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STORMWATER MANAGEMENT FOR URBAN ENVIRONMENTS

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Note: The following is the notation used in this paper: (.) for decimals and (   ) for thousands. Currencies are expressed as US$ for Dollars of the United States of America.

Elmhurst College, a hundred-thirty-five year old private learning institution, is proceeding with a campus redevelopment project that will include a one hundred seventy bed residence hall. In addition, the college continues to be a role model for sustainable site design and an educational resource for both students and the community.

The need for additional housing, due to increased enrollment demanded creative ideas as supplied by long time planning partner, Wight and Company. The Wight Company is a full service firm with a strong resume featuring LEED™ (Leadership in Energy and Environmental Design) professional's committed to sustainable design principles. As demonstrated by past projects, they have created a plan that will incorporate cutting edge water management techniques that will enhance land usage and decentralize rainwater impact.

The stormwater from building roofs and other impervious surfaces will be captured by post structural BMPs, (Best Management Practices) treated, stored and made available for groundwater recharge. In addition, there will be other "green" aspects of this project e.g.; solar panels will be used to heat the water used for showers, etc., 95% of the demolition materials will be recycled, energy and water efficient fixtures will be used throughout the building and environmentally friendly finishes, carpets, furniture, adhesives, etc, will be used as well. The master plan for this campus will employ Low Impact Design (LID) and all pavements will be converted to permeable pavers to better maintain the aspects of this arboretum on campus and to help promote a better community-learning environment for both students and visitors.

An integral part of this ecological train will be a permeable pavement system designed for a hundred year storm event by Advanced Pavement Technology (APT) that will serve as an underground retention facility as well as a parking lot surface. This permeable pavement system will be part of a sustainable site design that will also utilize bio-swales, rain gardens and numerous runnels to move and control overflow rainwater above ground. Rainwater harvesting will be employed for supply of a high efficiency irrigation system. A native landscape using grasses and other appropriate planting materials that are indigenous to the Midwest have been selected to create a prairie habitat that will actually be burned back each year.

The roof water from the dormitory is captured and stored in a series of PVC pipes with 132 485 liters capacity that will be used for irrigation and has been covered with plaza pavers similar to the parking lot pavers. The water flow from the tanks is routed to rain gardens at the perimeter of the building where additional roof water will be captured, detained and sent as overflow waters to the permeable pavement at a lower elevation. Based on an elevated PVC pipe for a 2-year and a 100-year storm, water will be released to the Salt Creek. In addition, Wight has created a plan that will also contribute to better stormwater management, naturally. The existing oak trees, as part of this campus, a registered arboretum, will continue to prosper by implementing areas of native plants in lieu of turf grass and the natural wildlife habitat will also prosper in this urban environment. These methods of sustainable site design as applied to a more natural water management style will produce less stormwater runoff and loading of an already over worked city stormwater system.

The keystone for this site plan is a one-hectare area, with over a 200 car parking lot that will serve as a detention/retention facility replacing the need for a surface water retention facility there being no land available for such a structure. Underground storage will be provided beneath the permeable pavement surface in the void areas of the aggregates. In addition, this system of aggregate layers will act as an infiltration trench and will collect and treat first-flush pollutants and improve water quality. Because this system will provide more time on site via detention and retention, groundwater recharge will be promoted and also a better microbial action will be established as this system will mimic Mother Nature regarding natural surface infiltration and time on site, while creating a peak time controlled release format. Control structures are integrated in the bio-swales and will also provide access for water samples by the students.

Design for this site considered pre-development rates and post-construction rates as well as adjoining topography run-off to develop a storage volume of 4 070 m^3 for retention. The use of CA-1 aggregates as shown in the cross-section (See Figure 1) will provide storage in air voids between each aggregate as determined by a quarry void ratio test that will be approximately 41%-43% (See Table 1). A conservative credit was determined to be 40% that will yield an excavated area beneath each phase approximately 1 860 m^2, 2.1 m deep and filled with CA-1 clean crushed aggregates.

