Sustainable Stormwater Treatment in Iowa City:

Permeable Pavement and Bio-Retention Technologies

Evaluation and Design Report

May 1, 2015

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THE UNIVERSITY OF IOWA
IOWA INITIATIVE FOR SUSTAINABLE COMMUNITIES

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Executive Summary

Armada Consulting consists of team member from the University of Iowa's College of Civil Engineering with relevant engineering experience includes projects involving runways, roads, military bases, HMA, concrete, stormwater management systems, and hydrologic studies. At the request of Jason Havel, City Engineer of Iowa City, we have thoroughly studied the effects of precipitation runoff on existing road and storm sewer systems, and on localized flooding and environmental and social sustainability. This research has guided our decision to create three preliminary green street design prototypes to improve stormwater management in Iowa City.

The area of interest declared was the east-west portion of North Dodge Street Court and the basic requirement was to redesign the street to meet the new traffic demands of the post-developed community. While the nature of the request did not have hard constraints, we considered minimizing maintenance and installation cost and fitting within the geophysical space allowed in the easements. Our criteria as a firm were to improve groundwater and runoff quality, reduce runoff quantity, satisfy traditional street and storm sewer design life and expected repair, and improve the quality of life for those impacted by our design.

The final design of the three prototypes consists of a permeable pavement called PaveDrain to infiltrate all precipitation falling on the pavement surface into the native soil below. Bioretention cells collect the runoff from the residential acreage and pass it to the pavement storage area for infiltration. These cells biologically treat the runoff by removing pollutants through root uptake. These two best management practices, or BMPs, fit within the easements, reduce runoff quantity and increase water quality. The cells and pavement are specified to respectively treat and store the 10-year, 24-hour storm, but the system is capable of nearly handling the 25-year before discharging excess into a nearby nature reserve.

Armada Consulting anticipates that the PaveDrain and bioretention cell system has total project cost of $295,000, compared to traditional residential street design cost of $156,600. The benefits to the immediate community and Iowa City's downstream neighbors certainly outweigh the present unconventionality—so much that Iowa City may expect similar concepts to become the future standard for stormwater management.

1 Introduction and Background

Iowa City is interested in the application of permeable pavement and bioretention within the city under the umbrella of ‘green street’ designs—implemented BMPs developed to address growing concern for sustainable stormwater management my mimicking the local hydrology prior to development (Metropolitan Washington Council of Governments, 2013). The city would like to develop a site that will serve as demonstration and to help promote and develop green street technologies for implementation in future infrastructure needs. Many Iowan cities have successfully implemented and reaped the benefits of green street designs, from extraordinary business district transformations in Charles City to site-specific approaches on individual properties in Coralville. To address municipal effluent discharge standards and ethical responsibility in watershed health, the city of Coralville has established an entire municipal role of stormwater coordinator to foster sustainable resilience to changing hydrography.

The city of Iowa City has an abundance of opportunities to encourage this same resilience, for our present community and the Iowa City of 2050. To explore these opportunities, the city has requested Armada Consulting to redesign the pavement and stormwater management of North Dodge Street Court, Iowa City using permeable pavement and/or bioretention technologies.

North Dodge Street Court was selected because it is a small street with light residential traffic—making installation and impact assessment easier. The dead-end street presently serves ten parcels directly, and may become an access point for further community development on the north side of the street. The site is too distant from the rest of the municipal infrastructure to make traditional stormsewer viable, and the hydrologic connectivity to Hickory Hill Park through Pappy Dickens preserve make it ideal for Iowa City’s first pass at green infrastructure. Green infrastructure provides immediate safety, convenience, and aesthetic benefits to the community. If the permeable pavement and stormwater management design proves to be effective on North Dodge Street Court, the city of Iowa City may further pursue sustainable stormwater BMPs throughout Iowa City.

2 Existing Conditions

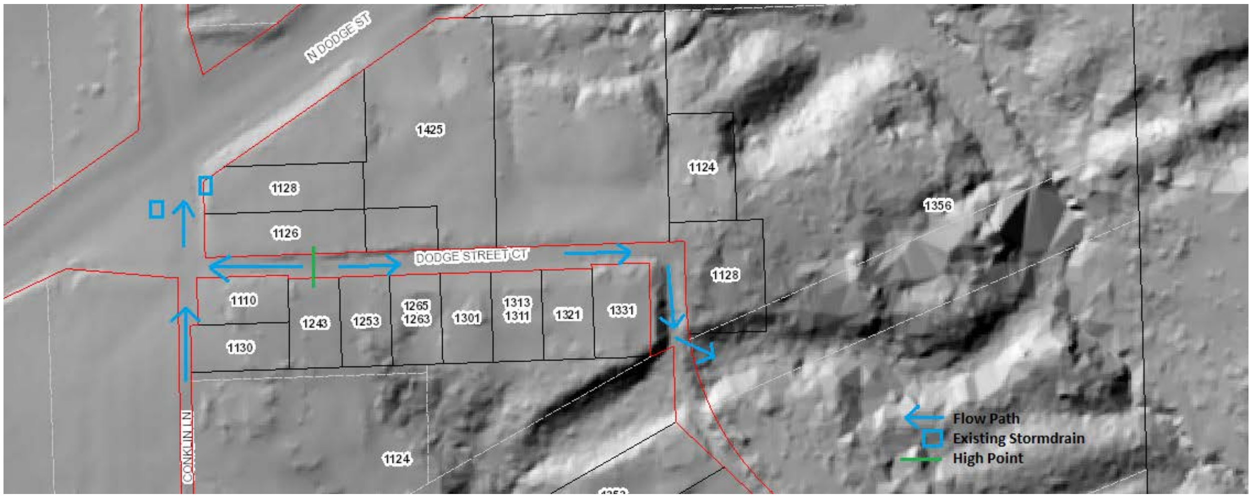
2.1 Neighborhood Characteristics

Currently residents on the south side North Dodge Street Court have driveway access to the road and are permitted to park on the north side of the street. Development on the north side of the street is anticipated to handle stormwater on-site and will not be contributing to the runoff at North Dodge Street Court. Access to the new development will likely be connected to North Dodge Street with no additional driveways connecting to North Dodge Street Court at this time. Figure 2-1 shows the North Dodge Street Court site and the location of the new development.

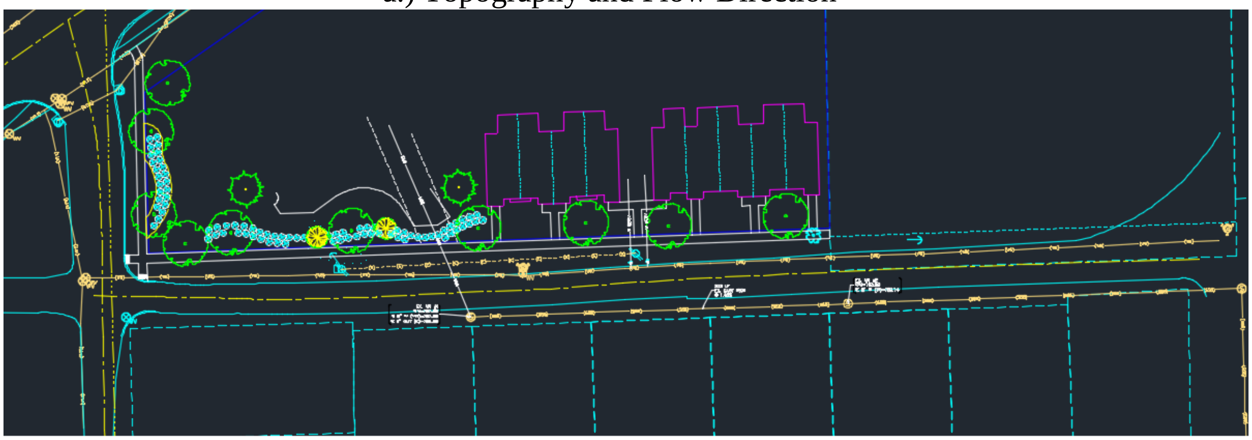
Figure 2-1. North Dodge Street Court Site

2.2 Topography, Drainage, & Utilities

North Dodge Street Court gently slopes away from the high-point (located towards the west end of the street.) Runoff west of the high point flows to Conklin Lane (~1.8%) and then enters a storm drain at North Dodge Street (Figure 2-2 a). Runoff east of the high point flows to the east end of North Dodge Street Court (~1.6%) and then follows the road south to enters the gully shown in Figure 2-2 a. The gulley drains to Pappy Dickens Preserve. A sanitary sewer runs along the south side of North Dodge Street Court with a proposed connection to the new development (Figure 2-2 b). There is also a water main and overhead power lines that runs along the north side of the street (Figure 2-2 b). The right of way (ROW) along the street varies between approximately 28 feet and 33 feet. A layout of total utilities within and around the site are provided in Figure 2-2 b.



a.) Topography and Flow Direction



b.) Utility Location

Figure 2-2. North Dodge Street Court Topography, Drainage, & Utilities

2.3 Soils

According to the Natural Resources Conservation Service (NRCS) soil survey map (Figure 2-3) the site (163B) consists of Fayette silt loam, 2 to 5% slopes. The depth to both the confining layer and the water table are each more than 80 inches from the surface. The natural drainage class is well-drained. Further soil analysis should be completed at the site prior to implementing an infiltration system.

Figure 2-3. NRCS Soil Map

2.4 Pavement Condition

The current asphalt road is about 636 feet long by 20 feet wide (Figure 2-4). The proposed new roadway width will be uniformly 28 feet from curb back to curb back to accommodate increased traffic from the development. As the North Dodge Street Court presently has no curb, gutter, or any storm drain intakes, any adjustments to bring the street to typical Iowa City standard will involve cutting into the existing easements to handle traffic safety and stormwater management. This will directly impact the residents along North Dodge Street Court and serve the design needs of both the present and developing communities.

The asphalt has begun to deteriorate in areas that often experience stormwater flow and ponding—most obviously along the sides and cutting across the south end of the street. The road is scheduled to be upgraded as the projected traffic volumes increase after development of the property north of the street. The current standards in Iowa City roads are 7-inch Portland Cement Concrete (PCC) and storm sewer to handle a design storm with a recurrence interval of ten years, duration of 24 hours, and type II rainfall distribution (10-year 24-hour storm). The present configuration does little to address the stormwater in the area aside from crowning in the pavement cross-section.

Figure 2-4. North Dodge Street Court looking east from the high point

2.5 Hydrologic Analysis

The National Resource Conservation Service (NRCS) Curve Number (CN) method was used to characterize the runoff for the 10-year 24-hour design storm. Because the basin is so small, the travel time and time of concentration are negligibly small, indicating that once runoff begins to develop it is immediately visible on the street. The CN assumptions were that the basin consisted of ¼-acre lots at 38% imperviousness after the turf had been reestablished post-construction. These assumptions best characterize the bulk of the parameters expected for the duration of the design life, but care should be taken with regards to fresh grading and increased impervious area with any construction associated with the new development. BMPs for sedimentation should address protecting the inlets for the green street design in the event that more construction occurs after the street upgrade.

All soil data was obtained from the NRCS soil survey database and an expected infiltration rate minimum of 0.27 inches/hour at a depth of 4 feet, may be expected for infiltration BMPs. This information is preliminary and must be confirmed with bore data to validate the prelimary designs. In the event that the actual native soil cannot infiltrate at a minimum of 0.27 inches/hour, infiltration may not be viable and other BMPs such as retention and detention may be the only solution to low-impact stormwater hydrology. Table 2-1 shows a summary of the site conditions. Table 2-2 shows a summary of the calculated runoff results, and detailed calculations may be found in Appendix E.

Table 2-1. Summary of Site Conditions

Site Data		Hydrologic Data	
Total Site Drainage Area = 1.2 ac		Minimum infiltration rate (f) (in/hr)	Weighted CN
Impervious Area = 0.5 ac			
Soils: HSG C	(Silt Loam) 0 - 10 inches	0.27	85
	(Silty Clay Loam) 10 - 47 inches	0.06	
	(Silt Loam) 47 - 60 inches	0.27	

Table 2-2. Summary of runoff results

Design Storm	Runoff Volume (Qc) (in.)	Peak Flow (cfs)		Total Runoff Volume (ft^3)
		East Dodge St. Ct.	Conklin Intersection	
5 yr 24 hr	2.29	1.02	0.18	6,283
10 yr 24 hr	2.83	1.26	0.23	12,386
25 yr 24 hr	3.34	1.49	0.27	22,324
50 yr 24 hr	3.73	1.66	0.3	19,746
100 yr 24 hr	5.34	2.37	0.43	23,411

3 Approach

This section will provide an overview of three infiltration methods and three permeable paving methods that could replace traditional storm sewer and Portland Concrete Cement (PCC) pavement. For the stormwater management system traditional storm sewer was compared to bio-swales, bioretention cells, and infiltration trenches. It is worth noting that these BMPs are entirely viable in other areas of Iowa City with different slopes, available plan area, and soil composition. For this reason, we highly recommend considering a range of BMPs to improve water quality in future municipal designs.

3.1 Design Objectives

Our objective is to provide three preliminary designs for a road upgrade that address the future design requirements for traffic flow, stormwater management, and community wellbeing. The upgraded system should have the capacity to detain the municipal requirement of a 10-year 24-

hour design storm, and accommodate the anticipated traffic volumes The main philosophical objectives is to be able to be transfer the concepts to other areas in Iowa City to help manage the city's impact on the water quality and quantity of Ralston Creek and the Iowa River and in a robust, sustainable manner.

3.2 Shortcomings of Traditional Design

Traditional pavement designs have improved greatly over the years to resist deformation from consistent loading, resist mechanical and chemical weathering, and transport runoff to stormwater systems. These improvements are based on classic design objectives that were very pragmatic, but are outdated as a metric of success in light of recent environmental and health concerns. A new category of objectives includes environmental impact, sustainability, and watershed approaches to resource conservation and reestablishment.

Resisting deformation and mechanical weathering are still primary objectives, but approaching stormwater runoff has evolved into an issue of water quality and quantity. The demand for a stormwater management system that meets the modern watershed needs gives rise to new sustainable and green technologies. Armada Consulting has chosen bioretention and permeable pavement techniques as the easiest first step to meeting present and future infrastructure demands.

3.3 Water Quality and Community Health

The most efficient way to address water quality is to allow mother nature to treat the initial wash of pollutants frequently associated with stormwater by infiltrating them into the groundwater system to dilute, or by uptaking them with root systems. The required treatment volume in Iowa is the Water Quality Volume (WQv) and is defined as the first 1.25" of runoff (Iowa Department of Natural Resources, 2013) and is the same volume for any storm in a given watershed. Most infiltration and bioretention BMPs require lower runoff velocities, which provide the additional advantage of dropping sediment out of the water passed through the basin outlet.

3.3.1 System Details

Infiltration moves water from the surface of the land down into the soil profile (Iowa Department of Natural Resources, 2013). Strictly infiltration techniques can only treat physical pollution such as sediments and hard metals. Bioretention systems can remove these pollutants, and can additionally treat soluble and organic pollutants such as nitrate and phosphorous. The infiltration capacity, or maximum rate that water can infiltrate, depends on the type of soil. Water that infiltrates into the soil column can be expected to recharge, or replenish, the groundwater table. Many of these BMPs are explicitly designed in the Iowa Storm Water Management Manual.

3.3.2 Infiltration Trenches

Infiltration trenches are long, narrow trenches filled with aggregate. They have no outlets and are designed to allow runoff to percolate through the aggregate and into the native soil. The void space in the aggregate layer functions a storage area in the event that the native soil cannot accept the rate of discharge in the storm. They are typically appropriate for small sites and can remove suspended solids, some nitrogen, some phosphorous, metals, bacteriological growth, and some hydrocarbons. It is recommended not to use this system with native soil infiltration rates less than 0.5 inches/hour. (Iowa Department of Natural Resources, 2013).

3.3.3 Bio-Swales

Bio-swales, or dry swales, are open channels enhanced with engineered soil mixes, underdrains and specific flora that increase pollutant uptake. It is a preferred system for residential areas since it is dry most of the time. The entire WQv can be treated and stored, and the system should be designed to drain in about a day. The system cannot be used on steep slopes and potentially has higher maintenance requirements than a curb or gutter system.

3.3.4 Bioretention Cells

Bioretention cells are shallow landscaped depressions that can temporarily store and infiltrate stormwater runoff. Bioretention cells typically consist of a subdrain, rock subbase, pervious soil layer, mulch layer, and surface vegetation. A typical cross section of a bioretention cell is provided in Figure 3-1.

