Off Road Benefits of Permeable Interlocking Concrete Pavements

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Abstract:

Life-cycle costing can be used to benchmark pavement type options such as permeable and conventional pavements to determine which is the most cost effective. Traditionally when performing a life-cycle cost analysis between permeable and conventional pavements, only the standard capital costs for initial construction and maintenance and rehabilitation costs for each pavement types are considered. However, to truly evaluate compare permeable and convention, the analysis should take into account the benefits associated with permeable pavements such as a reducing stormwater runoff volume (and facilities), reducing stormwater runoff peak flows, reducing surface ponding, reducing stormwater pollutant load, decreased downstream erosion and increase groundwater recharge, etc. This paper describes the process to determine the off pavement benefits of permeable pavements.

Key Words: PICP; life-cycle cost, benefits, pollutant load, erosion, groundwater recharge, off-road

1. Introduction

Life-cycle costing has become an essential component of any modern infrastructure design. It has long been realized that maintenance and rehabilitation costs, not just the immediate initial construction costs should be considered when evaluating investments in similar pavement alternatives.

Municipal pavements are typically designed for an initial service life of between 15 and 25 years. At the end of the service life, some form of rehabilitation action such as removal and resetting of interlocking concrete pavers for interlocking concrete pavements (ICP) or a mill and overlay for flexible asphalt pavements is completed. Life-cycle costing is a technique that quantifies all the costs necessary to construct and maintain a pavement over a set analysis period, typically between 25 and 50 years. Future costs are discounted to today's dollars by using a discount rate which accounts for the effects inflation (future value of money) and interest rates (the cost of money) to determine the net present value of future costs. By comparing the total life-cycle cost of two or more pavement options, it is possible to make informed decisions on the best pavement alternative for a particular application.

Life-cycle costing can be used to benchmark other potential options such as permeable and conventional pavements to determine which is the most cost effective. Traditionally when performing a life-cycle cost analysis between permeable and conventional pavements, only the standard capital costs for initial construction and maintenance and rehabilitation costs for each pavement types are considered.

The initial construction costs associated with permeable pavements is typically higher than conventional non-permeable pavements. However, to comprehensively evaluate compare permeable and convention, the analysis should account for benefits associated with permeable pavements such as a reducing stormwater runoff volume (and facilities), reducing stormwater runoff peak flows, reducing surface ponding, reducing stormwater pollutant load, decreased downstream erosion and increased groundwater recharge, etc. Therefore, overall long-term life-cycle costs have the potential to be very competitive if consideration is given to off-road benefits such as stormwater management and water quality improvements.

This paper outlines the cost benefits of off-road elements associated with the installation of a permeable pavement system.

2. Non-Traditional Life-Cycle Benefit Considerations

The installation of permeable pavement has several stormwater quantity and quality management benefits, however, consideration of these additional off-road benefits is often discussed but rarely quantified within an LCCA. The objective of this section is to consider some of these additional benefits and how they could impact the LCCA. Some benefits to consider include:

- Reduced stormwater facilities;
- Reduced stormwater flow in combined sewer systems;
- Land use;
- Stormwater runoff control;
- Water quality improvement;
- Reduced winter maintenance activities;
- Utility cut restoration;
- Pavement striping; and
- Traffic calming.

2.1 Stormwater Facility Reduction

By promoting infiltration versus runoff, one permeable pavement benefit is the potential to reduce or eliminate various required stormwater management facilities such as stormwater management ponds and sewer pipes. These benefits and associated costs are of importance for new development areas where the entire stormwater management system needs to be constructed.

Stormwater Managmeent Ponds

Stormwater management ponds are typically large temporary (detention) or permanent (retention pools of water often considered a Best Management Practice (BMP) to help control runoff to prevent flooding, downstream erosion and improve water quality. Permeable pavements provide an alternative or additional stormwater control measure that could be used to potentially minimize or eliminate the use of stormwater ponds. For developers, this could result in an increase in developable land. One of the key design components is to determine how much pervious surface would be required to reduce or eliminate the need for permanent ponds.

To properly compare permeable pavements against conventional pavements, the traditional BMP stormwater management system costs including, initial construction, routine maintenance and rehabilitation costs need to be included in the costs associated with conventional pavements. The potential costs savings in reducing or eliminating stormwater ponds, could have a significant life-cycle cost advantage for PICPs.

Storm Drainage Systems

For new development sites, the installation of permeable pavements may provide an opportunity to reduce the number or size of the storm sewer pipes, catch basins, outlet structures, etc., by reducing the flow rate into the sewer system. For existing urban infrastructure, significant use of permeable pavements may allow capital sewer upgrades to be deferred by reducing estimated future flow rates.