These areas will be fed with rainwater and stormwater run-off that has been captured thru openings in the concrete paver surface that has been filled with open-graded aggregates. The aggregate structures will now serve as a holding area or retention pond that will accommodate a hundred year storm. The bottom of this excavation will be of an in situ clay matrix that will have low permeability as well as the sides. There will be a layer of geo-textile placed at the sub-grade and CA-1 interface, but it normally is not required, however, it was a decision made by the design team, therefore it was used. Typically, CA-1 aggregates will bridge clay soils more efficiently and provide a stronger sub-base than CA-7 aggregates. The stresses on the soils at this point do not exist and the primary function of this area is permanent storage for water with some infiltration occurring and the filter fabric should be considered a detriment to this process and therefore only becomes a place for potential clogging over time. When the detention is analyzed this fabric may be viewed as a separator and will help reduce migration of clay soils entering the aggregate under wet soil conditions. However, again, we have found that the CA-1 materials bridge poor soils, especially in a saturated condition better that the use of smaller aggregates or DGA aggregates.

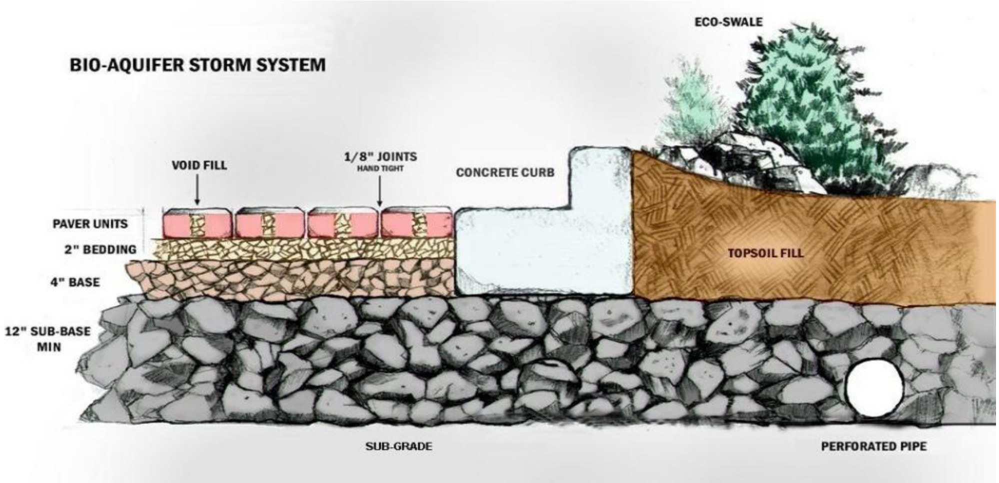

Figure 1. Bio-Aquifer Storm System (BASS).

Table 1. Vulcan Void Ratio Report.

Data from four (4) recent tests performed In accordance with ASTM C 33 on McCook CA-01 material was as follows:	
SSD Specific Gravity	2 744
Absorption	1.30 %
Average Compacted Unit Weight	96.10 lbs/cu ft
Compacted Unit Weight Range	93.10 to 98.65 lbs/cu ft
Average % Voids	43.04
% Voids Range	41.53 to 44.82

The detention area, which includes a sub-base, base, setting bed and wearing course, has been designed to capture and treat first-flush pollutants, promote a flow path to the retention area and also support vehicular and pedestrian traffic. This area will support approximately 925 m^3 of storage or 130 mm of rain.

In addition, the structural loading of this cross-section as depicted by Figure 2, will, with each layer co-efficient as assigned, yield a structural number of 3.75 equal to a 360 mm full depth asphalt roadway. This system is more than capable too carry fire trucks. This design is typical for this system and not driven by loading or vehicular applications, but when phase II was constructed, this area did accept over one thousand fully loaded semi-trucks with over 9 kg axle loading without distortion or damage to the permeable pavement system. The aggregates specified for these layers are also Illinois Department of transportation (IDOT) specific and graded so that the CA-7 layer acts as a choking layer and precluded the need for geo-textile fabric as a means of segregation.