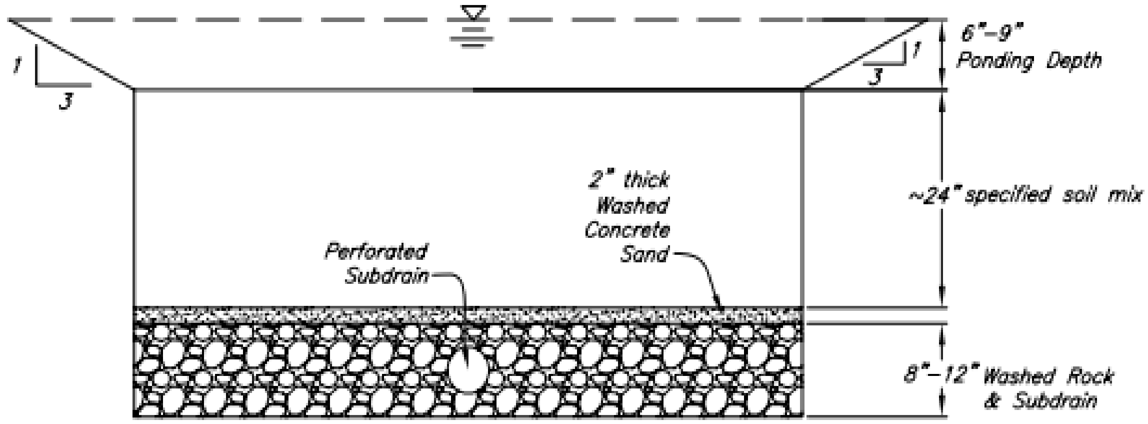


Figure 3-1. Typical Bio-Retention Cell Cross Section – Drawing provide from Iowa Rain Garden and Installation Manual (Iowa Storm Water Education Program, Iowa Stormwater Partnership, United States Department of Agriculture)

Bioretention cells infiltrate the collected stormwater into the rock subbase where the WQv is then drained into the underlying soils and/or into the perforated subdrain. A variety of vegetation can be incorporated into the cells such as: grasses, flowering perennials, shrubs, or trees. Unfortunately, the efficacy of bioretention cells is governed by the water table relative to the surface and requires low runoff entrance velocities to prevent damage to flora. They may regularly require landscaping maintenance in growth pruning and mulch replacement, and removal of sediment. Bioretention cells are ideal for low-traffic areas as they can be used to reduce the remaining runoff rates not accommodated by permeable pavement as well as treat runoff from intersecting streets that are not permeably paved. The cells are flexible in size and design capacity, can encourage diverse urban ecosystems, and provide pleasing aesthetics that may increase property values. Some examples of bioretention systems are provided in Figure 3-2.

Figure 3-2. Examples of Bio-Retention Systems

3.4 Water Quantity and Community Safety

Permeable pavements allow rainfall to percolate into the soil instead of gathering in sheet flow or puddles. In some cases, the runoff reduction from permeable pavement reduces the need for a traditional stormwater treatment system of drains and pipes discharging into surface water. Water first passes through the permeable pavement to an aggregate subbase, where it can infiltrate into the surrounding soil or overflow to stormwater systems (Figure 3-3). Infiltration is a means to 'slow' the hydrograph by eliminating the storage volume as an overland flow mechanism. The water infiltrated into the ground still influences the discharge of the effected surface water, but is delivered as steady intermediate or base flow at the water table instead of a flash of runoff over the surface. The pollutants infiltrated are not treated.

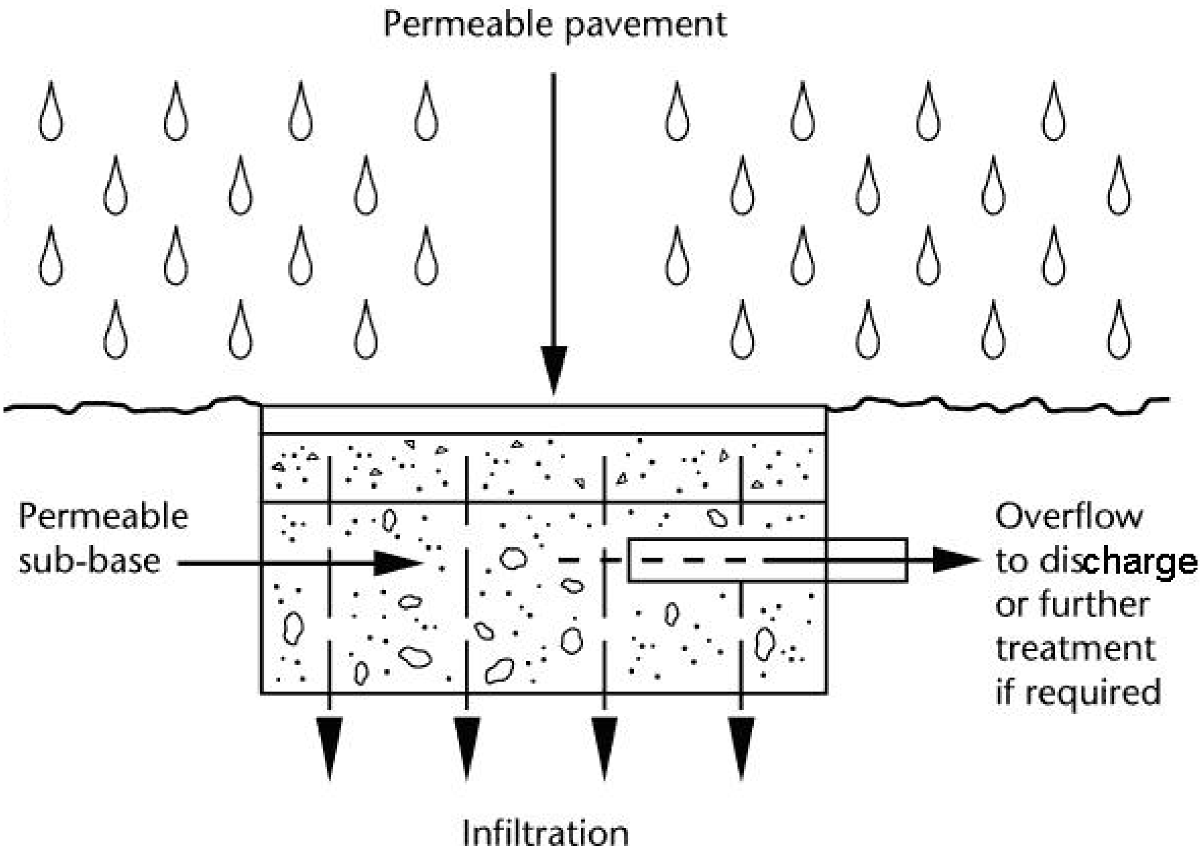


Figure 3-3. Diagram of Permeable Pavement (Iowa Storm Water Education Program, Iowa Stormwater Partnership, United States Department of Agriculture)

3.4.1 System Details

There are multiple options that qualify as permeable pavement. The most common selections are pervious concrete, porous asphalt, and permeable pavers. Because the options differ in materials and display, they must be compared and contrasted in order to find the design that seems best fit the system needs.

Most permeable pavement can pass 200-250 in/hr of runoff (Iowa Department of Natural Resources, 2013). These rates depend highly on the void spaces and their ability to absorb and infiltrate the water into the subbase layers—this means that permeable pavement systems require routine vacuuming to remove fines and maintain infiltration capacity.

In addition to surface infiltration all forms of permeable or pervious pavement have limitations in their capacity to infiltrate stormwater effectively into the native soil. The total infiltration is governed by the infiltration rate of the underlying native soil. The native soil should have an infiltration rate of at least 0.5 in/hr to avoid surplus volume of runoff in the aggregate layer. All permeable pavement designs contain a perforated overflow drain that sits beneath the surface at phreatic surface of the design storage. Water beyond this subdrain must be physically allowed to flow out from the pavement storage and into a stormdrain or alternate retention unit.

The Iowa Stormwater Management Manual (ISWMM) advises “a maximum time of 72 hours is typical, while a 48 hour draindown represents a more conservative approach” for the voids to be almost completely empty—this requirement dictates the maximum storage (volume beneath the subdrain) that a permeable system may have.

The residential traffic rates of North Dodge Street may reduce long-term maintenance costs by contributing minimally to clogging, however, the success of BMPs to avoid sedimentation in the abutting construction areas during development will also play a large roll in required maintenance.

Armada Consulting provides information about pervious concrete, pervious asphalt, and pavers for comparison to traditional concrete and traditional asphalt, and ultimately recommends a local development called PaveDrain in the final design.

3.4.2 Conglomerate Alternatives: Pervious Concrete and Pervious Asphalt

Conglomerate alternatives are modified concrete and asphalt mixes that have reduced fines in the total composition. The lack of fines increases the void space between larger aggregates and allows water to pass through the road surface and into the aggregate storage layer below. Conglomerates are formed through a chemical process of mixing Portland cement, or asphalt mixes with coarse aggregates, in which there is a potential for contaminating of the runoff if not applied properly. The lack of fines is sometimes controversial, as some claim that the increased void space encourages potholing because individual grains have less contact, while others claim that since the water does not stand in the surface it discourages potholing.

3.4.2.1 Pervious Concrete—PC

Pervious concrete is ideal for low traffic areas, recreational paths, and residential locations with minimal traffic volumes.

Figure 3-4. Pervious Concrete – Photo courtesy of the Portland Cement Association (Portland Cement Association , 2007)

3.4.2.2 Porous Asphalt

Porous asphalt (PA) surface is composed of uniformly-graded hot mix asphalt (Figure 3-5) and is ideal for preventing ponding.

Figure 3-5. Comparison of traditional asphalt (left) and porous asphalt (right) when wet – (Hafner, Bassuk, Grabosky, & Trowbridge, 2007)

3.4.3 Permeable Pavers (brick)

Permeable pavers and modular pavements can be concrete and brick pavers, geowebs, or manufactured concrete and plastic units. The gap between each paver is considered the void space, and infiltration happens in these gaps (Figure 3-6). These gaps are typically filled with gravel (chip-fill), soil, grass.


Figure 3-6. An example of brick pavers in West Union, Iowa (City of West Union, 2011)

One noteworthy advantage of pavers is that they can be purchased through commercial vendors, in which prices are more competitive and quality is more uniform. One disadvantage that separates pavers from PC and PA is that block pavers must be laid perfectly level to prevent damage form plows during the winter (Iowa Department of Natural Resources, 2013)

3.4.3.1 PaveDrain

PaveDrain is a specific type of permeable paver designed to withstand traffic loading by distributing force through pavers with support arches. The design of this system does not require a chip-fill between the modules, which will reduce maintenance costs associated with vacuuming and re-chipping the pavement. These pavers were also found to be able to withstand snow removal without any major issues. A typical section of a pave drain system can be seen in Figure 3-7. A letter of testimonial from the city of Goshen, IN can be found in Appendix B.

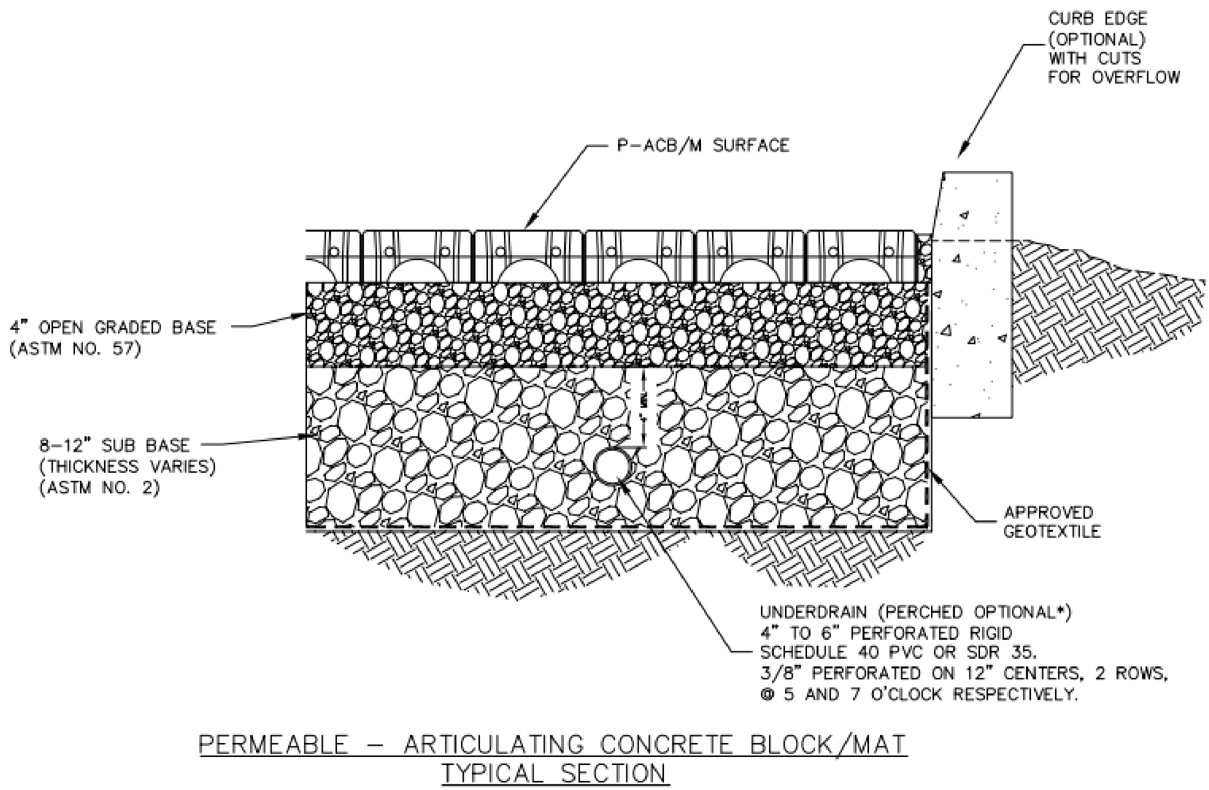


Figure 3-7. PaveDrain – Articulating concrete block/mat typical section

3.5 Considerations to New Technology

For this design we are concerned with balancing lower runoff quantity and higher water quality against the cost and design life of the system. The main drawbacks include increased necessary maintenance and installation costs compared to traditional designs.

For bioretention, maintenance occurs in the form of subdrain inspection and care for the plantings. In a worst-case scenario, a municipality can have point-source stormwater effluent so polluted that it cannot meet the National Pollution Discharge Elimination System (NPDES) standards. Bioretention maintenance is a tradeoff that allows one annual drain inspection, weeding, and when necessary, planting to prevent needing to send stormwater to a traditional treatment facility to reduce pollutant concentration.

For permeable pavement, maintenance cannot be avoided since performance of the permeable pavement in terms of infiltration is directly affected by factors such as clogging. This is because the permeable surface has a high void content to allow the water to infiltrate. In areas where snowfall is a concern, salt or sand are used to prevent ice from forming. Even though salt and sand assist in driving conditions, they do not benefit the pavement itself, especially permeable pavement. The salt and sand wear away at the surface, but they also can clog the voids in the permeable pavement rendering the environmental advantages null. Removing void congestion is achieved through the use of vacuums that can be costly upfront to purchase or rent, and require per-use payment of a vacuum-truck operator. The other disadvantage regards the installation—permeable pavements generally require more money upfront than the traditional pavement designs because of the skill or proprietary knowledge in formulas, mixing, and application. The overall system costs associated with permeable pavement are similar to traditional systems it requires fewer drainage components.

In addition to treatment and storage, bioretention and permeable pavement can improve aesthetics of an area by reducing ponding during storms and increasing the visual appeal. During the dry season, the brick colors and lay patterns can help direct foot and automobile traffic in the place of paint, and plantings in the bioretention cells add texture and reduce noise and air pollution.

3.6 Preliminary Development of Solutions

For the pavement systems Traditional Pavements (PCC & Asphalt) were compared to pervious concrete, porous asphalt, and permeable pavers.

Each solution was compared across the following categories: cost (materials and installation), maintenance, design life, runoff (reduction), water quality, aesthetics, and the site requirements. Each technology was rated from least desired to most desired from 1-4 and then totaled. Results from the analysis can be seen in & Table 3-2, which depicts a design matrix used to score each solution and identify the best-fit BMP for the site.

Table 3-1. Stormwater Management Systems Decision Matrix

Stormwater Management Systems								
Technology	**Cost**	**Maintenance**	**Design Life**	**Runoff**	**Water Quality**	**Aesthetics**	**Site Requirement**	**Total**
Traditional Storm Sewer	1	1	4	1	1	1	1	**10**
Water Quality Swales	4	2	3	2	2	3	2	**18**
Bio-Retention Cells	2	3	3	4	3	4	4	**23**
Infiltration Trench	3	4	3	4	4	2	3	**23**

Table 3-2. Pavement Systems Decision Matrix

Pavement Systems								
Technology	**Cost**	**Maintenance**	**Design Life**	**Runoff**	**Water Quality**	**Aesthetics**	**Site Requirement**	**Total**
Traditional Pavement	4	2	3	1	1	1	1	**13**
Pervious Concrete	2	3	3	4	4	1	2	**19**
Porous Asphalt	4	3	3	4	4	1	3	**22**
Permeable Pavers	1	4	4	4	4	4	4	**25**

Detailed comparisons and literature that was used to create the decision matrices can be found in Appendix D.

For water quality, bioretention and infiltration trenches scored the same in the broad categories. However, since a residential community may have children, Armada Consulting chose bioretention cells to avoid the risk of children misplacing the gravel.

In the pavement category permeable pavers scored the highest. Within the permeable pavers, PaveDrain was chosen because of ease of installation and it does not require the extra maintenance of a chip-fill.

