Cost and Benefit Analysis of Permeable Pavements in Water Sustainability

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ESM 121 Final Paper. 5/25/2015

Abstract:

The use of permeable pavements is one method UC Davis can adopt to enhance its water sustainability.The implementation of permeable pavements in place of standard impermeable asphalt would theoretically increase water infiltration into underground storage and the filtration of rainwater, while reducing runoffs. We will do a cost and benefit analysis of the different types of permeable pavements over a period of 25 years to find the most cost effective alternative. It will be difficult in measuring the exact value without making some assumptions to simplify calculations, such as the area of UC Davis available for permeable pavement. Also, we will also taking into account the hydrological differences of each pavement's performance into our decision. The hypothesis is that the installation of permeable pavements will be more costly initially compared to standard impermeable asphalt. However, the benefits received over time from installing permeable pavements will make it more cost effective while also improving water sustainability on the campus. We hope that this research paper will shed insight on the monetary and hydrological differences between different alternatives of permeable pavements so that institutions thinking of installing permeable pavements can make an educated decision.

Introduction:

UC Davis at one point was ranked #1 in Sierra Club's magazine 2012 Cool Schools Survey for its sustainable practices in transportation, waste management, and green purchasing. This magazine ranks schools based on their environmental achievements and goals. UC Davis' West Village was praised by the magazine for being the largest planned zero net energy community. Its wide variety of eco-friendly public transportation methods give students more options to travel while reducing their ecological footprint. In their cafeterias', UC Davis buys organic and sustainably grown vegetables and manages an extensive recycling and composting program. The university is also a leader in green innovations with the creation of a bio digesting machine, hybrid racing car, and improvements in lighting technology.

Since then UC Davis has fallen in ranking to an embarrassing #55 in 2014. We believe that through the use of permeable pavement, a practice of ranked #5 campus, Stanford University, we will be able to increase our water sustainability ratings and thus our ranking as well. Permeable pavement is a practice of paving which allows stormwater to infiltrate into the ground instead of becoming runoff water. This method allows the recharge of underground water storage basins which will eventually be absorbed by the soil. Other benefits include reduced flooding, removal of pollutants, diminished deicing.

Objective:

The main objective of our project is to determine whether the use of permeable pavements in any future construction plans at UC Davis will lead to a larger monetary net benefit than using regular asphalt. In order to figure this out, we will perform a cost benefit analysis, over a span of 25 years, comparing the different types of pavement if we covered half of UC Davis' campus with pavement. Due to inflation rates and uncertainty, our monetary values and measurements we calculated from documents, published in previous years, will be changed to equivalent values in present terms. In multiple tables, we will lay out the cost of installing and maintaining each type of pavement. In a separate table, we will show the benefits or cost avoided of using permeable pavements. From this research we were able to choose the best scenario that yielded the greatest net benefits.

Hypothesis:

In terms of installation, maintenance, and water treatment costs, we believe that the installation of permeable pavements for future additions to UC Davis' campus will yield greater monetary benefits than using standard asphalt pavement.

Data Sources:

Data for our research project will be provided through various official reports and documents.

Costs of installation and maintenance of the pavements:

1. University of Maryland
2. Wisconsin's Department of Transportation
3. Lake County Forest Preserves organization. In terms of the costs of treating waste

Permeable Pavement Runoff Values:

1. Biological and Agricultural Engineering Department at North Carolina State University

Cost of Water Treatment:

1. UC Davis Institute of Transportation Studies

UC Davis has been doing research on the costs and benefits of implementing permeable pavement in the Sacramento area for a few years now. A report done by UC Davis' Institute of Transportation Studies in 2010 has created a framework for the life-cycle costs and environmental life-cycle assessments for fully permeable pavements. The U.S. Department of Transportation Federal Highway Administration has also written sustainability reports in regards to permeable pavement on highways. Both of these sources have analyzed permeable pavement on a larger scale and from their data we plan to apply to to the UC Davis campus. Research done for the Journal of Hydraulic Engineering. Experiments compared the differences in runoff volume, total outflow volume, and flow rate between permeable pavements and asphalt.

Methods and Assumptions:

There were many different areas we were interested in when it came to water sustainability practices UC Davis could potentially participate in. We primarily were interested in runoff management and storage for campus use. In the year 2014, UC Davis used 1,018,308,333 gallons of water. Since we wanted to see ways that UC Davis can maximize its sustainability, we were interested in how Davis can utilize its runoff water to provide for this high demand of water.