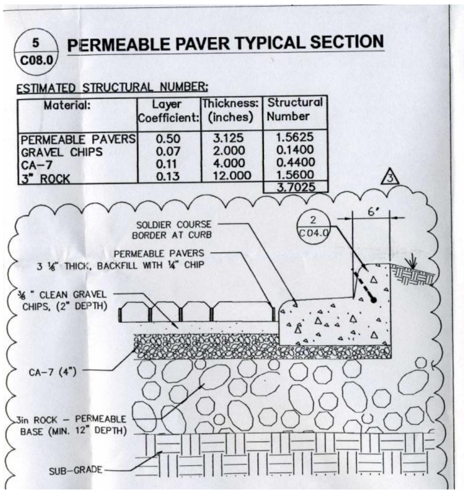

Figure 2. Permeable paver typical section.

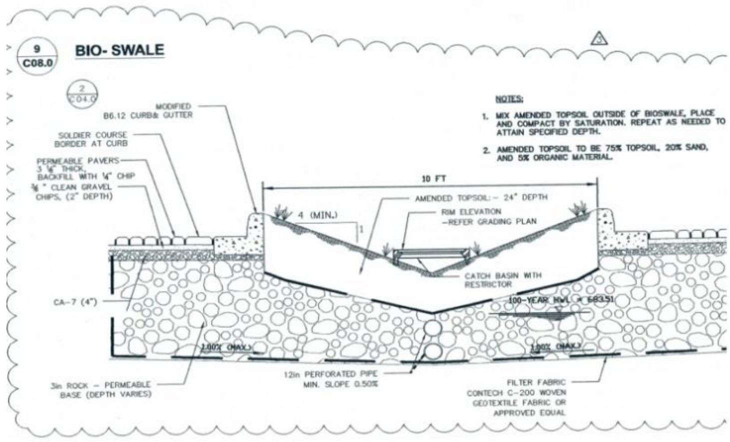

Figure 3. Bio Swale.

Another facet of this design involves the use of bio-swales (See Figure 3) to provide an area for capture and treatment of first flush pollutants should there be runoff from the permeable pavement surface. Grades are established that will promote flow to inlet points that have been created in the chair back of the curb. In these bio-swale areas manholes and inspection tubes are placed for future access to monitor water level and take water samples to determine the water quality and effectiveness of this system. Plant material will be chosen that will best perform in this environment as their root system will also breakdown the pollutants that may get swept into the bio-swale during an intense storm and resultant runoff.

The underground conveyance for this site is essentially a gravity feed system with a vertical outlet structure that has control of the release of treated stormwater to the city's over-burdened stormwater system. The water flow also has been treated at this point and will be used to protect and promote groundwater recharge and as a resource for Salt Creek. After the design/development phase and during the construction drawing phase, the LEED issues were evaluated by the design team and many ideas were discussed-some relevant and others not feasible. One of these issues regarding the retention area was the use of recycled concrete. An IDOT certified crusher was contacted regarding supplying material for this project during phase II and could provide material that met the required BASS™ sieve analysis requirements, but did not have the ability to wash the materials or control the amount of No. 100 ASTM and ASTM No. 200 particles that would prove detrimental over time. In addition, it was pointed out by the engineering of Wight and APT, that the possible introduction of small lime and cement dust particulates would eventually create an impervious crust at the bottom of the retention structure and preclude any infiltration over time. The cost savings when washing was applied made the recycled materials cost prohibitive and therefore standard crushed limestone aggregates were used.

However, some other areas that would contribute to a LEED [USGBS, 2005] rating for Elmhurst College, which will be the regions first college or university housing unit to achieve this status, may be achieved from sustainable site design practices. Improvement of stormwater run-off SS6.1 and water quality SS6.2 are two areas that this system will have an impact for a more natural stormwater management methodology.

Past studies regarding infiltration support rates as high as 200 mm/h to 230 mm/h [USEPA, 2004] and also studies being conducted at University of North Carolina State [NCSU, 2004], support the design for this project. In addition, Muth [MUTH, W., 1994] has determined curve numbers associated with the rational method for stormwater run-off as low as 0.15. These actions are due primarily to the use of open graded aggregates that possess flow rates in excess of 4 540 liters/h assuring engineers that the rapid entry of water into the system will not be impeded, even when heavy clogging occurs. The mature infiltration design life at twenty years will still be 76 mm/h and more than capable of handling an average two year 24 h storm event of 25.4 mm/h to 38 mm/h rate.