4 Criteria & Constraints

The basic criteria of the North Dodge Street Court redesign are to meet the new traffic demands of the post-developed community. The traditional minimum is a 7 inch PCC street with 1 ½ foot gutters to allow evacuation of a 10-year 24-hour design storm. The new design must perform similarly. All piping must be below the frost line.

A criteria inherent in the site specificity of any design is the existing conditions. Since we are unable to perform a thorough investigation of the soil, a minimum depth of 4 feet of excavation is initially suggested to guarantee contact with more infiltratable native soils. Prior to implementing infiltration technologies a site survey should be conducted and hydrologic data such as: soil analysis, water table depth, contributing watershed area, and surrounding structures (buildings, wells, ect.). Section 2J of ISWMM provides guidance on criteria required to properly infiltrate runoff into the soil. Table 4-1 summarizes the criteria needed for proper infiltration according to ISWMM.

Table 4-1. Infiltration Feasibility Summary

Infiltration Feasibility	
Criteria	Status
Infiltration rate (f) greater than or equal to 0.5 in/hr	Infiltration rate of 0.27 in/hr , design infiltration rate of 0.135 in/hr. Soil indicates moderate permeability, use of underdrain piping for partial exfiltration from pavement base. OK
Soils have a clay content of less than 20% and a silt/clay content of less than 40%	According to NRCS soil maps: Silt loam and silt clay loam at this site. CL soils. Typical CBR values 2-5. Meets criteria from Table 2 Section 2J-1 of ISMM. OK
Infiltration cannot be located on slopes greater than 6% or in fill soils	Slope is 2-4%; not fill soils. OK
Hotspot runoff should not be infiltrated	Not a hotspot land use. OK
Infiltration is prohibited in karst topography	Not in karst. OK
The bottom of the aggregate base must be separated by at least 2 feet vertically from the seasonally high water table.	According to NRCS the water table is more than 80 inches. The aggregate base can be up to 56 inches deep and meet these criteria. OK
Infiltration facilities must be located 100 feet horizontally from any water supply	Water supply wells are > than 100 ft. from the site
Maximum contributing area generally less than 5 acres. (Optional)	1.2 acres. OK
Setback 25 feet down-gradient from structures	> 25 ft. from down gradient house on far east end of North Dodge St. CT.

While the nature of the request did not have hard constraints, we considered minimizing maintenance and installation cost and fitting within the geophysical space allowed in the easements. Much of this preliminary design is geometrically dependent on the availability of the north half of the street. If the north half of North Dodge Street Court is developed to mave many driveways and sidewalks intersecting the street, bioretention must be approached in a more modular way, potentially connecting cells in series through a larger network of subdrains.

Our criteria as a firm were to improve groundwater and runoff quality, reduce runoff quantity, satisfy traditional street and storm sewer design life and expected repair, and improve the quality of life for those impacted by our design. To improve water quality, the Water Quality Volume of the first 1 ¼ inches of runoff must be prevented from entering a receiving body untreated. TO reduce runoff quantity, the design must be able to detain and infiltrate the 10-year 24-hour design storm. The traditional street and stormsewer designs are met by providing similar strength to the 7 inch standard and diverting runoff from the driving surfaces, as well as requiring at maximum comparable maintenance and repair measured in man-hours and paygrade to a traditional system.

Our main indicator for improving quality of life for those impacted by the design is most succinctly captured with the concept of property value. Putting noteworthy consideration towards increasing pedestrian safety, decreasing water and air pollution, increasing aesthetic appeal and decreasing the potential to negatively impact the local amenities found in Hickory Hill Park are all ways to increase to property value for residents directly on North Dodge Street Court and for those driving through to the new development.

4.1 Challenges

Iowa City can sometimes be seen as conservative in terms of willingness to be on the forefront of new technology. Unfortunately, this may directly compete with the philosophy of encouraging high educational standards, having the intimacy of a small town despite the presence of a large university, and pride in our diversity and resilience in the face of change. To provide a healthy cultural and ecologic environment for our children to grow, to enable our communities with gathering places, and to thrive by any municipal standard, our present decision-makers must have the foresight and courage to adapt to changing external factors. Understanding the temporal interplay between infrastructure and our philosophies as a community is challenging because it marries two previously estranged spheres of civilization.

Challenges specific to North Dodge Street Court are the lack of budget allocation, non-involvement with the existing North Dodge Street Court residents, and not having definitive information on plans within the new development. Since the development has no arterial connections besides North Dodge Street Court, phasing of the pavement needs to allow residents to access their homes. Additionally, ensuring public awareness and approval of the project is necessary to foster a sense of ownership and strengthen the success of the design as a whole.

The grade of the street proved challenging in designing a subbase because the subbase should be nearly horizontal. To avoid excessive excavation costs, terraced sections with check dams within the subbase had to compensate for the change in elevation.

5 Design Options

A total of three final design options were explored and compared to a traditional residential street design. Each design would consist of a 28 feet wide by 236 feet long road surface and a stormwater management system. All designs must also stay within the city ROW. The three alternatives are: Design Option 1 – Pave drain only system, Design Option 2 – Bioretention only system, and Design Option 3 – Pave drain with bioretention system. Assessment of each alternative is provided in detail in the following sections.

5.1 Traditional Design – PCC with Storm Drains

For comparison, a traditional street design was estimated using standard 7 inch PCC pavement with a 6 inch modified subbase and traditional storm sewer intakes connected to reinforced concrete pipe (RCP). Section 2c-3 of the ISWMM recommends that storm sewer intakes be placed 500 feet from the crest of a road and 400 feet from each other. This design would require roughly 720 feet of 12 inch RCP and 4 single throat intakes (SW-507/SW-508) in order to connect to the existing storm sewer located at the intersection of Dodge St. and Conklin Ln. The total cost of the traditional design is $157,000. A summarized table of quantity and cost estimates is included in Table 5-1. Existing storm sewer plans used for design are located in Appendix A.

Table 5-1. Total Cost of Traditional Design Option

Material	Total Quantity	Units	Unit Price	Total Cost
7" PCC[1]	1625	SY	$ 41.07	$ 66,700
6" Modified Subbase[1]	330	CY	$ 37.64	$ 12,400
Concrete Curb[1]	636	LF	$ 32.84	$ 20,800
12" RCP[1]	720	LF	$ 56.53	$ 40,700
Storm Drains (SW-507/SW-508)[1]	4	EA	$4,000.00	$ 16,000
			Final Cost	$ 156,600

[1]IowaDOTBidx

This option is least desired as it will put increased loading on the existing stormwater system.

5.2 Design Option 1 – PaveDrain Only

This design option will be implementing a PaveDrain only system. The design was completed in accordance with the steps laid out in section 2J of the ISWMM. Detailed design steps and calculations are included in Appendix D. This system consisted of standard curb and gutter, PaveDrain blocks, open graded base - ASTM #57 (3/4-1 inch) clean recycled stone or concrete, sub-base – ASTM #2 (2-3 inch) clean recycled stone or concrete, a perched 4 inch subdrain, and geotextile fabric. Figure 5-2 shows a typical cross section of the PaveDrain system. A plan view of the PaveDrain system is included in Figure 5-1. Due to a restrictive soil layer the total depth of 4 feet was chosen for the system in order to reach a more permeable soil. The 4 inch perforated subdrain will be installed with a flow line depth of 27 inches above the bottom of the aggregate. This depth will allow all stormwater to infiltrate in to the soil within a 72 hour period (typical period between storms (ISWMM)). The storage available underneath the subdrain is about 14,000 feet^3. The storage required for a 10-yr, 24 hr storm is 12,400 feet^3 and the storage required for a 25-yr, 24 hr storm is 14,600 feet^3. This design will be capable of storing and treating a volume nearly that of the 25-yr storm. When storm runoff exceeds the storage capacity water will enter into the subdrain and then will be routed to either the existing stormdrain at the Dodge/Conklin intersection or will be directed into the Pappy Dickens preserve (Figure 5-1).

Figure 5-1. Plan View of PaveDrain Only Design

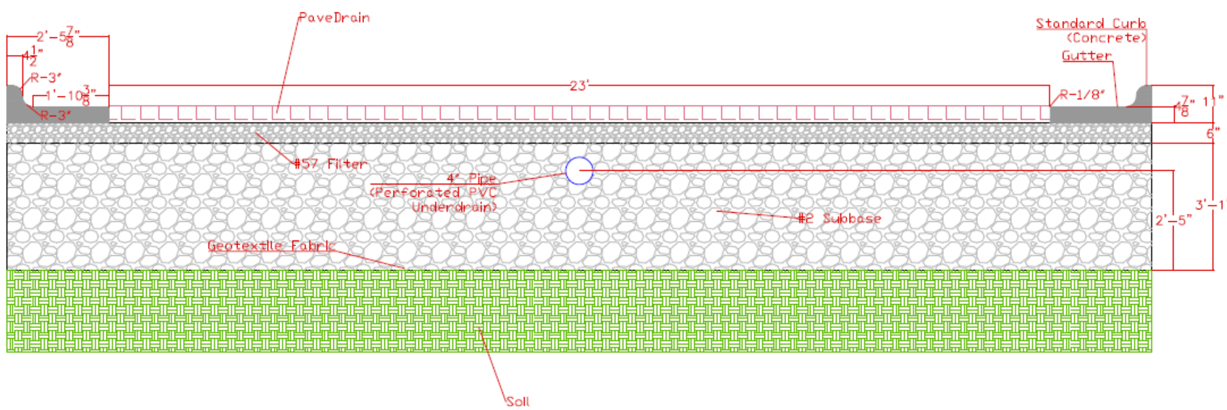


Figure 5-2. Typical cross section of PaveDrain System

Because permeable pavement systems require a relatively flat soil subbase to allow for even infiltration the system had to be terraced to accommodate the changes in elevation along the road surface. These terraced sections have concrete check dams installed at each end below the subdrain flow line. The check dams are used to hold the storage volumes in each respective section. Detailed drawings of the longitudinal profile and typical sections are included in Figure 5-3.

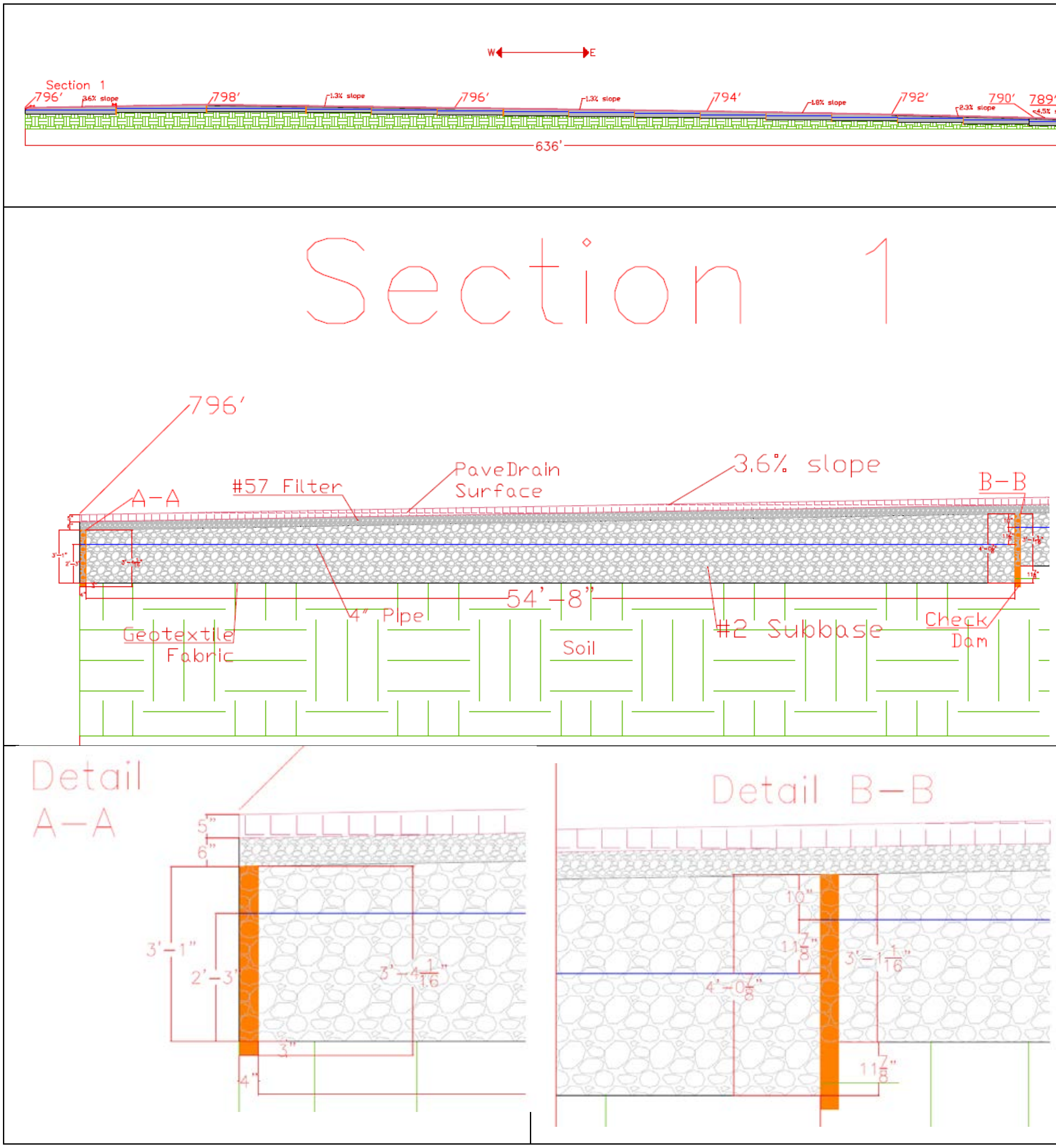


Figure 5-3. PaveDrain longitudinal profile and typical section details

PaveDrain units typically come in a 8 feet x 18 feet mat (144 sqfeet.) or individually where hand placement is required. Mat installation is performed with conventional construction equipment (excavator, crane, forklifeet, ect.) and 3-4 laborers (PaveDrain) (Figure 5-4). Care must be taken during the construction process to avoid sediment from washing in to the bedding coarse. Proper subgrade preparation will ensure a stable level pavement surface. The PaveDrain system is distributed by Quick Supply Company out of Des Moines, Iowa and manufactured in Eldridge, Iowa by regional block manufacturer King's Materials.

Figure 5-4. PaveDrain Installation.

Following installation it is recommended that the system be checked bi-monthly to assess the amount of infiltration occurring. A site with a significant amount of debris may need to be checked more frequently to properly determine a maintenance schedule. Cleaning can be accomplished using the PaveDrain Vac Head attached to a combination sewer truck (half day rental $700). Reported maintenance costs averaged about $0.50 - $0.75 /SF. In order to reduce the need for cleaning sand should not be applied to the surface during winter operations. While salt or brine are hard on all pavement surfaces it will not affect degrade the permeability. The edges of the PaveDrain blocks are chamfered so that edges are not caught during snow plow operations. Steel snow blades have shown to scrape and score the edges of the blocks without any significant damage. A snow plow with a rubber tipped blade will be less harsh on the surface. The design life of the PaveDrain system is approximately 50 years. If the aggregate layer would become degraded over time due to heavy sedimentation the PaveDrain system can be removed and re-installed once the aggregate layer has been replaced. The total cost of the PaveDrain only design is $281,000. A summarized table of quantity and cost estimates is included in Table 5-2.

Table 5-2. Total Cost of PaveDrain Only Design Option

Material	Total Quantity	Units	Unit Price	Total Cost
PaveDrain[1]	14625	SF	$ 13.00	$ 190,100
Concrete Curb[2]	636	LF	$ 32.84	$ 20,900
#57 Aggregate[2]	397	TON	$ 8.95	$ 3,600
#2 Aggregate[2]	2732	TON	$ 8.95	$ 24,500
4" PVC Pipe[2]	856	LF	$ 23.00	$ 19,700
Geotextile Fabric[2]	2485	SY	$ 2.02	$ 5,000
Check Dams (16 total)[2]	18	CY	$ 93.00	$ 1,700
Excavation, Class 10, Roadway and Borrow[2]	2881	CY	$ 5.42	$ 15,600
			Final Cost	$ 281,100

[1]Pave Drain

[2]IowaDOTBidx

One disadvantage to this system is that all stormwater runoff is directed toward the PaveDrain system without any prior treatment. Over time sediments from adjacent areas will entering the street will build up causing the increased need for maintenance.

5.3 Design Option 2 – Bioretention Only

This design uses a traditional PCC pavement surface, curb and gutter, with bioretention cells in place of traditional curb inlets. Four cells are required to treat the water quality volume and are located as shown in Figure 5-5, similarly to curb inlet placement. The residential driveways on the south side of the street present a spatial constraint on cell length. Because of the spatial constraint all of the street runoff needed to be treated on the north side where space was less constrictive. This was accomplished by slating the street at 1% slope towards the north side instead of crowning in the middle. The remaining runoff south of the street will be directed down the curb and gutter and into the small southwest cell. All runoff from the street and residential acreages will flow to a curb and gutter system with curb cutouts to enter the cell. A two-foot pea gravel flow spreader will slow entrance velocities.