Water Collection

The first step we took was researching the ways runoff water could be collected in stored. We looked into the hydrological differences between permeable and impermeable pavements. Since normal pavement is common we looked more specifically into permeable pavement and its compositions and functions. Once we had a better understanding of what permeable pavement was and does, we compared the permeability, or the amount of runoff water each substance would allow to pass through. The pavement's permeability was essential to our research is because the more water allowed to pass through the ground substance, the more underground water sources can be recharged and used for campus water demand.

Water Treatment

The next step after collecting water before it can be used is filtering water. In order for water to be considered potable it has to go through some type of filtering system to get rid of any potential pollutants. This research included looking into the filtration of permeable pavements and other sources of water filtration that can be used on campus. Through this we were able to see that permeable pavement itself, filters out water and does not need additional filtration. We also were able to find information on numerous water treatment plans for filtering water and the costs associated with installation and yearly costs.

Another assumption we used the proportion of pavement we have on campus. We could not find clear numbers on the amount of campus surface that was paved so we assumed that 50% of the campus is covered in pavement. These calculations can also be applied to a smaller portion of campus.

Calculations

Majority of the data we found in the sources on the different areas we researched were not in terms of the year 2015. SInce these numbers were in terms of different years we needed to calculate present value. In order to do that we used the formula:

Ft= P(1+i)t

Ft: the future value we calculated for (for year 2015)

P: the present cost that we had in the data (the baseline year the report gave)

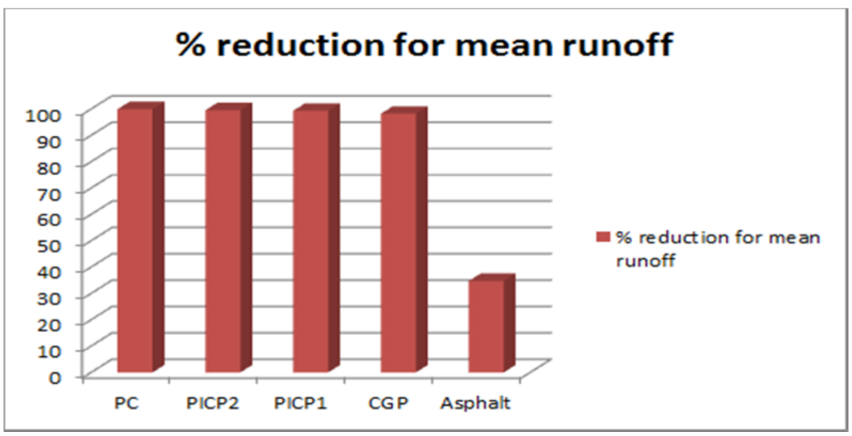
i: the interest rate

t: the time from the year the data was given in to current time (2015)

The value we used for i was 4%. In the UCD “Framework for Life-Cycle Cost Analyses and Environmental Life-Cycle Assessments for Fully Permeable Pavements” report by the Institute of Transportation Studies they noted that 4% was typically the discount rate that Caltrans used in their studies on permeable pavement. The discount rate is the time it takes the value of money into account and accounts for the difference between inflation and interest rate.

Calculation and Results:

We began with researching the the hydrological differences in runoff reduction between standard asphalt and different variations of permeable pavement. The study we used looked at real time performance over the course of a year (Collins 2007). The percentages shown is a mean out of each storm event throughout the year. Results show that the permeable pavements all reduce runoff percentages by similar percentages (at around 98%) whereas standard asphalt only reduced 32% of runoff.



Permeable Pavement Costs: Here are the costs for the different types of permeable pavement.

2015 values			
Surface Type	**Limitations/Application**	**Material average Cost/ ft^2**	**Average Life (years)**

Porous Asphalt	**low weight capacity**	***$1.11***	**17.5**
Pervious Concrete	**Small to large projects**	***$6.66***	**25**
concrete pavers	**Small to large projects**	***$11.10***	**25-30**

Permeable Pavers vs. Asphalt Parking Lot Construction/Maintenance:

1/2 Acre Parking Lot Costs over 25 Years				
	Frequency in 25 Years	Permeable Pavements	Frequency in 25 Years	Asphalt
Installation	1	$165,350.00	1	$109,000.00
Detention	1	$15,000.00	0	$0.00
Vaccum Sweep	25	$400.00	0	$0.00
Restore Permeability	5	$1,750.00	0	$0.00
Refresh Base	1	$8,100.00	0	$0.00
Crack Sealing	0	$0.00	25	$250.00
Seal Coat	0	$0.00	5	$20,000.00
Stripping	0	$0.00	1	$3,125.00
Patching	0	$0.00	5	$100.00
Replace Surface		$0.00	1	$32,000.00
	Total for 2003	*$207,200.00*	**Total for 2003**	*$250,875.00*
	Total for 2015	*$306,706.62*	**Total for 2015**	*$371,356.28*
	2015 Cost per Square Foot	*$14.08*	Cost per Square Foot	*$17.05*
	2015 Cost per Acre	*$613,413.23*	Cost per Acre	*$742,712.57*