Water quality improvement that will meet the requirements for NPDES (National Pollutant Discharge Elimination) has also been tested and documented as shown by charts from the University of Connecticut (See Tables 2 and 3) and the University of North Carolina State Water treatment coupled with a TSS (Totally Suspended Soils) removal rate greater than ninety percent; assures this permeable pavement system will provide this site with a long-term and low maintenance solution for stormwater management.

Table 2. Objective to decrease runoff.

University of Connecticut, September 2003. "Annual Report-Jordon Cover Urban Watershed Section 319 National Monitoring Program Project"			
TEST AND YEAR	**ASPHALT**	**PERMEABLE PAVEMENT**	**CRUSHED STONE**
		INCHES/HOUR (mm/h)	**INCHES/HOUR (mm/h)**
Single Ring Infiltrometer	0	7.7 (196)	7.3 (185)
Test 2002			
Single Ring Infiltrometer	0	6.0 (153)	5.0 (127)
Test 2002			
Flowing Infiltration	0	8.1 (207)	2.4 (60)
Test 2003			
Average infiltration rates from asphalt, permeable pavement and crush stone driveways.			

Table 3. Objective to decrease water pollution.

DECREASE REDUCE: NITROGEN-65% BACTERIA-85% PHOSPHOROUS-40%	**POLLUTION WATER**	**OBJECTIVE TO REDUCE**	
AVERAGE WEEKLY	**DRIVEWAY**	**CONCENTRATIONS**	**OF VARIOUS POLLUTANTS**
VARIABLE	**ASPHALT**	**PERMEABLE PAVEMENT**	**CRUSHED STONE**
Runoff depth (mm)	1.08 a	0.05 b	0.04 c
Total suspended soils (mg/l)	47.08 a	15.08 b	33.7 a
Nitrate nitrogen (mg/l)	0.06 a	0.02 b	0.03 ab
Ammonia Nitrogen (mg/l)	0.18 a	0.05 b	0.11 a
Total Kjeidahl Nitrogen (mg/l)	8.0 a	0.07 b	1.6 ab
Total Phosphorous (mg/l)	0.244 a	0.162 b	0.155 b
Copper (ug/l)	18.0 a	6.0 b	16.0 a
Lead (ug/l)	6.0 a	2.0 b	3.0 b
Zinc (ug/l)	87.0 a	25.0 b	57.0 ab
Mean weekly pollutant concentration in stormwater runoff from asphalt, paver, and crushed stone driveways. Within each variable, means followed by the same latter are not significantly different at the 95%			

Maintenance procedures for permeable pavement systems are similar as for impervious pavements, yet will develop cost savings that conventional pavements have not demonstrated. Typical post-structural BMP maintenance requirements by EPA (Environmental Protection Agency) will include an implementation and schedule for street sweeping to gather and remove debris and surface pollutants from the pavement surface. This schedule of once to twice per year would be the same for permeable pavement systems. The maintenance costs were estimated for Morton Arboretum by Gold & B. (See Tables 4 and 5) for a heavy duty and light duty asphalt impervious pavement as compared to the proposed permeable pavement system for the same area. Including capitalization, the break even point was at twenty two years and in fifty years, the asphalt pavement maintenance costs would be nearly ten times the cost of maintaining the permeable pavement.

Theses types of maintenance recovery costs have been determined by the facilities director of the Arboretum to be too conservative, as they are about half as planned. We also see evidence in winter maintenance conditions as demonstrated at Kane County Government Center, where pavers over a dense graded-aggregate base with a sand setting bed (in an impervious handicap parking area) will require salting after a twenty four hour freeze thaw occurrence where permeable pavers in the same area do not. This will lead to large savings as we see areas of permeable pavement freezing at lower temperatures and requiring less snow plowing and also immediate absorption of snowmelt in the openings without reforming on the surface. Therefore, less salt is required on parking and walking areas which results in large dollar savings.

Aesthetics for the campus was a design consideration that proved more important to the owner than utilizing SS7.1 LEED credits for Heat Island Effect; non roof thermal pollution reduction based on a solar reflectance testing of a combined albedo and reflectivity of greater than 0.29, per ASTM E 903 and ASTM 2005. While this credit is achievable with concrete pavers, the shape, color and pattern were selected to maintain the ambiance of the college buildings and existing environment.