Figure 5-5. Plan View of Bioretention Only Design

Infiltration rates of the engineered soil matrix govern the vertical flow into the cell. Stormwater is permitted to pond to a depth of 9 inches above the soil matrix before diverting into a grated 8 inch vertical overflow shaft (Figure 5-6).

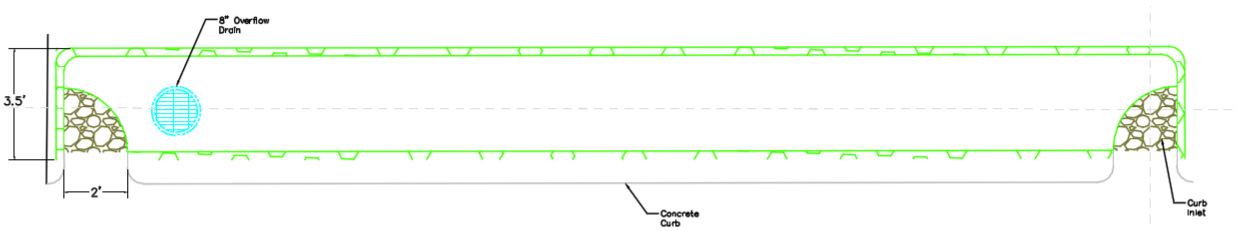


Figure 5-6. Plan View of Bioretention Cell - typical section

The overflow shaft connects to the required 8 inch perforated subdrain, placed along the longest horizontal axis of the cell at the bottom of the stone aggregate. The aggregate layer is 2 feet deep to reach the infiltration depth minimum of 4 feet, and to permit the pipes to be below the frost line (Figure 5-7).

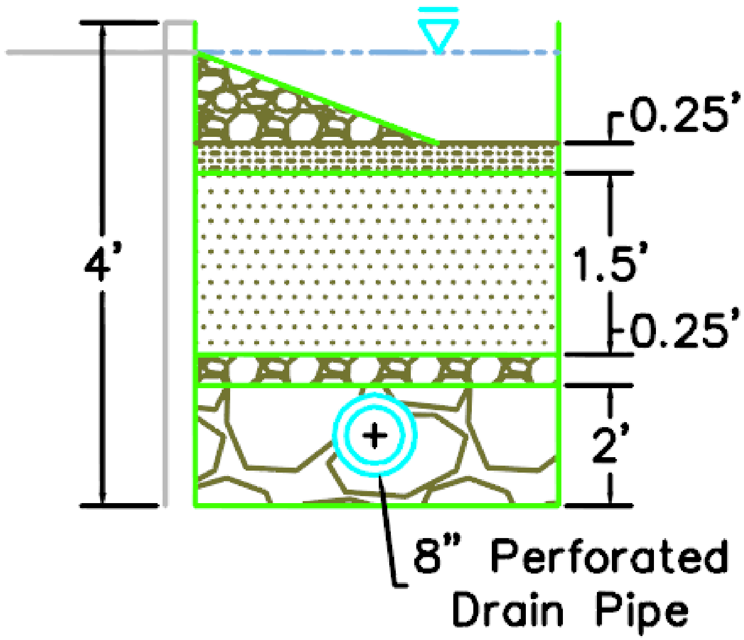


Figure 5-7. Cross Section of Bioretention Cell – typical section

At the outer bounds of the cell, the perforated subdrain connects to a nonperforated storm drain that either drains to the storm drain intake on North Dodge Street or daylight in Pappy Dickens Preserve (Figure 5-5 & Figure 5-8).

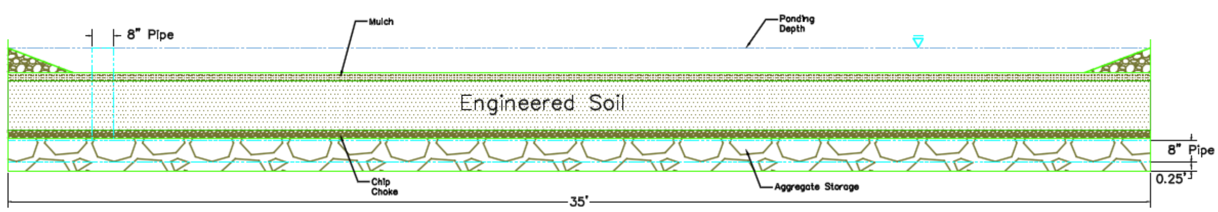


Figure 5-8. Longitudinal Profile of Bioretention Cell – typical section

The total cost of the Bioretention only design is $135,900. A summarized table of quantity and cost estimates is included in Table 5-3.

Table 5-3. Total Cost of Bioretention Only Design Option

Material	Total Quantity	Units	Unit Price	Total Cost
Fine Shredded Mulch[1]	8	CY	$ 41.15	$ 300
Engineered Soil Matrix[1]	47	CF	$ 84.45	$ 4,000
3/8" Chip Choke Layer[2]	9	TON	$ 27.30	$ 300
1-2" Aggregate Storage[2]	63	CY	$ 54.89	$ 3,500
Excavation[2]	378	CY	$ 5.42	$ 2,000
Perforated PVC Pipe[2]	926	FT	$ 23.23	$ 21,500
Shrubs and Grasses[1]	850	SF	$ 5.00	$ 4,300
7" PCC[2]	1625	SY	$ 41.07	$ 66,700
6" Modified Subbase[2]	330	CY	$ 37.64	$ 12,400
Concrete Curb[2]	636	LF	$ 32.84	$ 20,900
			Final Cost	$ 135,900

[1]lowimpactdevelopment.org

[2]IowaDOTBidx

A disadvantage to this system is that it is only capable of treating the stormwater quality thus the need for traditional stormwater management systems will still need to exist to treat larger volume flows. Detailed calculations may be found in Appendix F.

5.4 Design Option 3 – PaveDrain with Bioretention Cells

This design option will be implementing both the PaveDrain system along with the Bioretention cells. The advantage of this system is that by using the bioretention cells to treat the stormwater quality most of the sediment will be removed prior to reaching the PaveDrain system. This will help reduce maintenance needs and prolong the overall life of the system. A plan view of the combined system is provided in Figure 5-9.

Figure 5-9. Plan View of PaveDrain with Bioretention Cells Design

This system consists of the same components listed in the above sections. The one difference is that now the bioretention cells will feed into the PaveDrain system where before they were routed though the storm drainage system. The total cost PaveDrain with bioretention cells design is $295,000. A summarized table of quantity and cost estimates is included in Table 5-4.

Table 5-4. Total Cost of PaveDrain with Bioretention Design Option

Material	Total Quantity	Units	Unit Price	Total Cost
Fine Shredded Mulch[1]	5	CY	$ 41.15	$ 200
Engineered Soil Matrix[1]	31	CY	$ 84.45	$ 2,600
3/8" Chip Choke Layer[2]	6	TON	$ 27.30	$ 200
1-2" Aggregate Storage[2]	41	CY	$ 54.89	$ 2,200
Excavation[2]	244	CY	$ 5.42	$ 1,300
Perforated PVC Pipe[2]	199	FT	$ 23.23	$ 4,600
Shrubs and Grasses[1]	550	SF	$ 5.00	$ 2,800
PaveDrain[1]	14625	SF	$ 13.00	$ 190,100
Concrete Curb[2]	636	LF	$ 32.84	$ 20,900
#57 Aggregate[2]	397	TON	$ 8.95	$ 3,600
#2 Aggregate[2]	2732	TON	$ 8.95	$ 24,500
4" PVC Pipe[2]	856	LF	$ 23.00	$ 19,700
Geotextile Fabric[2]	2485	SY	$ 2.02	$ 5,000
Check Dams (16 total)[2]	18	CY	$ 93.00	$ 1,700
Excavation, Class 10, Roadway and Borrow[2]	2881	CY	$ 5.42	$ 15,600
			Final Cost	$ 295,000

[1]lowimpactdevelopment.org

[2]IowaDOTBidx

This design is recommended because it is the most sustainable solution to meet all requirements.

6 Final Design Conclusions

Over the past few months, Armada Consulting has worked to redesign North Dodge Street Court in Iowa City to create a more sustainable road design that improves water drainage and decreases negative impacts to the environment. Armada has been successful in its efforts and recommends PaveDrain with bioretention cells system to implement on North Dodge Street Court. A plan view of the final design is shown in Figure 6-1

Figure 6-1: Final design plan view

Although PaveDrain with biorentention cells is the most costly, it is the most sustainable design option for Iowa City. This design provides the storage requirements beyond the 10-yr- 24 hr storm, improves water quality, reduces loading on the stormwater management system, has a 50 year design life, supports local businesses, can use recycled materials, and improves the overall aesthetics of the neighborhood. A comparison of the total costs is listed below in Table 6-1.

Table 6-1. Final Project Cost Comparison

Design Option	Total Project Cost
Traditional PCC w/ Storm Drains	$ 156,600
PaveDrain Only	$ 281,100
Tradition PCC w/ Bioretention	$ 135,900
PaveDrain w/ Bioretention	**$ 295,000**

This area of Iowa City drains predominately into Pappy Dickens Preserve, which is hydrologically connected to Hickory Hill Park and Ralston Creek. Hickory Hill Park is presently an 185-acre park acquired in 1967 (City of Iowa City, 2012). It is presently a shared recreation point among joggers, hikers, dog-walkers, bird-watchers, and skiers (Friends of Hickory Hill Park, n.d.) and provides priceless aesthetic and social benefits to the eastern residential area of Iowa City as well as environmental diversity and a refuge for smaller native fauna. Stormwater is charged with degrading surface waters with bacteria, sediment, chemical pollutants, heavy metals, and thermal pollution (Iowa Storm Water Educational Program, 2015). The health of Ralston Creek and the value of the park for wildlife are believed to decline with the urbanization of upstream areas, as increased runoff erodes trailheads and increased pollution puts sensitive flora at risk (Jones, n.d.). Bioretention BMPs are estimated to remove 86% of total suspended solids, 43% of total nitrogen, and 71-90% of total phosphorous of stormwater (Iowa Department of Natural Resources, 2013). Using PaveDrain to slow the hydrography and bioretention cells to treat the water quality volume from the residential lots will help decrease the negative impacts development has on Hickory Hill Park and Ralston Creek.

Using PaveDrain to infiltrate the stormwater will also reduce standing and flowing water on top of the roadway. This reduction in ponded water on the road surface will increase the quality of life for residents of North Dodge Street Court by curtailing mosquito habitat in the summer, lessening ice buildup in the winter, and increasing the aesthetic appeal of the street as a whole (Schweikert, 2014). If implemented in more areas throughout Iowa City, the effects of hydrograph reduction would benefit downstream neighbors like Kalona and Hills by causing naturally occurring floods to be less flashy (Iowa Storm Water Educational Program, 2015) and more manageable.

Most importantly, rainfall is a resource over a nuisance—many Iowans use groundwater a source of drinking water, and recharging rainfall into the unconfined and ofeeten overdrawn Silurian aquifer is a benefit to Iowa City and her neighbors. The hyetograph, or rainfall time-series, is the best way to visualize this asset, Figure 6-1.

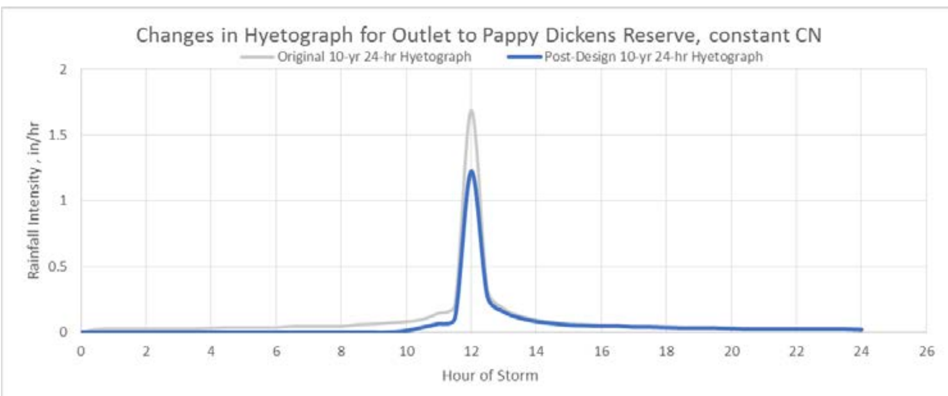


Figure 6-2 Changes in Hyetograph

Using bioretention to treat the water quality volume will help reduce the environmental footprint of the residential area of North Dodge Street Court. Instead of flowing into a stormsewer, pollutants like excess lawn care chemicals and detergents from car, window, and home washing can be remediated in the root systems of the native flora.

The system as a whole is likely more sustainable than a traditional pavement and stormsewer addition on two fronts: long term maintenance and environmental viability. The combination of PaveDrain and bioretention cells likely has better long term maintenance because the system is not in competition with itself. With a traditional pave and stormsewer system, the pavement requires salting and sanding in the winter, and the pipes operate at maximum efficiency at minimum sedimentation. Using PaveDrain will require less salt and sand in the winter as the water will not re-freeze on the surface during freeze-thaw patterns, and using bioretention will entrain sediments that would have otherwise travelled from lawn surfaces, driveways, and shingles. The environmental longevity of the system is encouraged by the use of diverse, native plantings that are well-accustomed to the seasonal variability of Iowan climate.

Bioretention with native landscaping can also increase the quality of the street's ambience by introducing color and texture to an otherwise uniform area and by dampening noise from the street. These can increase property values and overall landowner satisfaction.

ThePaveDrain and bioretention cell design is the most appropriate first step towards responsible stormwater management. This design grants Iowa City the opportunity to showcase the benefits of green technology to encourage community understanding and foster sustainable growth.

