoff temporarily stored on a street surface.

Project Description

To alleviate system surcharging, a strategy that combined the following elements was used:

- Street storage
- Downspout disconnection
- Flow regulators
- Subsurface storage
- New storm and combined sewer systems
- Improvements to existing storm and combined sewer systems

The goal of the project was to take full advantage of the street and inlet system for stormwater control as an alternative to installing expensive underground facilities such as complex configurations of storage vaults with flow regulators or additional pipes for increased storm drainage capacity.

The alternative street storage approach was based primarily on installing a system of street berms 7 to 9 inches high at the curb line that detain water on the street surface. Figure 1 is a photograph that shows this technique. In addition, installing flow regulation devices at catch basin outlets reduced the rate of storm water flow to the CSS so both the inlet structure and the street can be used

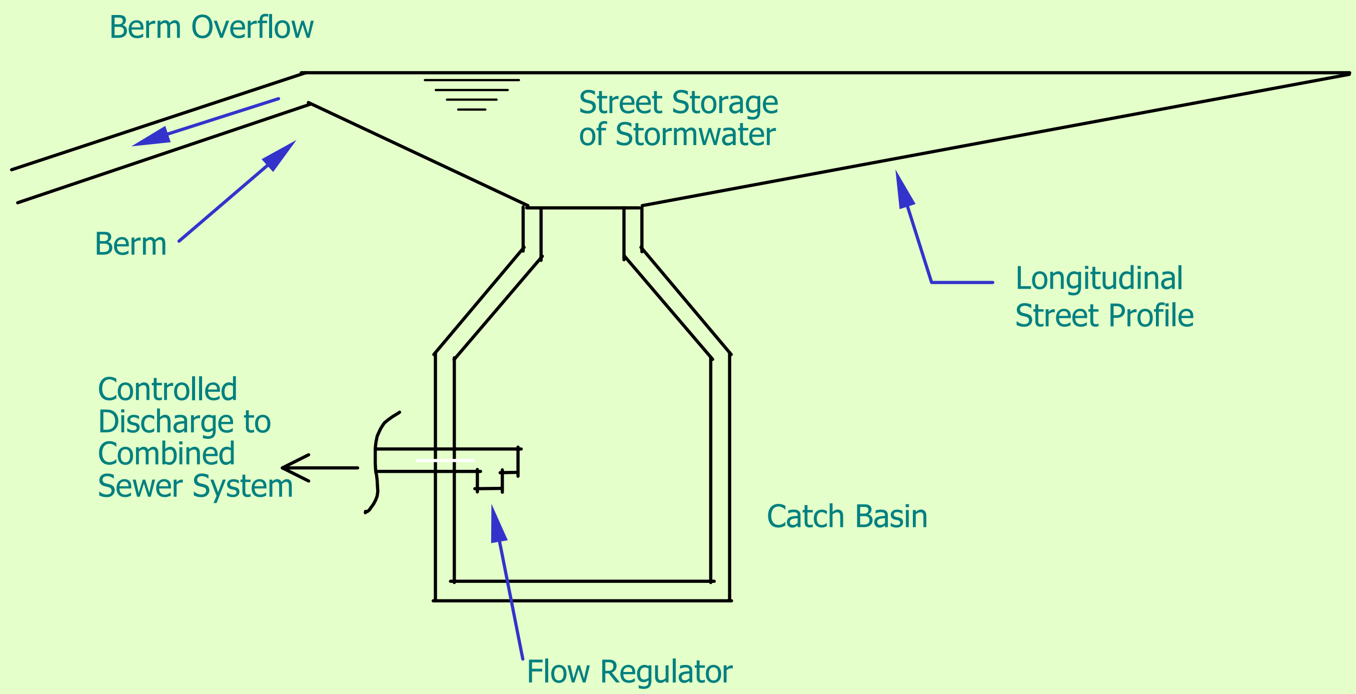

Figure 2. Schematic diagram of the street storage system (Note: not to scale and great vertical exaggeration).

for storage. Figure 2 illustrates this concept. Subsurface storage facilities were installed in the street right-of-way and in other public areas as part of the storm drainage system at critical points in the system and in high-traffic areas, parking areas, and pedestrian walkways where ponding was not acceptable. Overall, street storage accounts for over half of the total stormwater storage capacity. The other half is accounted for in subsurface and off-street storage.

Project Summary and Benefits

Many benefits were realized from this project. First, researchers estimate a cost advantage from using street storage over conventional sewer separation systems to alleviate CSS surcharges. Figure 3 shows the estimated costs for the Skokie system to be approximately 38 percent of the costs for conventional approaches to sewer separation. A breakdown of costs associated with the street storage approach reveals that berm/flow regulator installation is a small fraction of the overall project cost, as shown in Figure 4. The street storage system could aid in traffic control because the berms function much like speed humps as traffic calming structures. Also, the storage system reduces the frequency and volume of combined sewer overflows, resulting in fewer stormwater-related pollutant events in receiving waters. Since the system's installation in 1983,

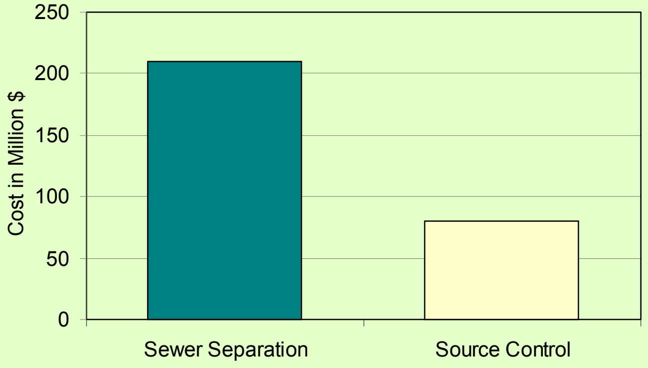

Figure 3. Cost comparison between the traditional sewer separation approach and a source control approach using street surface storage.

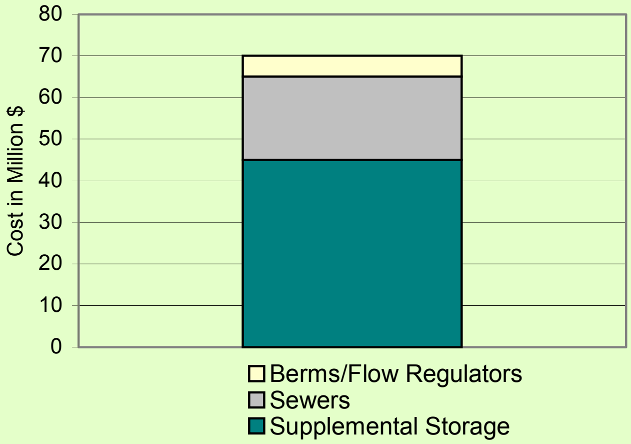

Figure 4. Costs associated with the CSS surcharge relief project.

consisting of 2,900 flow regulators, the Skokie Public Works Department has not reported any problems with icing of ponded areas during winter weather because the water typically remains on the street surface for less than 30 minutes.

Several lessons were learned as a result of this project. First, researchers emphasized the importance of using a comprehensive approach to stormwater management that explores funding and cooperation from different sources, including streetscaping and revitalization programs. Second, early and frequent stakeholder involvement and strong outreach and education programs that clearly identify the benefits of street storage were necessary to gain support for the project from citizens. Finally, a comprehensive inspection and maintenance program with training for public works staff was essential to ensure that street storage systems functioned as designed.

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