Table 4. Life cycle cost recovery.

THE MORTON ARBORETUM MAIN PARKING LOT SEMINAR-NOVEMBER 18, 2004 PERMEABLE BRICK PAVEMENT			
YEAR	**MAINTENANCE ITEM**	**PER YEAR EXPENDITURE (US$)**	**ACCUMULATED EXPENDITURE (US$)**
1	**Initial Install**	980 000	---
3	**Striping**	2 625	982 625
5	**Striping and Cleaning**	5 625	989 250
23	**Striping**	2 625	1 028 875
57	**Striping and Cleaning**	5 625	1 109 500
		Hanscomb	Faithful & Gould

Table 5. Life cycle cost recovery.

THE MORTON ARBORETUM MAIN PARKING LOT SEMINAR-NOVEMBER 18, 2004 HEAVY DUTY/STANDARD ASPHALT PAVEMENT			
YEAR	**MAINTENANCE ITEM**	**PER YEAR EXPENDITURE (US$)**	**ACCUMULATED EXPENDITURE (US$)**
1	**Initial Install**	650 000	---
3	**Minor Patch, Crack Filler & Seal Coating**	24 375	674 375
5	**CrackFiller,Seal Coating and Striping**	30 500	704 875
23	**Minor Patch, Crack Filler & Seal Coating**	36 625	1 058 250

57	**Mill & Overlay, Patching and Striping**	109 375	1 819 500
		Hanscomb	Faithful & Gould

Thermal pollution reduction will be achieved using trees and other shading techniques, in addition, bio-swales have been employed as well. Mock ups for color were provided in a herringbone pattern and were larger than normal to convey shading that would be developed when using mechanical equipment for installation. There are other non credit LEED items that this system will supply to help provide additional sustainable site practices e.g. local materials supplied within 800 kilometers, local labor, recycled post consumer content in slag and fly ash used in manufacturing of concrete pavers, and innovative ideas and applications.

Construction of a permeable pavement system using trained contractors experienced with open graded aggregate placement and compaction as well as the logistics and equipment required to staff a mechanically installed permeable pavement project are essential to the successful performance of this system. Sequence of construction including a method statement from the manufacturer and paver contractor are prerequisites prior to the start of a project. Another item to be employed is a preconstruction meeting with all parties present for the design team and owner and contractors. This project derived good information and understanding by all parties from this type of meeting that yielded a project that was completed on time and within budget even under severe winter conditions as we shall see in the following photos.

During the completion of phase I, the college has since received a grant from the DuPage County Stormwater District for partially funding of this innovative strategy for managing and monitoring stormwater. In summary, it was best said by Dr. Bryant Cureton, President of Elmhurst College, "what better place than a learning institution to promote our mission by developing our campus as a model of sustainable design that will be a hands on educational resource for our students and the community."

1. REFERENCES

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ASTM E 903 Standard Test Method Albedo, p. 8.

ASTM (2005). Standard Test for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrated Spheres, p.8.

Figure 8. Sub-base placement.

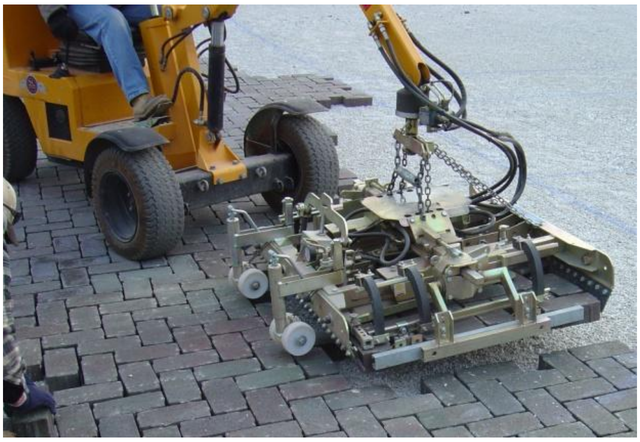

Figure 9. Paver installation.

Figure 10. Completed job.