In the analysis of permeable pavements in comparison to regular asphalt, there are a variety of different costs associated. Permeable pavements require more initial costs (money and labor) than required for normal asphalt installation. The high initial cost associated with permeable surfaces is due to with the design and infrastructure necessary to properly let surface water permeate to the underlying soil. A large amount of excavation is necessary to install the underlying layers of aggregate material, forming a layers underneath the permeable surface. These base layers not only offer support for the top surface but also assist in the process of water filtration. The high installation cost of permeable pavements leads to much less maintenance required over the life of the surface in relation to that of regular asphalt. The only regular upkeep needed for permeable pavements is vacuuming, in order to maintain high permeability.

Common asphalt has relatively low installation costs, due to the lack of base layers necessary. The lower installation cost of regular asphalt is followed by high upkeep/ maintenance cost throughout it’s lifetime. These upkeep costs are related to cracking and patching of worn out surfaces. Asphalt has a high surface tension (very little flexibility) that is highly affected by weathering, temperature and geologic stress (earthquakes, ground uplift and sinkholes). The surface of asphalt cracks regularly under the different stressors and requires constant maintenance to maintain safe roads. This upkeep over the asphalt lifetime makes it a more expensive choice than permeable pavements, without offering the benefit of water recharge and filtration.

The money saved by installing permeable pavements is $64,649.66 over a 25 year span for ½ acre.

Water Treatment:

In order for water runoff collected from campus to be used for UC Davis's water demand it will need to be filtered and treated in some way. Permeable pavement is structured to filter out water as it passes through the layers of ground before reaching the groundwater source. The costs of treating water that went through permeable pavement would be $0. The benefits of permeable pavement for water treatment is amount of money saved, by not needing a water treatment center. We found data on the installation cost and annual costs of different water treatment practices that could be used if we did not have permeable pavement. We found the costs in terms of the year 2007 and used the present value formula Here are there different best management plan (BMP) treatment options, their costs in terms of 2007, 2015 and in terms of cubic water treated. The amount of money saved from not treating runoff, represents a large benefit of the installation of permeable pavement.

BMP PRACTICE	AVG CONTRUCTION COST		Annual Cost	
	2007	2015	2007	2015
Wet Basin	$557,726.00	$763,286.54	$21,206.00	$29,021.88
Multi-chambered treatment train	$342,806.00	$469,153.68	$7,147.00	$9,781.16
Oil-Water Separator	$159,583.00	$218,400.35	no data	no data
Delware Sand Filter	$286,250.00	$391,752.89	$2,497.00	$3,417.32
Storm-Filter	$379,795.00	$519,775.68	no data	no data
Austni Sand Filter-Concrete	$301,989.00	$413,292.80	$2,553.00	$3,493.96
Biofiltration Swale	$71,913.00	$98,417.91	$4,124.00	$5,643.98
Biofiltration Strip	$78,404.00	$107,301.29	$671.00	$918.31
Infiltration Trench	$181,784.00	$248,783.96	$1,982.00	$2,712.50
Extended Detention Basin	$214,847.00	$294,032.95	$4,999.00	$6,841.48
Drain Inlet Insert	$192,923.00	$264,028.45	$3,728.00	$5,102.03
Dran Inlet Insert	$460.00	$629.54	no data	no data
Total	*$2,768,480.00*	*$3,788,856.04*	*$48,907.00*	*$66,932.61*

BMP Cost per Cubic Meter of Water Treated				
BMP PRACTICE	Annual Cost		Annual Cost per m^3 of water	
	2007	2015	2007	2015
Wet Basin	$21,206.00	$29,021.88	$40.00	$54.74
Multi-chambered treatment tra	$7,147.00	$9,781.16	$14.00	$19.16
Oil-Water Separator	no data	no data	no data	
Delware Sand Filter	$2,497.00	$3,417.32	$5.00	$6.84
Storm-Filter	no data	no data	no data	
Austni Sand Filter-Concrete	$2,553.00	$3,493.96	$8.00	$10.95
Biofiltration Swale	$4,124.00	$5,643.98	$1.00	$1.37
Biofiltration Strip	$671.00	$918.31	$4.00	$5.47
Infiltration Trench	$1,982.00	$2,712.50	$9.00	$12.32
Extended Detention Basin	$4,999.00	$6,841.48	$7.00	$9.58
Drain Inlet Insert	$3,728.00	$5,102.03	no data	no data
Dran Inlet Insert	no data	no data	no data	no data
Total	*$48,907.00*	*$66,932.61*	*$88.00*	*$120.43*