7 References

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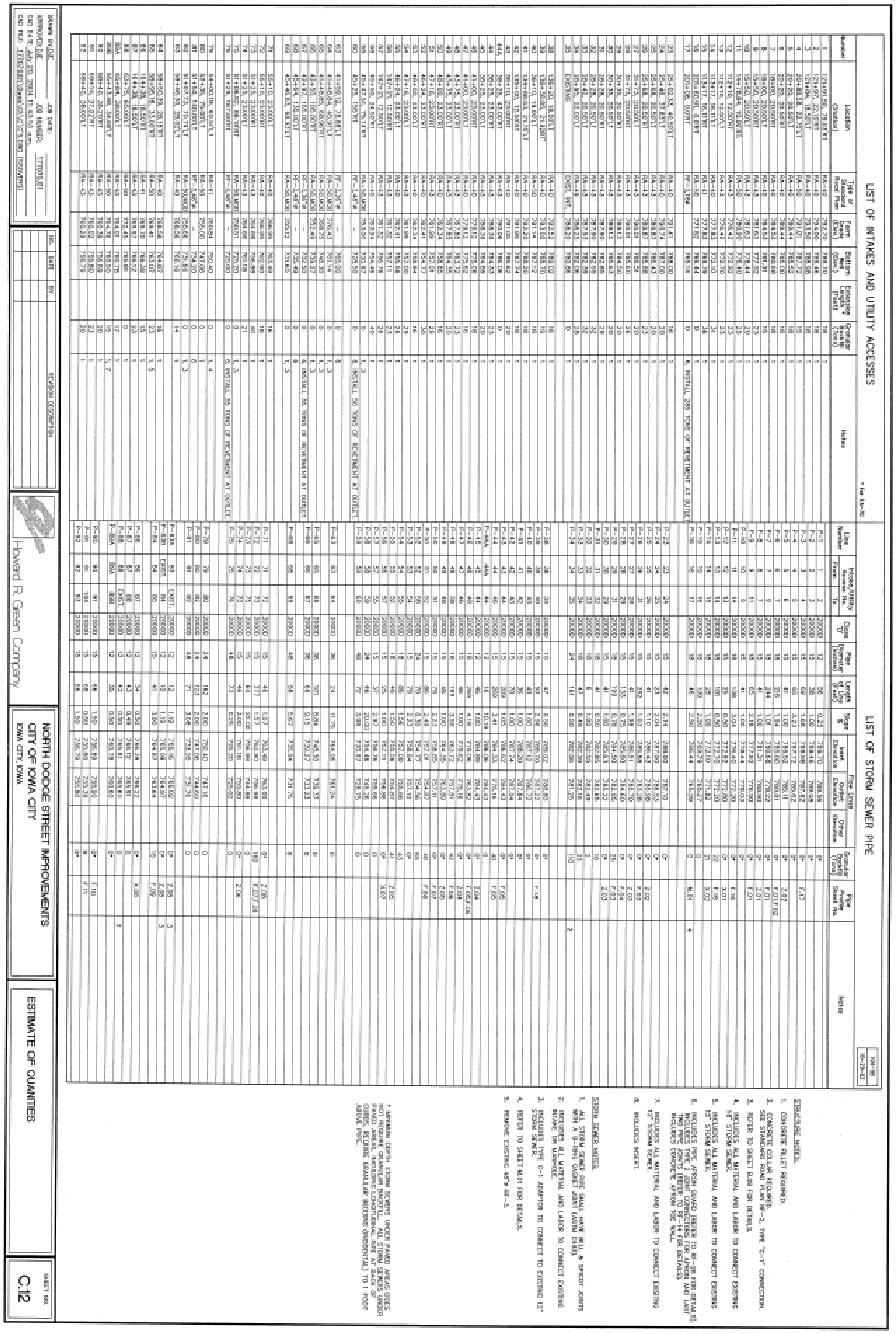
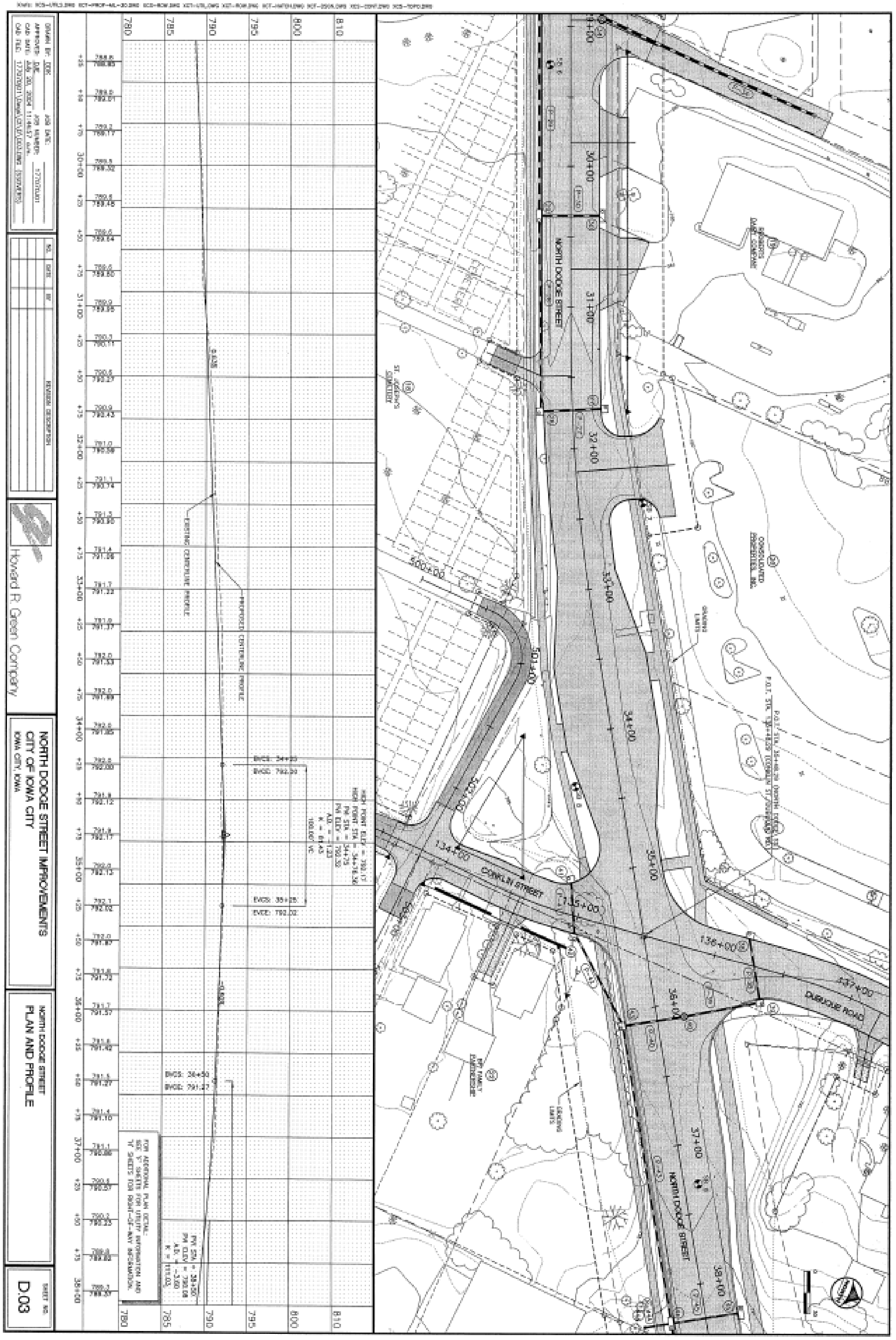
Appendix A. –Existing Storm Sewer Plans




NORTH DODGE STREET IMPROVEMENTS
CITY OF IOWA CITY
IOWA CITY, IOWA
Howard R. Green Company
NORTH DODGE STREET
PLAN AND PROFILE
D.03
NORTH DODGE STREET
CONKLIN STREET
DUBUQUE ROAD

Appendix B. PaveDrain - Permeable Street Design

Pave drain design

Design goal is to capture and store the runoff from a 10 yr 24 hr storm.

Site Data		Hydrologic Data	
Total Site Drainage Area = 1.2 ac		Minimum infiltration rate (*ƒ*) (in/hr)	Wieghted CN
Imperviou Area = 0.5 ac			
Soils: HSG C	(Silt Loam) 0 - 10 inches	0.27	85
	(Silty Clay Loam) 10 - 47 inches	0.06	
	(Silt Loam) 47 - 60 inches	0.27	

A total nominal depth of 48 inches was chosen to reach the soils with a higher infiltration rate.

Existing Conditions:

- Street is 635.6 feet. Long
- Developed site ¼ acre lots (38% impervious) 90% of Area and Streets 10% of area.
- Land Slope from high point is ± 1.8% towards Conklin and 1.6% towards the East end of N. Dodge st ct.
- Soil data from NRCS maps indicate a depth of ~48 inches should be used to obtain higher infiltration rates. A nominal rate of 0.135 in/hr will be used for design (0.27 in/hr /2 = 0.135 in/hr). Design safety factor = 2.
- There is an existing storm sewer at the intersection of N. Dodge St. and Conklin. Currently runoff west of the high point on North Dodge St. Ct. drains down Conklin to the storm drain. All runoff east of the high point drains down North Doge St. Ct. and then enters the gulley east of the site in the Pappy Dickens Preserve area.
- There is currently a new development being constructed on the North side of North Dodge St. Ct.

  Runoff:

  Runoff was computed using NRCS methods.

Design Storm	Runoff Volume (Qc) (in.)	Peak Flow (cfs)		Total Runoff Volume (ft^3)
		East Dodge St. Ct.	Conklin Intersection	
5 yr 24 hr	2.29	1.02	0.18	6,283
10 yr 24 hr	2.83	1.26	0.23	12,386
25 yr 24 hr	3.34	1.49	0.27	22,324
50 yr 24 hr	3.73	1.66	0.3	19,746
100 yr 24 hr	5.34	2.37	0.43	23,411

Design criteria and applicability:

Inflitration Feasibility	
Criteria	Status
Infiltration rate (f) greater than or equal to 0.5 in/hr	Infiltration rate of 0.27 in/hr , design infiltration rate of 0.135 in/hr. Soil indicates moderate permability, use of underdrain piping for partial exfiltration from pavement base. OK
Soils have a clay content of less than 20% and a silt/clay content of less than 40%	According to NRCS soil maps: Silt loam and silt clay loam at this site. CL soils. Typical CBR values 2-5. Meets criteria from Table 2 Section 2J-1 of ISMM. OK
Infiltration cannot be located on slopes greater than 6% or in fill soils	Slope is 2-4%; not fill soils. OK
Hotspot runoff should not be infiltrated	Not a hotspot land use. OK
Infiltration is prohibited in karst topography	Not in karst. OK
The bottom of the aggregate base must be separated by at least 2 feet vertically from the seasonally high water table.	According to NRCS the water table is more than 80 inches. The agregate base can be up to 56 inces deep and meet these criteria. OK
Infiltation facilities must be located 100 feet horizontally from any water supply	Water supply wells are > than 100 ft. from the site
Maximum contributing area generally less than 5 acres. (Optional)	1.2 acres. OK
Setback 25 feet down-gradient from structures	> 25 ft. from down gradient house on far east end of North Dodge St. CT.

Aggregate Base Calculations:

a. Minimum depth (dp) method (ISWMM).

d_p (inches) = $[(Q_C)(A_C/A_P) + P - fT] / V_r$

-Contributing catchment area, Ac = 26,722 feet^2

-Permeable pavement area, Ap=17,797 feet^2

-Select design rainfall event, P (in.), and corresponding runoff volume, Qc (in.).

- Nominal fill time for pavement, T = 2 hours (2 hours is typical (ISWMM))

-Design infiltration rate, *f*= 0.135 in/hr

-Nominal void ratio, Vr= 0.35 (Assumed void ratio of #57/#2 subbase)

Design Storm	Rainfall (P) (in.)	Runoff Volume (Qc) (in.)	Minimum depth for Storage (dp)
5 yr 24 hr	3.84	2.29	20.0
10 yr 24 hr	4.44	2.83	24.1
25 yr 24 hr	5.42	3.34	29.0
50 yr 24 hr	6.25	3.73	33.1
100 yr 24 hr	7.13	5.34	42.5

b. Maximum depth (dmax)

$d_{max} = (fT_s / n) = (fT_s / V_r)$ (inches)

-Design infiltration rate, *f*= 0.135 in/hr

-Drain down time, Ts = 72 hours (maximum time before the next storm event occurs)

-Nominal void ratio, Vr= 0.35 (Assumed void ratio of #57/#2 subbase)

Using this criteria the maximum depth for a drain down time of 72 hours is, **d_{max} = 27.77 inches**.

Because the total nominal depth is 48 inches a subdrain will be installed at 27 inches from the soil subgrade to allow for the required drain down time. At this depth the permeable pavement system will be able to store above the desired 10 yr storm volume.

c. Minimum required subbase thickness for structural support

-The total nominal design depth of 48 inches is larger than the depth requirements for structural support listed in Table 5 of the ISWMM.

Table 5: Recommended minimum open-graded base and subbase thicknesses for permeable pavements (inches)

Climate	No Frost	No Frost	No Frost	No Frost	Frost	Frost	Frost	Frost
	Soaked CBR	>15	10 - 14	5 - 9	Gravelly Soils	Clayey Gravels, Plastic Sandy Clays	Silty Gravel, Sand, Sandy Clays	Silts, Silty Gravel, Silty Clays
ESALs *	Layers of subbase	inches	inches	inches	inches	inches	inches	inches
Pedestrian	No. 57 No. 2	4 6	4 6	4 6	4 6	4 6	4 6	4 6
50,000	No. 57 No. 2	4 8	4 8	4 8	4 8	4 8	4 8	4 8
150,000	No. 57 No. 2	4 8	4 8	4 8	4 8	4 8	4 10	****
600,000	No. 57 No. 2	4 8	4 8	4 10	4 8	4 14	4 18	****

* ESALs = 18kip (80kN) Equivalent Single Axle Loads

**** Strengthen subgrade with aggregate subbase to full frost depth

1. All thicknesses are after compaction and apply to full, partial, and no exfiltration systems.
2. Pedestrian applications should use a minimum base thickness of 10 inches.
3. Thicknesses do not include the No. 8 bedding course (2 inches) plus the paver unit thickness (typical 3.125 inches) for permeable paver systems; a standard pervious concrete thickness of 6-inches and 5 to 6 inches of porous asphalt surface would be similar in thickness to the permeable paver bedding course and pavers.
4. Geotextile over the subgrade is recommended.
5. Silty soils or others with more than 3% of particles smaller than 0.02 mm are considered susceptible to frost action.
6. All soils have a minimum CBR of 5%.

d. Minimum 2 feet. separation from the seasonally high water table.

-According to NRCS the water table is more than 80 inches below the surface.

-The aggregate base can be up to 56 inches deep and meet these criteria.

-At a 48 inch depth the separation from the water table will be ≈ 2.5 feet.

e. Geotextile Fabric

-To create a barrier between the soil sub-grade and the aggregate base a geotextile fabric is recommended. The filter fabric provides a separation and filter to prevent migration of fine soil particles (silt/clay fines) into the reservoir layer reducing storage capacity.

-Further soil analysis is required to select a geotextile fabric in accordance with Figure 4 of the ISWMM.

Figure 4: Geotextile Filter Criteria

U.S. Federal Highway Administration (FHWA)
For fine grained soils with more than 50% passing the No. 200 sieve:
Woven geotextiles: Apparent Opening Size (AOS) $\leq D_{85}$
Non-woven geotextiles: $AOS_{geotextile} \leq 1.8\ D_{85}$
$AOS \leq 0.3$ mm or $\geq$ No. 50 sieve

For granular soils with 50% or less passing the No.200 sieve:
All geotextiles $AOS_{geotextile} \leq B \times D_{85soil}$
Where:
$B = 1$ for $2 \geq C_u \geq 8$
$B = 0.5$ for $2 \geq C_u \geq 4$
$B = 8/C_u$ for $4 < C_u < 8$
$Cu = D_{60}/D_{10}$ (Uniformity coefficient)

Permeability criteria: k (fabric) $\geq$ f (soil)

Clogging criteria
Woven: Percent of open area $\geq 4\%$
Non-woven Porosity $\geq 30\%$

American Association of State Highway and Transportation Officials (AASHTO)
For soils $\leq 50\%$ passing the No. 200 sieve:
$O_{95} < 0.59$ mm ($AOS_{fabric} \geq$ No. 30 sieve)

For soils > 50% passing the No. 200 sieve:
$O_{95} < 0.30$ mm ($AOS_{fabric} \geq$ No. 50 sieve)

Notes:
1. D_x is particle size at which x percent of the particles are finer. Determined from the gradation curve. i.e. D_{10} is the size particle of soil or aggregate gradation for which 10% of the particles are smaller and 90% are larger.
2. O_x is geotextile size corresponding to x particle size based on dry glass bead sieving. i.e. O_{95} is the geotextile size opening for which 95% of the holes are smaller.
3. Apparent opening size (AOS) is essentially the same but normally defined as a sieve number rather than as a size (ASTM D 4751). POA is percent open area (for woven fabrics only).
4. Permeability, K, of the soil and geotextile (non-woven only) are designated k_s and k_G respectively.

f. Undrain piping

-A 4 inch diameter perforated PVC underdrain pipe will be installed with a flow line depth of 27 inches above the bottom of the aggregate.

-This place the flow-line of the underdrain piping above the storage depth for the 10-yr, 24 hour storm.

-The total storage capacity of the base below the underdrain piping is about, $\mathbf{V_{ST} = 14{,}000\ feet^3}$ the storage required for the 10-yr, 24 hour storm is $\mathbf{V_{10\text{-}yr} = 12{,}400\ feet^3}$
The storage required for a 25-yr, 24 hour storm is $\mathbf{V_{25\text{-}yr} = 14{,}600\ feet^3}$

This storage volume meets the detention requirements for the 10 year runoff and also would store the majority of the 25 year runoff as well.

Appendix C. PaveDrain info

Metropolitan
St. Louis Sewer
District

2350 Market Street
St. Louis, MO 63103-2555
(314) 768-6200
www.stlmsd.com

July 25, 2012

Mr. Dave Schuster
ASP Enterprises
1099 Cassens Industrial Ct.
Fenton, MO 63026

RE: Pavedrain Articulating Permeable Paving Surface - A Structural BMP

Dear Mr. Schuster,

The Metropolitan St. Louis Sewer District (MSD) has reviewed your application of the Pavedrain Articulating Permeable Paving Surface and hereby grants the product Provisional Use Level (PUL) approval. MSD understands that Pavedrain is an articulating concrete block mat system that enhances surface permeability by the open space created between the blocks. Pavedrain is recognized as a permeable pavement in satisfying MSD stormwater management requirements.

MSD has determined that Pavedrain may be used under the following conditions:

1. Proposed uses and designs of Pavedrain, must be in general conformance with the information and methodologies provided by ASP Enterprises and PaveDrain LLC received March 28, 2012 and the detail attached to this approval letter.
2. Channel Protection Volume (CPv) storage may be provided in the sub base stone beneath the articulating block and bedding layer.
3. The articulating block mat shall rest on a 4-inch thick layer of base stone (ASTM No. 57 or similar size), and a layer of subbase stone (ASTM No. 2 or similar size), all underlain by MSD type 4 filter fabric. The thickness of the subbase will vary depending on storage and anticipated traffic loads. However, a minimum 12-inch thick subbase will be required for all applications.
4. The post-developed curve number (CN) for the footprint of the Pavedrain Articulating Permeable Paving Surface may be reduced. Reduced CN numbers are provided below.

Soil	A	B	C	D
CN	61	61	74	80

5. The Pavedrain system will be considered as pervious area for the purpose of calculating Water Quality Volume (WQv) and 5 percent impervious when calculating the differential runoff with PI factors. However, the Pavedrain will be considered as 100 percent impervious area for the purpose of calculating pipe sizes downstream and when evaluating a site's annual post developed runoff condition.
6. Pavedrain may be considered as a stand-alone BMP in certain design instances. Those designs are subject to MSD review and approval.