2.2 Combined Sewer System Flow Reduction

Agencies within older cities operate and maintain combined sewer overflow (CSO) systems where stormwater runoff and wastewater are combined into one system. In this type of system, the combined flow is treated at a wastewater treatment plant (WWTP) prior to being discharged. In some cities, the WWTP cannot process the incoming combined sewage flows. In such cases, millions of dollars have been spent to create underground storage facilities that detain and slowly release flows at a rate that can be treated by the WWTP.

The actual and predicted combined flow rates are a key factors in the management and operation of the system and WWTP. By reducing the amount of stormwater runoff entering the system, the combined flow rate entering the WWTP is reduced. A reduced flow rate can decrease the management and operating costs of the plant. Several agencies realize the benefits associated with reducing or eliminating stormwater runoff entering the combined system and are investigating ways to separate their systems. However, due to the presence of and often complex underground infrastructure, separating sewer systems can be very difficult and quite costly so alternatives for on-site stormwater control are necessary. Alternatives include permeable pavements to decrease flows.

Wastewater Treatment Plant Operating Costs

In general, treatment plants have three major operating costs: fixed, mechanical treatment and chemical treatment. Some of mechanical and chemical treatment costs are a function of the flow rate entering the plant. The combined flow is treated within a WWTP by various mechanical processes that require the use of energy. Inflow pumping and aeration require the most amount of energy within a WWTP. Inflow pumping is a function of flowrate. Therefore, a reduction in energy cost (benefit) could be realized from reduced flow rates. By reducing the flow rate entering the plant, it is also possible to reduce the costs associated with chemical treatment, however, this is highly dependent on the plant location and local water quality regulations.

Combined Sewer Drainage Systems

Eliminating stormwater flow may allow funds for CSO capital upgrades to be defferred by reducing estimated future flow rates.

Future WWTP Upgrades

Every year agencies spend millions of dollars on capital plant upgrades to meet the demand placed on their system. By reducing or diverting stormwater away from CSO systems, future plant upgrade expenditures may be deferred.

2.3 Reducing and Controlling Stormwater Runoff

There are several impacts associated with high volumes of stormwater runoff including: environmental, human, and economic. By reducing stormwater runoff, the impacts can be minimized or controlled. These may include: runoff temperature reduction, freshwater/estuarian ecosystem protection, reduced flooding and property damage, improved water quality, reduced stormwater management costs required for regulatory compliance, reduction in impervious cover fees, improvement to teh urban foliage canopy, multi-use sytsems by combining permeable pavements with other systems such as recreational fields and parks and rainwater harvesting to reduce the use of the municipal water system.

2.4 Water Quality Improvement

In addition to reducing stormwater runoff, permeable pavements are also considered an effective method for reducing pollutants from urbanized areas [1]. According to the North Carolina Department of Environment and Natural Resources, design pollutant removal efficiencies can be in the order of 85 percent for total suspended solids (TSS), 35 percent for Total Phosphorus and 30 percent for Total Nitrogen [2].

In general, wastewater treatment facilities include treatment processes to reduce effluent nutrient concentration levels to protect the receiving water. While most facilities include secondary treatment to deal with elements such as phosphorous and nitrogen, they cannot generally meet drinking water standards without adding enhanced biological and chemical processes. There are many processes that could be used an each facility needs to determine the most effective for their particular facility and situation. Capital costs may include storage for sludge, addition of fermenters, degree of automation desired and the facility size and availability of expansion space (economies of scale). Operation and maintenance costs may include the cost of chemicals, and labor, sludge handling, use of a fermeter and facility size (economies of scale).

To assess the benefit for LCC consideration, the capital investment required to achieve equivalent design pollutant removal efficiencies using other treatment systems should be considered. For example, a typical

regulation for TSS removal is 80 percent. Installing a permeable pavement could achieve this goal. The cost for achieving this goal through other treatment strategies needs to be added to the cost for conventional pavement.

Research completed by Tetra Tech [3,4] in concert with the U.S. Environmental Protection Agency's (EPA) Office of Wetlands, Oceans, and Watersheds (OWOW), calculated the life-cycle cost for chemical (total phosphorus) removal for small and medium size wastewater treatment plants. This included capital and operation costs annualized over 20 years. The study used cost data from the EPA to estimate expansion and retrofitting plants for chemical addition, enhanced biological phosphorus removal (EBPR) and EBPR plus chemical addition (EBPR+C). The CH2MHill study [5] was used to estimate the costs of constructing and retrofitting discharge lagoons. It should be noted that cost for specific treatment plants would be unique and depend on specific site variables (e.g. influent pH, sludge disposal costs, alkalinity, electricity costs and removal percentages) but they provide an estimate for the purpose of understanding the potential value of achieving the desired total phosphorous removal.