Using permeable pavements cuts out the costs of water treatment, depending what your water use will go towards. If UC Davis plans on using its collected water for non-potable uses on campus this cuts out the treatment costs. The benefit of permeable pavement would be the money saved from not having a treatment plant which would be an installation cost of $3,788,856.04 and annual costs of $66,932.61.

Conclusions:

From the research conducted, permeable pavements are a valuable alternative to common asphalt. There are a variety of different permeable surfaces that are available for a range of applications. For example, porous asphalt is the cheapest available surface material but it’s applications are limited due to low weight bearing capacity. This surface would be best for bike paths or walking paths that do not have car traffic. For high traffic roads, permeable pavers or pervious concrete would be an ideal surface. If a strategy of mixed surfaces for the range of applications on the UC Davis Campus, it would not only represent a savings over the life of the surface as well eliminating a large portion of runoff water treatment associated with current asphalt surfaces.

Entirely replacing current the asphalt surfaces for permeable pavements will represent a large installation cost. This cost is a barrier for this conversion and with university funding, the cost of a campus wide conversion may be too large. There is cost effective and plausible application that should be seriously considered, that will not add excessive costs to the university budget. For any future asphalt replacement projects or new developments being planned on campus should incorporate permeable pavement surfaces, rather than the current impervious asphalt surfaces. This application represents a smooth and cost effective transition to permeable urban surfaces. If the university were to decide to implement a larger transition to permeable surfaces, this would decrease the amount of surface maintenance cost and reduce the amount of runoff water treatment. The benefits of permeable surfaces are far greater than current impervious asphalt and with proper funding and planning, represents a more sustainable and cost effective option for the urban surfaces of UC Davis and the surrounding areas.

Recommendations/Limitations:

Limitations to our project include the fact that we do not know the exact area that UC Davis is covered in pavement. We assumed that about half the campus was covered in concrete and this could skew the monetary values we have calculated. The value of water could also complicate our findings. Water is worth different amounts from people to people and place to place. In places or times when water is scarce, the need to reduce runoff and increase infiltration into underground basins the value of water will jump up and thus the installation of permeable pavement will seem more beneficial. Another limitation we came across in our research is that we may be oversimplifying parts of our project. For example, our project does not account for how many people use the pavements at UC Davis to ride their bikes which could lead to greater maintenance costs. Although, based on our research, permeable pavements have shown to minimize the costs of multiple aspects in its usage at UC Davis, we currently do not recommend replacing all the regular asphalt pavement on campus with permeable ones. The need for labor and equipment in the process of removing the current asphalt will come at great costs. In addition, there will extra unaccounted costs such as people unable to use the road to get to class during the replacement process.

References:

Collins, Kelly A. Hunt, William F. Hathaway, Jon M. “Hydrologic and Water Quality Comparison of Four Types of Permeable Pavement and Standard Asphalt in Eastern North Carolina.” (2007). *Permeable Interlocking Pavement Institute.* Web. Accessed May 13, 2015.

Kerlin, Kat. "UC Davis Is Nation's 'Coolest School' (VIDEO) :: UC Davis News & Information." *UC Davis News & Information*. UC Davis, 14 Aug. 2012. Web. 04 June 2015.

Uc Davis Institute of Transportation Studies,. (2015). *Laboratory Testing and Modeling for Structural Performance of Fully Permeable Pavements: Final Report*. University of California Davis Uc, Davis.

University of Maryland,. (2015). *Permeable Pavement Fact Sheet Information for Howard County, Maryland Homeowners*. University of Maryland, Howard County.

Wang, Ting, John Harvey, and David Jones. "A Framework for Life-Cycle Cost Analyses and Environmental Life-Cycle Assessments." *UC Davis Institute of Transportation Studies*. N.p., June 2010. Web.

Wisconsin Department Of Transportation,. (2015). *Comparison of Permeable Pavement Types: Hydrology, Design, Installation, Maintenance and Cost*. Wisconsin Department Of Transportation.