Page 1 of 3

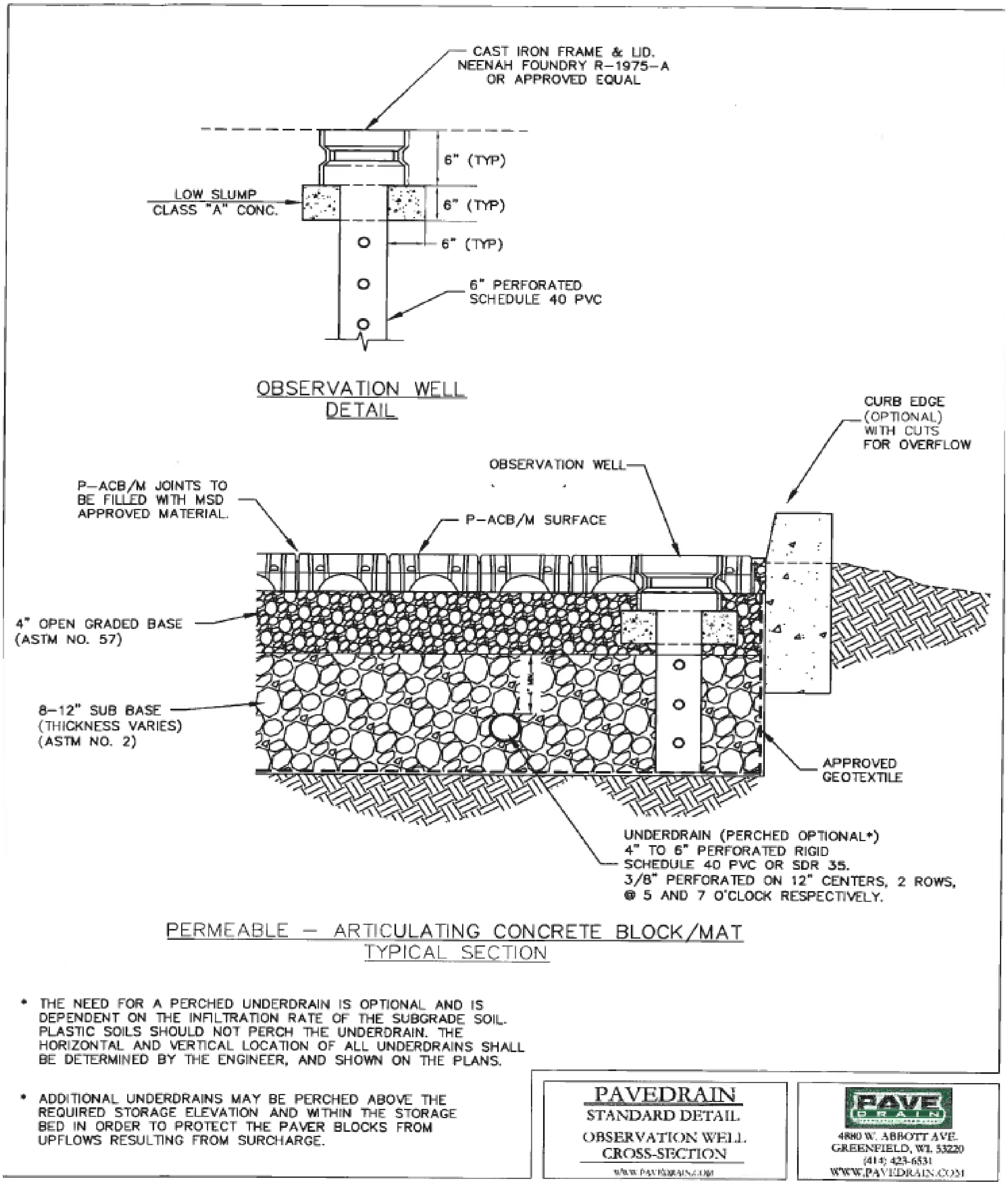
7. Project specific design calculations and maintenance plans must be included within the project's "Stormwater Management Facilities Report" prepared by the consulting Engineer.

MSD reserves the ability to withdraw or modify this approval based on subsequent information, including information indicating that Pavedrain does not satisfy MSD rules, requirements, or construction and material specifications. Please provide MSD with a representative sample of the product your supplying manufacturer is producing.

Sincerely,

Jason T. Peterein, P.E.
Civil Engineer (BMP Committee Chairman)
Engineering / Planning / Development Review
Metropolitan St. Louis Sewer District

Page 2 of 3


CAST IRON FRAME & LID.
NEENAH FOUNDRY R-1975-A
OR APPROVED EQUAL
6" (TYP)
LOW SLUMP
CLASS "A" CONC.
6" (TYP)
6" (TYP)
6" PERFORATED
SCHEDULE 40 PVC
OBSERVATION WELL
DETAIL
CURB EDGE
(OPTIONAL)
WITH CUTS
FOR OVERFLOW
OBSERVATION WELL
P-ACB/M JOINTS TO
BE FILLED WITH MSD
APPROVED MATERIAL.
P-ACB/M SURFACE
4" OPEN GRADED BASE
(ASTM NO. 57)
8-12" SUB BASE
(THICKNESS VARIES)
(ASTM NO. 2)
APPROVED
GEOTEXTILE
UNDERDRAIN (PERCHED OPTIONAL*)
4" TO 6" PERFORATED RIGID
SCHEDULE 40 PVC OR SDR 35.
3/8" PERFORATED ON 12" CENTERS, 2 ROWS,
@ 5 AND 7 O'CLOCK RESPECTIVELY.
PERMEABLE - ARTICULATING CONCRETE BLOCK/MAT
TYPICAL SECTION
* THE NEED FOR A PERCHED UNDERDRAIN IS OPTIONAL AND IS DEPENDENT ON THE INFILTRATION RATE OF THE SUBGRADE SOIL. PLASTIC SOILS SHOULD NOT PERCH THE UNDERDRAIN. THE HORIZONTAL AND VERTICAL LOCATION OF ALL UNDERDRAINS SHALL BE DETERMINED BY THE ENGINEER, AND SHOWN ON THE PLANS.
* ADDITIONAL UNDERDRAINS MAY BE PERCHED ABOVE THE REQUIRED STORAGE ELEVATION AND WITHIN THE STORAGE BED IN ORDER TO PROTECT THE PAVER BLOCKS FROM UPFLOWS RESULTING FROM SURCHARGE.
PAVEDRAIN
STANDARD DETAIL
OBSERVATION WELL
CROSS-SECTION
PAVE DRAIN
4880 W. ABBOTT AVE.
GREENFIELD, WI. 53220
(414) 423-6531
WWW.PAVEDRAIN.COM

Engineering Department
CITY OF GOSHEN
204 East Jefferson Street, Suite 1 • Goshen, IN 46528-3405

Phone (574) 534-2201 • Fax (574) 533-8626 • TDD (574) 534-3185
engineering@goshencity.com • www.goshenindiana.org

June 17, 2014

PaveDrain, LLC
Global Water Center
247 Global Water Center
Milwaukee, WI 53204

Attention: Mr. Doug Buch, President

RE: JEFFERSON STREET RECONSTRUCTION

Dear Mr. Buch,

We had multiple, experienced and respected construction people from around our area that had strong reservations to the City of Goshen's use of the PaveDrain system for the reconstruction of Jefferson Street during the Fall of 2013. The City's storm sewer in this area is currently undersized, and during some rain events the storm sewer would surcharge causing the storm sewer to back up into nearby building basements. We are pleased to report that the PaveDrain system has performed extremely well under what could only be considered exceptional circumstances. Including the following:

- ❑ Worst winter in Goshen in over 100 years with a frost depth of up to five feet along with record snowfall. The freeze-thaw and frost heave were not an issue. We snow plowed it with a rubber tipped blade to keep the surface of the block looking new.
- ❑ Multiple spring rains. The flooding and basement issues that have plagued this area have been solved.
- ❑ Bicycle Race. The City of Goshen recently held a sanctioned bicycle road race. I personally verified that the racers experienced no ill effects from riding on the PaveDrain system.
- ❑ Minimal settling. This is a tribute to the efforts of the contractor, HRP Construction. Issues of twisting or settling blocks has not occurred.

We are pleased to announce that we are going forward with additional PaveDrain projects this year including the River Race Project that was recently awarded. We look forward to working with the PaveDrain system again in the near future.

Sincerely,

Mary Cripe, P.E.
City Engineer

Appendix D. Detailed Comparisons for Stormwater and Pavement Technologies

Detailed Comparisons

1. Stormwater Management Systems

1.1. Traditional Storm Sewer

Storm drain systems need to be cleaned regularly. Routine cleaning reduces the amount of pollutants, trash, and debris both in the storm drain system and in receiving waters. Clogged drains and storm drain inlets can cause the drains to overflow, leading to increased erosion (Livingston et al., 1997). Cleaning increases dissolved oxygen, reduces levels of bacteria, and supports in-stream habitat. Areas with relatively flat grades or low flows should be given special attention because they rarely achieve high enough flows to flush themselves (Ferguson et al., 1997).

Some common pollutants found in storm drains include:

- trash and debris
- sediments
- oil and grease
- antifreeze
- paints
- cleaners and solvents
- pesticides
- fertilizers
- animal waste
- detergents

Cleaning storm drains by flushing is more successful for pipes smaller than 36 inches in diameter.
A water source is necessary for cleaning.
Wastewater must be collected and treated once flushed through the system

http://www.iowadnr.gov/Environment/WaterQuality/WatershedImprovement/WatershedBasics/Stormwater/StormwaterManual.aspx

Material & Installation Costs (Current)

12 inch RCP ~ $45.00 / LF (from recently bid projects in Iowa City)

Storm Drains (Intake, Type SW-507, Single Open Throat (No Grate) ~ $4,000 EA (from Jason Havel Email)

Additional infrastructure may include detention basins and/or increased storm water treatment capacity.

http://www.icgov.org/default/apps/equipment/construction.asp

-Maintenance Costs

The cost of a vactor truck can range from $175,000 to $200,000, and labor rates range from $125 to $175 per hour (Ferguson et al., 1997). Ferguson et al. (1997) also cited costs of $1.00 to $2.00 per foot for storm drain system cleaning

http://water.epa.gov/polwaste/npdes/swbmp/Storm-Drain-System-Cleaning.cfm

-Design Life

Army Corps of Engineers recommends a design life of 70-100 years for precast concrete pipe

http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2902.pdf

-Runoff Reduction (infiltration)

None

-Water Quality

Not Improved

-Aesthetics

None

-Site Requirements

Not Recommended. This design will not improve water quality or reduce runoff quantities

1.1. Water Quality Swales

Grassed Swale
Source: LID Center

Design Criteria:

- o Broad, shallow channel vegetated along bottom and sides with grasses designed to accommodate peak flow of design storm
- o Side slopes must be 3:1 (rise : run) or less
- o Slope in flow direction must be 5 percent or less
- o Grass along sides of channel is kept at a height greater than the maximum design stormwater volume
- o Soils must have a minimum permeability rate of 0.27 inches per hour (SCS A/B soils groups) or be improved with amendments
- o An optional gravel layer can provide storage of stormwater in excess of WQV; engineered soil can improve filtration

Maintenance:

- o Conduct routine periodic maintenance that is required of any grassed area: mow, weed, water, aerate and reseed.
- o Maintain grass height equal or greater to the design flow depth.
- o Minimize or eliminate us of fertilizers, herbicides, and pesticides.
- o Remove sediment and debris after severe storm events.
- o Inspect swales (and check dams) for erosion and repair and reseed as needed.

Advantages:

o Useful for small drainage areas with low stormwater velocities

o Use existing natural low areas to treat stormwater o Can be sized to convey any design storm required

o Reduce stormwater volume

o Enhance quality of downstream waters

o Reduce runoff velocity

o Minimal maintenance requirements

Disadvantages:

o Not applicable to large drainage areas in excess of 10 acres (much smaller areas are recommended)

o Not recommended for areas with slopes greater than 5% or where velocities exceed 3 to 4 feet per second --- without the use of check dams

o Not applicable where soil infiltration rates are less than 0.3 inches per hour

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Material Costs (2005 Dollars)

Grading S.Y. $0.10 - $0.15

Erosion control material S.Y. $1 - $2

Sod S.F. $2 - $4

Grass seed S.F. $1 - $2

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Maintenance Costs (2005 Dollars)

Mowing $100/yr

Reseeding $50/yr

Aeration $50/yr

Cost calculations were based upon a water quality swale with a surface area of 900 square feet.

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Design Life

25 yrs. then remove and replace

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Runoff Reduction (infiltration)

Grass swales can provide effective control under light to moderate runoff conditions, but their ability to control large storms is limited. Grass swales are ofeeten used as a pre-treatment measure for other downstream BMPs, particularly infiltration devices.

Iowa Stormwater Management Manual

-Water Quality

Water quality treatment in standard grass swales is provided by managing the slope and vegetation in the channel to slow the velocity to ~1 fps for the water quality design storm (≤ 1.25 inches)

BENEFITS Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids		■	
Nitrogen	■	■	
Phosphorous	■	■	
Metals		■	■
Bacteriological	■		
Hydrocarbons	*	*	*

* Insufficient Data

Iowa Stormwater Management Manual

-Aesthetics

Average

-Site Requirements

Recommended for WQv in combination with other d/s BMP's Size is limited to land available thus amount of runoff handled is limited. Could be used in combination with additional BMP's and still be effective.

1.2. Bio-Retention Cells

VIII.2.Bioretention Cells

Bioretention cell in a commercialr parking lot
Source: LID Center, Inc

Design Criteria:

- Excavated to a minimum depth of one to three feet (deeper excavation can provide for additional storage in the soil or gravel layers, or more surface ponding)
- Cells, or "rain gardens," contain grasses and perennials, shrubs, and small trees
- A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.
- Underdrains are recommended in areas with low subsoil permeability. Observation (cleanout) wells should also be installed, if underdrains are used.

Maintenance:

- Conduct routine periodic maintenance as required of any landscaped area.
- Inspect the treatment area's components and repair or replace them if necessary.
- Remove accumulated sediment and debris, replace any dead or distressed plants, and replenish the mulch layer on an annual basis.
- Repair any eroded areas as soon as they are detected.

Advantages:

o Useful for small drainage areas

o Useful in impervious areas (e.g. parking lots, traffic medians)

o Effective for retrofit

o Enhance the quality of downstream water bodies

o Improve landscape appearance, absorb noise, provide shade and wind breaks

o Maintenance needs similar to any other landscaped area

Disadvantages:

o Not recommended for areas where mature tree removal would be required

o Not recommended for areas with high sediment loads

o Not appropriate where the surrounding soil stratum is unstable

o Not applicable for large drainage areas

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Material Costs (2005 $)

Excavation C.Y. $8 - $10

Bioretention media C.Y. $40 - $60

Filter fabric S.Y. $1 - $5

Gravel C.Y. $30 - $35

Underdrain (perforated pipe 4” dia.) L.F. $8 - $15

Plants Ea. $5 - $20

Mulch C.Y. $30 - $35

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Maintenance Costs (2005 $)

Mulching and Debris Removal $350 / yr

Replace Vegetation $200 / yr

Cost of a bioretention cell to treat runoff from ½ impervious acre consists of both installation costs and annualized costs. Cost calculations were based upon a bioretention cell with a surface area of 900 square feet, sized to treat the first 0.5” of runoff.

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Design Life

A bioretention cell is assumed to have a lifespan of 25 years, at which point it would be removed and replaced

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Runoff Reduction (infiltration)

In bioretention cells, stormwater runoff collected in the upper layer of the system is filtered through the surface vegetation, mulch layer, pervious soil layer, and then stored temporarily in a stone aggregate base layer. The Water Quality Volume (WQv) is drained from the aggregate base by infiltration into the underlying soils and/or to an outlet through a perforated pipe subdrain. Systems can operate either off-line or online. They are designed with a combination of plants that may include grasses, flowering perennials, shrubs, or trees. Integrated upstream treatment is provided by a perimeter grass filter strip or grass swale for initial capture of sediment.

Iowa Stormwater Management Manual

-Water Quality

a. **Water quality**. Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the bioretention cell is designed to perform a specific function (see Figure 3).

1) Pretreatment practices reduce incoming runoff velocity and filter particulates from the runoff.

2) The ponding area provides for temporary storage of stormwater runoff prior to its evaporation, infiltration, or uptake and provides additional pollutant settling capacity.

3) The organic or mulch layer provides filtration, as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material.

4) The modified soil in the bioretention cell acts as a filtration system, and clay organic matter in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients, and other pollutants.

5) Herbaceous and woody plants in the ponding area provide vegetative uptake of runoff and pollutants, and also serve to stabilize the surrounding soils, but will require maintenance such as trimming, pruning, and selective removal of volunteer species.

6) Finally, an aggregate layer provides for positive drainage and aerobic conditions in the modified soil, and provides a final polishing treatment media.

BENEFITS Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids		■	
Nitrogen		■	
Phosphorous	■		
Metals		■	■
Bacteriological			■
Hydrocarbons			■

Iowa Stormwater Management Manual

-Aesthetics

Good to Great

-Site Requirements

Recommended for WQv in combination with other u/s BMP's. Stormwater in excess of the water quality volume (WQV) can be detained by allowing additional ponding and/or subsurface storage in the bioretention cell, thereby reducing the runoff volume and peak discharge rate. Voids in the soil and gravel layers provide stormwater storage capacity. The depth of the gravel layer may be increased to add storage capacity. Exfiltration into the subsoil can reduce the volume of stormwater that ultimately enters the conveyance system. Volume reduction depends on the available detention storage in the gravel layer and ponding area. It also is a function of the flow rate into the cell and the maximum flow rate into the subsoil. These factors are related to the storm intensity and drainage area size.

1.3. Infiltration Trench

Source: California Stormwater Manual

An infiltration trench is a shallow excavated trench, typically 3 to 12 feet deep, that is backfilled with a coarse stone aggregate, allowing for the temporary storage of runoff in the void space of the material. Discharge of this stored runoff occurs through infiltration into the surrounding naturally permeable soil. Trenches are commonly used for drainage areas less than five acres in size. An infiltration basin is a natural or constructed impoundment that captures, temporarily stores and infiltrates the design volume of water over several days. Infiltration basins are commonly used for drainage areas of 5 to 50 acres with land slopes that area less than 20 percent. Typical depths range from 2 to 12 feet, including bounce in the basin.

Best Management Practices Construction Costs, Maintenance Costs, and Land Requirements Prepared for Minnesota Pollution Control Agency June 2011 Barr Engineering

Advantages:

- Appropriate for small sites with porous soils
- Infiltration trenches reduce runoff volume and filter pollutants
- Provide stream base flow and recharge groundwater.
- As an underground BMP, trenches are unobtrusive and have little impact on site aesthetics

Limitations:

- Use should be restricted to small drainage areas – generally less than 5 acres
- Suitable for NRCS HSG-A/B soils; limited application in HSG-C soils; not recommended in HSGD soils. Do not use with soil infiltration rates < 0.5 in/hr
- Seasonal high water table should be 4 feet below bottom of trench
- Susceptible to clogging by sediment – use upstream BMPs for sediment removal
- Restricted in karst areas
- Placement under paved surfaces or in industrial or commercial settings not recommended

Maintenance requirements:

- Remove sediment accumulation to ensure proper functioning
- Inspect for clogging – install an integrated observation well/piezometer to check water level
- Remove sediment from pre-treatment areas

Iowa Stormwater Management Manual

-Material Costs (2005 $) No Data available assumed similar to bioretention

Excavation C.Y. $8 - $10

Filter fabric S.Y. $1 - $5

Gravel C.Y. $30 - $35

Underdrain (perforated pipe 4" dia.) L.F. $8 - $15

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Maintenance Costs (2005 $) No Data available assumed similar to bioretention

Sediment and Debris Removal $350 / yr

Cost of a bioretention cell to treat runoff from ½ impervious acre consists of both installation costs and annualized costs. Cost calculations were based upon a bioretention cell with a surface area of 900 square feet, sized to treat the first 0.5" of runoff.

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Design Life

Assumed same as bioretention cell: assumed to have a lifespan of 25 years, at which point it would be removed and replaced

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

-Runoff Reduction (infiltration)

The required trench storage volume is equal to the WQv. For smaller sites, an infiltration trench can be designed with a larger storage volume to include the Cpv

A trench must be designed to fully dewater the entire WQv within 24 to 48 hours afeeter a rainfall event. The slowest infiltration rate obtained from tests performed at the site should be used in the design calculations.

Iowa Stormwater Management Manual

-Water Quality

Infiltration trenches can remove a wide variety of pollutants from stormwater through sorption (the action of soaking up or attracting substances), precipitation, filtering, and bacterial and chemical degradation. Pre-treatment areas up-gradient of the infiltration site are provided to remove a larger portion of the TSS and overall sediment load. Examples of some pre-treatment areas include grit chambers, water quality inlets, sediment traps, swales, and vegetated filter strips (SEWRPC 1991; Harrington 1989).

Pollutant Removal Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids			■
Nitrogen		■	■
Phosphorous		■	
Metals			■
Bacteriological			■
Hydrocarbons		■	

-Aesthetics

Average

-Site Requirements

Recommended for WQv in combination with other u/s BMP's. Stormwater in excess of the water quality volume (WQV) can be detained by allowing additional ponding and/or subsurface storage in the bioretention cell, thereby reducing the runoff volume and peak discharge rate. Voids in the soil and gravel layers provide stormwater storage capacity. The depth of the gravel layer may be increased to add storage capacity. Exfiltration into the subsoil can reduce the volume of stormwater that ultimately enters the conveyance system. Volume reduction depends on the available detention storage in the gravel layer and ponding area. It also is a function of the flow rate into the cell and the maximum flow rate into the subsoil. These factors are related to the storm intensity and drainage area size.

2. Pavements

2.1. Traditional Concrete & Traditional Asphalt

-Material Costs

$40/ SY for 7" PCC pavement (Jason Havel email)

$40/CY for 6" modified subbase (Jason Havel Email)

$0.50 - $1 per sq feet. Asphalt (Iowa DOT)

-Maintenance Costs

~3,000 potholes patched per year (Iowa City Transportation Numbers)

~1400 yds. Of concrete per year (Iowa City Transportation Numbers)

~500 tons of Asphalt per year (Iowa City Transportation Numbers)

~2600 Tons of sweeping debris per year (Iowa City Transportation Numbers)

~$450,000 per year to plow and treat streets (Iowa City Transportation Numbers)

-Design Life

15 years for Asphalt (Iowa DOT)

30 years for concrete (Iowa DOT)

-Runoff Reduction (infiltration)

None

-Water Quality

Does not improve water quality

-Aesthetics

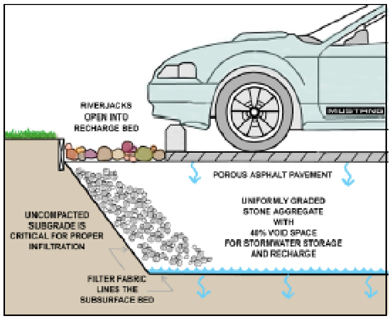
Same

-Site Requirements

Not Recommended. This design will not improve water quality or reduce runoff quantities

2.2. Permeable / Porous Pavement

VIII.7.Permeable / Porous Pavement



Permeable pavement cross-section
Source: Cahill and Associates

Design Criteria:

- Asphalt or concrete with reduced fines and a special binder allowing water to pass through voids OR paving blocks installed with gaps between units that are filled with aggregate or soil and turf grass
- Porous paving is underlain with a subbase of aggregate comprised two layers:
  - Upper layer – fines
  - Lower layer – coarse aggregate
    - structural support
    - reservoir
- Geotextile fabric separates aggregate layers from the soil below
- Underdrains and cleanouts may be needed where infiltration rates are low

Maintenance:

- Primary Goal –
  Prevent clogging of voids by fine sediment particles
  - Vacuum pavement three (3) to four (4) times annually
  - DO NOT pressure wash pavement (forces particles deep into voids)
  - DO NOT apply abrasive materials as treatment for snow/ice safety hazards
- Inspect regularly for clogging as well as structural soundness.

Advantages:

o Useful in parking lots, driveways, road shoulders and paths

o Uses site features that cause stormwater management problems as part of a creative solution

o Conserves space allocated to stormwater management

o Effective for retrofit

o Enhance quality of downstream waters by decreasing runoff volume and peak discharge, as well as filtering pollutants and aiding recharge of groundwater

Disadvantages:

o Only feasible in areas level enough for vehicular and pedestrian uses

o Without adequate training, personnel can permanently damage structures o Not feasible where sediment loads cannot be controlled

o Not appropriate where the seasonal groundwater table – or bedrock - is within two (2) to four (4) feet of the bottom of the infiltration trench

http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf

2.3. Pervious Concrete

-Material Costs

$2 - $7 per sq feet for concrete (2005 $)

http://ntl.bts.gov/lib/43000/43500/43570/TSR-2011-permeable-pavements.pdf

Subbase and other materials are the same for all permeable pavements.

-Maintenance Costs

$400 to $500 per year for vacuum sweeping a half-acre parking lot three to four times

Annually

http://ntl.bts.gov/lib/43000/43500/43570/TSR-2011-permeable-pavements.pdf

-Design Life

15 - 20 years

-Runoff Reduction (infiltration)

393 in./hr

http://www.usawaterquality.org/conferences/2004/posters/beanNC.pdf

-Water Quality

Water Quality is improved

-Aesthetics

Same

-Site Requirements

Winter abrasives (sand) should not be applied. Sand plugs pervious surface. Free Thaw cycles may shorten design life. Snow blades should be kept 1" off of surface. Not recommended for the site.

Porous Asphalt

-Material Costs

$0.50-$1 per sq feet asphalt (same as traditional)

http://ntl.bts.gov/lib/43000/43500/43570/TSR-2011-permeable-pavements.pdf

Subbase and other materials are the same for all permeable pavements.

-Maintenance Costs

$400 to $500 per year for vacuum sweeping a half-acre parking lot three to four times

Annually

http://ntl.bts.gov/lib/43000/43500/43570/TSR-2011-permeable-pavements.pdf

-Design Life

15 to 20 years

http://ntl.bts.gov/lib/43000/43500/43570/TSR-2011-permeable-pavements.pdf

Runoff Reduction (infiltration)

787 in/hr

http://www.usawaterquality.org/conferences/2004/posters/beanNC.pdf

-Water Quality

Water Quality is improved

-Aesthetics

Same

-Site Requirements

Winter abrasives (sand) should not be applied. Sand plugs pervious surface. Free Thaw cycles may shorten design life. Snow blades should be kept 1" off of surface. Not recommended for the site.

2.4. Pave-Drain

-Material Costs

- Depending on the project location and project size a conservative installed cost of PaveDrain is $10-12 per square foot. This typically includes an installed 6 - 8" layer of clear stone (AASHTO

#57). The installation of the PaveDrain will be around $2.00- $2.50 per square foot. The materials cost will be $5.00-$6.00/Square foot, delivery will add $0.75-$1.00 per square foot depending on the distance to the jobsite. Color blocks adds ± $1 per square foot.

-Maintenance Costs

- From Doug Buch founder of pave drain- What little maintenance has occurred has varied from $0.50 - $0.75/Square foot. Most jobs have only required a partial cleaning. The rental of the PaveDrain Vac Head and Combination Sewer Truck was $700 for half a day. The area cleaned was around 1,500 Square feet. Therefore this was cleaned for $0.47/Sqfeet.

Pave drain does not require gravel to be placed between the pavers like other paver designs thus cleaning the Pavedrain will not require replacement gravel.

-Design Life

- Approximately 50 years

-Runoff Reduction (infiltration)

- The PaveDrain system was tested according to ASTM C1701/C1701M-09 by an independent third party engineering firm. The test was conducted on a PaveDrain project that had not been maintained for 18 months and still infiltrated in excess of 4,000 in/hr per one foot diameter.

  - Infiltration test- http://www.pavedrain.com/pdf/press/PaveDrain-Infiltration-Results-MDE.pdf

-Water Quality

Water Quality is improved

-Aesthetics

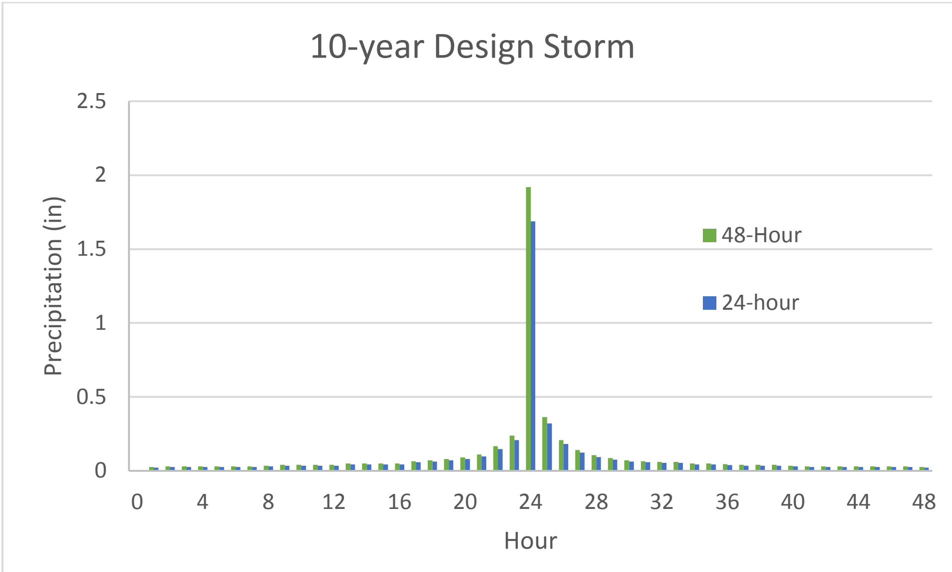
Aesthetics are improved

-Site Requirements

Winter abrasives (sand) should not be applied. Sand plugs pervious surface. Snow blades may be used to clear surface.

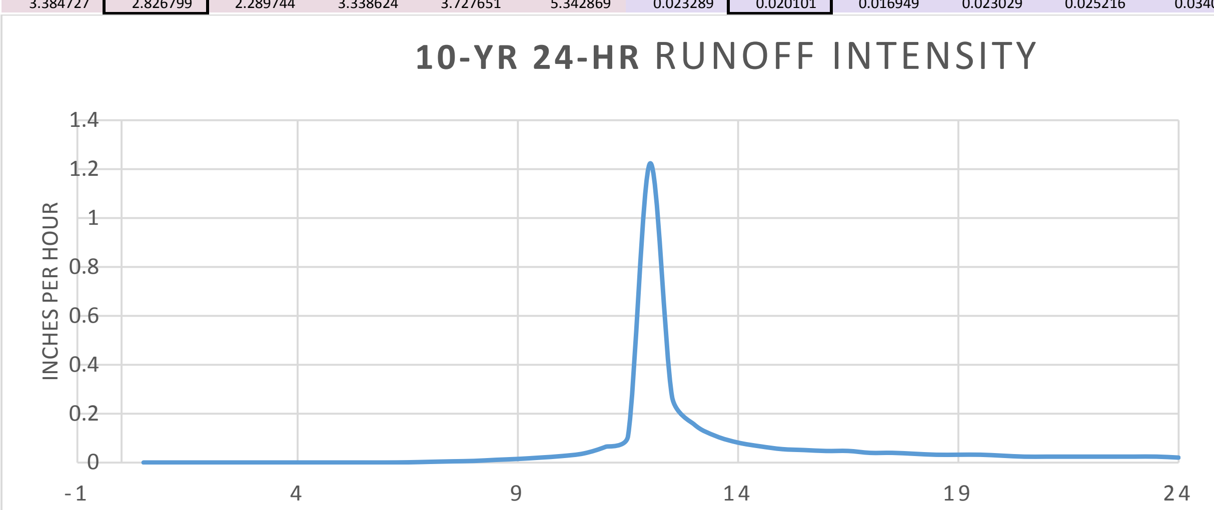
Appendix E. Hydrologic Analysis

Design Storm Hyetograph: Hourly Rainfall						Design Storm: Cumulative Rainfall					
10-yr 48-hr	10-yr 24-hr	5-yr 24-hr	25-yr 24-hr	50-yr 24-hr	100-yr 24-hr	10-yr 48-hr	10-yr 24-hr	5-yr 24-hr	25-yr 24-hr	50-yr 24-hr	100-yr 24-hr
0	0	0	0	0	0	0	0	0	0	0	0
0.02525	0.0222	0.0192	0.025	0.0271	0.03565	0.02525	0.0222	0.0192	0.025	0.0271	0.03565
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	0.05555	0.04884	0.04224	0.055	0.05962	0.07843
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	0.08585	0.07548	0.06528	0.085	0.09214	0.12121
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	0.11615	0.10212	0.08832	0.115	0.12466	0.16399
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	0.14645	0.12876	0.11136	0.145	0.15718	0.20677
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	0.17675	0.1554	0.1344	0.175	0.1897	0.24955
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	0.20705	0.18204	0.15744	0.205	0.22222	0.29233
0.03535	0.03108	0.02688	0.035	0.03794	0.04991	0.2424	0.21312	0.18432	0.24	0.26016	0.34224
0.0404	0.03552	0.03072	0.04	0.04336	0.05704	0.2828	0.24864	0.21504	0.28	0.30352	0.39928
0.0404	0.03552	0.03072	0.04	0.04336	0.05704	0.3232	0.28416	0.24576	0.32	0.34688	0.45632
0.0404	0.03552	0.03072	0.04	0.04336	0.05704	0.3636	0.31968	0.27648	0.36	0.39024	0.51336
0.0404	0.03552	0.03072	0.04	0.04336	0.05704	0.404	0.3552	0.3072	0.4	0.4336	0.5704
0.0505	0.0444	0.0384	0.05	0.0542	0.0713	0.4545	0.3996	0.3456	0.45	0.4878	0.6417
0.0505	0.0444	0.0384	0.05	0.0542	0.0713	0.505	0.444	0.384	0.5	0.542	0.713
0.0505	0.0444	0.0384	0.05	0.0542	0.0713	0.5555	0.4884	0.4224	0.55	0.5962	0.7843
0.0505	0.0444	0.0384	0.05	0.0542	0.0713	0.606	0.5328	0.4608	0.6	0.6504	0.8556
0.06565	0.05772	0.04992	0.065	0.07046	0.09269	0.67165	0.59052	0.51072	0.665	0.72086	0.94829
0.0707	0.06216	0.05376	0.07	0.07588	0.09982	0.74235	0.65268	0.56448	0.735	0.79674	1.04811
0.0808	0.07104	0.06144	0.08	0.08672	0.11408	0.82315	0.72372	0.62592	0.815	0.88346	1.16219
0.0909	0.07992	0.06912	0.09	0.09756	0.12834	0.91405	0.80364	0.69504	0.905	0.98102	1.29053
0.1111	0.09768	0.08448	0.11	0.11924	0.15686	1.02515	0.90132	0.77952	1.015	1.10026	1.44739
0.16665	0.14652	0.12672	0.165	0.17886	0.23529	1.1918	1.04784	0.90624	1.18	1.27912	1.68268
0.23735	0.20868	0.18048	0.235	0.25474	0.33511	1.42915	1.25652	1.08672	1.415	1.53386	2.01779
1.919	1.6872	1.4592	1.9	2.0596	2.7094	3.34815	2.94372	2.54592	3.315	3.59346	4.72719
0.3636	0.31968	0.27648	0.36	0.39024	0.51336	3.71175	3.2634	2.8224	3.675	3.9837	5.24055
0.20705	0.18204	0.15744	0.205	0.22222	0.29233	3.9188	3.44544	2.97984	3.88	4.20592	5.53288
0.1414	0.12432	0.10752	0.14	0.15176	0.19964	4.0602	3.56976	3.08736	4.02	4.35768	5.73252
0.10605	0.09324	0.08064	0.105	0.11382	0.14973	4.16625	3.663	3.168	4.125	4.4715	5.88225
0.08585	0.07548	0.06528	0.085	0.09214	0.12121	4.2521	3.73848	3.23328	4.21	4.56364	6.00346
0.0707	0.06216	0.05376	0.07	0.07588	0.09982	4.3228	3.80064	3.28704	4.28	4.63952	6.10328
0.06565	0.05772	0.04992	0.065	0.07046	0.09269	4.38845	3.85836	3.33696	4.345	4.70998	6.19597
0.0606	0.05328	0.04608	0.06	0.06504	0.08556	4.44905	3.91164	3.38304	4.405	4.77502	6.28153
0.0606	0.05328	0.04608	0.06	0.06504	0.08556	4.50965	3.96492	3.42912	4.465	4.84006	6.36709
0.0505	0.0444	0.0384	0.05	0.0542	0.0713	4.56015	4.00932	3.46752	4.515	4.89426	6.43839
0.0505	0.0444	0.0384	0.05	0.0542	0.0713	4.61065	4.05372	3.50592	4.565	4.94846	6.50969
0.04545	0.03996	0.03456	0.045	0.04878	0.06417	4.6561	4.09368	3.54048	4.61	4.99724	6.57386
0.0404	0.03552	0.03072	0.04	0.04336	0.05704	4.6965	4.1292	3.5712	4.65	5.0406	6.6309
0.0404	0.03552	0.03072	0.04	0.04336	0.05704	4.7369	4.16472	3.60192	4.69	5.08396	6.68794
0.0404	0.03552	0.03072	0.04	0.04336	0.05704	4.7773	4.20024	3.63264	4.73	5.12732	6.74498
0.03535	0.03108	0.02688	0.035	0.03794	0.04991	4.81265	4.23132	3.65952	4.765	5.16526	6.79489
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	4.84295	4.25796	3.68256	4.795	5.19778	6.83767
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	4.87325	4.2846	3.7056	4.825	5.2303	6.88045
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	4.90355	4.31124	3.72864	4.855	5.26282	6.92323
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	4.93385	4.33788	3.75168	4.885	5.29534	6.96601
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	4.96415	4.36452	3.77472	4.915	5.32786	7.00879
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	4.99445	4.39116	3.79776	4.945	5.36038	7.05157
0.0303	0.02664	0.02304	0.03	0.03252	0.04278	5.02475	4.4178	3.8208	4.975	5.3929	7.09435
0.02525	0.0222	0.0192	0.025	0.0271	0.03565	5.05	4.44	3.84	5	5.42	7.13



Curve Numbers	Group B	Group C	Fraction of Area
1/4 acre lots (38% impervious)	75	83	0.9
Newly Graded, no vegetation	86	91	0.9
Streets	100	100	0.1
Weighted Curve Numbers			
During Development	87.4	91.9	
After Established	77.5	84.7	
S			
During Development	1.441647597	0.88139282	
After Established	2.903225806	1.80637544	
Ia			
During Development	0.288329519	0.17627856	
After Established	0.580645161	0.36127509	
Travel Time	Time it takes water to travel from furthest point to outlet		
	Conklin	**N. Dodge. St. Ct.**	
l, distance between points, ft	260	360	
v, average velocity ft/s	1	1	
Tt = l / (3600 v), hours	0.072222222	0.1	
Lag Time	Delay between rainfall onset and peak runoff		
	Conklin	**N. Dodge. St. Ct.**	
a_x, in mi^2	0.000289184	0.0015969	
Q_x, runoff from area, inches	1	1	
T_x, travel time from centroid to ref.	8.03289E-08	4.4358E-07	
A, total area of watershed above ref. mi^2	0.000289184	0.0015969	
Qa, total runoff	0.235566599	0.2355666	
$L = \Sigma a Q_x T / A Q_a$, in hours	0.000000341	0.000001883	
Time of Concentration	Hydraulically most distant to outlet		
	Conklin	**N. Dodge. St. Ct.**	
$L/0.6 = T_c$ hours	0.000000568	0.000003138	

Cumulative Runoff (in.), Group C After Established						Hourly Runoff (in.), Group C After Established					
10-yr 48-hr	10-yr 24-hr	5-yr 24-hr	25-yr 24-hr	50-yr 24-hr	100-yr 24-hr	10-yr 48-hr	10-yr 24-hr	5-yr 24-hr	25-yr 24-hr	50-yr 24-hr	100-yr 24-hr
0	0	0	0	0	0						
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.000783	0	0	0	0	0	0.000783
0	0	0	0	0	0.004751	0	0	0	0	0	0.003968
2.99E-06	0	0	0	0.000457	0.01181	2.99E-06	0	0	0	0.000457	0.007059
0.000987	0	0	0.000813	0.002784	0.021698	0.000984	0	0	0.000813	0.002327	0.009888
0.004575	0.000796	0	0.004154	0.008282	0.037684	0.003588	0.000796	0	0.003341	0.005498	0.015985
0.010593	0.003623	0.000282	0.009894	0.016437	0.057324	0.006018	0.002826	0.000282	0.00574	0.008155	0.01964
0.018856	0.008358	0.002001	0.017852	0.027037	0.080268	0.008263	0.004736	0.001718	0.007958	0.0106	0.022945
0.029199	0.014875	0.005197	0.027866	0.039892	0.10621	0.010343	0.006516	0.003196	0.010014	0.012855	0.025942
0.04551	0.025817	0.011419	0.043718	0.059697	0.143974	0.016311	0.010942	0.006222	0.015851	0.019805	0.037764
0.066387	0.040479	0.020548	0.064066	0.084587	0.189211	0.020877	0.014663	0.009129	0.020348	0.02489	0.045237
0.09405	0.06057	0.033818	0.091087	0.117101	0.246027	0.027663	0.020091	0.01327	0.027021	0.032515	0.056817
0.129521	0.087021	0.052052	0.125798	0.158312	0.315655	0.035471	0.02645	0.018235	0.03471	0.041211	0.069627
0.178415	0.124295	0.078633	0.173715	0.214547	0.40783	0.048894	0.037274	0.026581	0.047917	0.056235	0.092176
0.261584	0.189082	0.126305	0.255347	0.309241	0.558259	0.083169	0.064787	0.047672	0.081632	0.094694	0.150428
0.396749	0.29666	0.207862	0.388216	0.461555	0.792414	0.135165	0.107578	0.081557	0.132869	0.152315	0.234155
1.861247	1.519548	1.195853	1.832838	2.073414	3.088191	1.464497	1.222887	0.987991	1.444622	1.611858	2.295778
2.176849	1.78875	1.419364	2.14464	2.417102	3.560959	0.315602	0.269202	0.223511	0.311803	0.343688	0.472767
2.359474	1.944994	1.549599	2.325106	2.615686	3.832842	0.182625	0.156245	0.130235	0.180466	0.198584	0.271884
2.48525	2.052774	1.639626	2.449409	2.752345	4.019476	0.125776	0.10778	0.090027	0.124303	0.136659	0.186634
2.580098	2.134137	1.707681	2.543154	2.855347	4.159916	0.094848	0.081363	0.068055	0.093745	0.103003	0.14044
2.657186	2.200316	1.763091	2.619349	2.93903	4.27388	0.077088	0.066178	0.05541	0.076195	0.083683	0.113963
2.720865	2.255016	1.808928	2.682294	3.008138	4.367907	0.06368	0.054701	0.045836	0.062945	0.069108	0.094027
2.780149	2.305967	1.85165	2.740896	3.072459	4.455353	0.059284	0.05095	0.042722	0.058602	0.064321	0.087446
2.834998	2.353127	1.891217	2.795116	3.131956	4.536184	0.054849	0.04716	0.039568	0.05422	0.059497	0.080831
2.889964	2.400408	1.930908	2.849454	3.191568	4.617119	0.054966	0.047281	0.039691	0.054337	0.059611	0.080935
2.935856	2.439898	1.964076	2.894822	3.241329	4.684641	0.045892	0.03949	0.033167	0.045368	0.049761	0.067522
2.981825	2.479468	1.997324	2.940268	3.291166	4.752232	0.045969	0.03957	0.033248	0.045445	0.049837	0.06759
3.023261	2.515147	2.027315	2.981233	3.336081	4.813119	0.041436	0.035679	0.029991	0.040965	0.044916	0.060888
3.060143	2.546913	2.054027	3.017696	3.376055	4.867285	0.036882	0.031766	0.026712	0.036463	0.039974	0.054166
3.097071	2.578727	2.080788	3.054206	3.416074	4.921491	0.036928	0.031814	0.026761	0.03651	0.040019	0.054206
3.134044	2.610587	2.107597	3.090761	3.456137	4.975737	0.036973	0.03186	0.026809	0.036555	0.040063	0.054246
3.166432	2.638502	2.131093	3.122783	3.491227	5.023234	0.032388	0.027915	0.023496	0.032022	0.035091	0.047497
3.194219	2.662457	2.151261	3.150256	3.521331	5.063969	0.027787	0.023955	0.020168	0.027474	0.030104	0.040735
3.222031	2.686437	2.171454	3.177755	3.551458	5.104725	0.027811	0.02398	0.020193	0.027498	0.030127	0.040756
3.249866	2.710441	2.191673	3.205276	3.581608	5.145501	0.027835	0.024004	0.020219	0.027522	0.03015	0.040776
3.277724	2.73447	2.211917	3.232822	3.611781	5.186298	0.027859	0.024029	0.020244	0.027545	0.030173	0.040797
3.305606	2.758523	2.232185	3.26039	3.641977	5.227115	0.027882	0.024053	0.020269	0.027569	0.030196	0.040817
3.333511	2.782599	2.252478	3.287982	3.672195	5.267951	0.027905	0.024076	0.020293	0.027591	0.030218	0.040837
3.361438	2.806699	2.272795	3.315596	3.702435	5.308807	0.027927	0.0241	0.020317	0.027614	0.03024	0.040856
3.384727	2.826799	2.289744	3.338624	3.727651	5.342869	0.023289	0.020101	0.016949	0.023029	0.025216	0.034061



Appendix F. Bioretention Calculation Details

		conk	east	SW Res.	
step 1: required WQv	Drainage area, sq. ft.	8062	44519	22651.2	sq ft
exit vel	WQ Runoff inches	1.25	1.25	1.25	**inches**
		839.79	**4637.39**		
	WQv using entire watershed	**17**	**6**	**2359.5**	**cf**
		0.2282	1.26022		
	peak rate	16	5		**cfs**
	assumed percent impervious:		45		
	Compute Rv		0.455		
	WQv impervious area only,	**382.10**	**2110.01**		
	Rv*P*DA/12in	**52**	**5**	**1073.573**	**cf**
Step 2: peak runoff rates	**10-yr 24-hr**				
		2.9437			
	precipitation when runoff = 1.25"	2	2.94372		**in**
		0.2282	1.26022		
	peak Q of storm:	16	5		**cfs**
	inline, partial treatment (remainder				
step 3: inline or offline system	**overflows)**				
step 3a: size outlet pipe	**pipe diameter**	6	6		**inches**
		0.3926	0.39269		
	pipe area	99	9		**sq. ft.**
		0.5811	3.20913		
	velocity, using continuity	46	7		**cfs**
step4	how to calculate spreader velocity?				
	allowable depth	3	**in**		
	slope of diaphragm	0.25	25		
	manning's of stony cobble (wrd,				
	chin)	0.05			
	manning's sheet flow on top of	0.1472			
	gravel	7	**per ft. width**		
step 5 entrance designs	Manning's through curb cut				
step 6 WQv ponding depth	select 9 inches for ponding depth				
step 7 design cross-sectional					
elements				**inches**	**feet**
	fine shredded mulch			3	0.25
	sand/org compost/ A-horiz. Soil			18	1.5
	3/8" chip choke layer			3	0.25
	1-2" aggregate storage ε=0.35			24	2
	subdrain				0
			SUM	48	4
step 8 footprint					

$$A_f = \frac{WQv \times df}{[k \times (hf + df) \times tf]}$$

	water quality volume, cf	WQv
	depth xs elements, f	df

coeff. Of permeability, ft/day of eng. Soil	k			
ponding depth, f	hf			
time to drain, days	tf			
	conk-1 cell	east-tiny	Tiny	
Water Quality Volume, NRCS	839.79 17	2277.89 6	2359.5	cf
Water Quality Volume, ISWMM	382.10 52	2110.01 5	1073.573	
XS element depth, df	4	4	4	ft
engineered soil permeability, k	2	2	2	ft/day
flood depth, hf	0.75	0.75	0.75	ft
time to drain, t in days	3	3	3	days
Plan Area, NRCS	**117.86 55**	**319.704 7**	**331.1579**	**sq. ft.**
Plan Area, ISWMM	**53.628 8**	**296.142 5**	**150.6768**	

step 10: System subdrain

Step 10: Subdrain System Design

For a bioretention cell, the subdrain system is needed to drain the aggregate layer over a 24 hour period. The design flow rate can be determined from the following equation:

Q = (k) x (Af) x (1 day / 24 hours) x (1 hour / 3,600 seconds)

Solve for (Q) = Average subdrain flow rate (in cubic feet per second)

Variables:
(Af) = Required ponding area to treat WQv, in square feet (from *Step 8*)
(k) = coefficient of permeability, in feet/day (from *Step 8*, based on modified soil - minimum k)

exit flow:	Conk	East	
	0.0027 28	0.00740 1	cfs

the recommended minumum of 8' for cleaning and inspection will be sufficient to carry this flow

Af	117.86 55	319.704 7	
length of subdrain= Af*10%/(1 ft*2sides)	5.8932 75	15.9852 3	ft

since the subdrain pipes will run the length of the cell, there is more than adequate piping
subdrain pipes can range from 3" to the chiplayer interface

step 11:

since system is not online, staged outlet design is not necessary
single-stage riser at maximum ponding depth (9")
single 8" pipe with grate over top

for bio-only design, riser connects to sudrains which connects to the storm sewer or outfalls in the gulley

AUTOCAD:	conk	east-central	east	SW res	
drawn plan area	100	300	300	150	**sq. ft.**
depth to perf.	16				**inch**
	1.333333333				**ft**
vol storage agg	133.3333	400	400	200	**sq. ft.**
void ratio	0.35				
void water storage	46.66667	140	140	70	**cf**
WQv to be stored	382.1052	2110.015104		1073.573	
depth of watershed runoff stored, ft	0.005788		0.006289	0.047396	
depth of watershed runoff stored, in.	0.069462		0.075473	0.56875	

COSTS

Excavation, total depth		4	ft	
excavation area, bio only		850	SQ FT	
excavation area, bio & pave		550	SQ FT	
	cf		cy	
excavation volumE, bio only		3400	378	
excavation volume, bio & pave		2200	244	
fine shredded mulch		0.25	ft	
sand/org compost/ A-horiz. Soil		1.5	ft	
3/8" chip choke layer		0.25	ft	
1-2" aggregate storage ε=0.35		2	ft	
BIOINFILTRATION ONLY				
fine shredded mulch VOLUME		212.5	cf	
sand/org compost/ A-horiz. Soil VOLUME		1275	cf	
3/8" chip choke layer VOLUME		212.5	cf	
1-2" aggregate storage ε=0.35 VOLUME		1700	cf	
PAVEDRAIN AND BIORETENTION				
fine shredded mulch VOLUME VOLUME		137.5	cf	
sand/org compost/ A-horiz. Soil VOLUME VOLUME		825	cf	
3/8" chip choke layer VOLUME VOLUME		137.5	cf	
1-2" aggregate storage ε=0.35 VOLUME VOLUME		1100	cf	
			bid price	total
connector pipe, bio only		631		14,658.13
bio only pipe length		295		6,852.85
bio and pave pipe length		190	23.23	4,413.70