2.5 Reduced Winter Maintenance Activities

The high surface permeability of a permeable pavement allows for surface water to be removed from the surface quickly and infiltrated into the system. Studies have shown that winter deicing chemicals and sand are rarely required. A study from the University of New Hampshire indicates that permeable pavements require up to 75 percent less deicing than conventional pavements [6]. The reduction in costs associated with winter maintenance for permeable pavements should be considered in the LCCA.

2.6 Utility Cut Restoration

Utility cuts can have a significant impact on the service life of the pavement. In a 2009 study completed for the City of Toronto pavement condition data was gathered for roadways with and without utility cuts to determine the impact of utility cuts on the degradation of pavements. The study indicated that utility cuts reduce the life of a typical municipal pavement by 5.5 percent. Over a 25-year service life, this represents a service life loss of 1.4 years. The findings of the study were used to develop a utility cut pavement degradation fee charged to utility companies to represent the loss of value of road life to the municipality [7].

PICP and ICP pavements provide the ability to temporarily remove the surface to address settlements and access underground utilities and then replaced without leaving any permanent evidence of a utility cut repair resulting in a combined cost savings in reduced utility cut restoration coats and little or no impact on reducing the pavement service life. For other materials, utility cuts would require the removal and disposal of the existing pavement and reinstatement of the upper pavement layers to match what was removed. In an urban environment, the reduced impact of utility cut restorations for PICP and ICP has the potential to significantly reduce the life-cycle cost of the pavement.

In addition, PICP and ICP permit "all season" repairs to interlocking concrete pavements, i.e. in northern environments, most asphalt plants are closed in the winter and it is difficult and expensive to cure concrete during below freezing conditions. This also has a reduced impact on travel delays to drivers due to the ability to make more rapid maintenance repairs to an interlocking concrete pavement compared to conventional pavement.

2.7 Roadway Paint Markings

PICP and ICP have the potential for reducing the maintenance cost for pavement and crosswalk markings as colored pavers can be used in lieu of paint or thermoplastic markings which require frequent updating or replacement.

2.8 Traffic Calming

PICP and ICP provide traffic calming without the use of speed bumps or humps. Some agencies use removable traffic calming devices. In northern environments subject to snow, these removable devices are installed in the spring and removed in the fall to facilitate snow removal operations. There is an annual cost associated with this activity.

3. Other Life-Cycle Cost Benefit Feasibility Ranking

For each of the off-road considerations, an assessment was completed to determine if the benefit is indeed quantifiable for LCCA purposes. Each benefit was then assigned a feasibility ranking on whether the information required to quantify the benefit would be easily accessible by designers and agencies. A summary of the rankings for incorporation into a LCCA are provided in Table 1.

Table 1. Other LCCA Consideration Benefit Feasibility Summary.

Benefit	Key Issue	Quantifiable	Feasibility Ranking
Stormwater Management Pond Reduction	• Reduce size or eliminate ponds. • Maintenance rarely completed. Lack of maintenance results in high rehabilitation costs to restore function. • May need to address existing and new development areas separately.	Yes	High
Stormwater Sewer System Upgrades	• Defer capital upgrades. • May be dependent on whether sewer system LCCA information is available.	Yes	Low
Combined Sewer System WWTP Operating Cost	• Reduce annual operating cost.	Yes	High
Combined Sewer System WWTP Upgrades	• Defer capital upgrades. • May be dependent on whether WWTP LCCA information is available.	Yes	Low
Combined Sewer System Pipe Sizes	• Reduce sizing. • Maybe difficult due to desire to move away from combined system instead of upgrading.	Difficult	Low
Stormwater Temperature Reduction	• Keep receiving waters at acceptable temperatures.	Difficult	Low
Freshwater Ecosystems	• Protect/repair systems. • Maintain fish populations, etc.	Difficult	Low
Flooding/Property Damage	• Reducing damage, cost, insurance, inconvenience, etc.	Risk Based	Medium
Stormwater Management Costs (Regulatory compliance)	• Reduce costs associated with meeting requirements.	Difficult	Medium
Erosion Control	• Prevent infrastructure damage due to erosion and loss of subgrade	Risk Based	Low
Multiuse System	• Dual use of land, i.e., parking lot and infiltration bed.	Yes	High
Rainwater Harvesting	• Reduced cost of fresh water for municipal, commercial or domestic irrigation and/or gray water system use.	Yes	Medium
Impervious Fees	• Reduce stormwater fees associated with high percentage of impermeable land use. • Related to development.	Yes	Medium
Urban Foliage Canopy	• Reduce the need and cost for external watering of urban trees. • Healthier, improved canopy and longer life spans. • Improved air quality, urban micro-climate, property values, and urban character.	Difficult	Low

Benefit	Key Issue	Quantifiable	Feasibility Ranking
Pollutant Removal	• Achieve similar design pollutant removal efficiencies for total suspended solids (TSS), total phosphorus, total nitrogen, metals, and/or oils.	Yes	High
Drinking Water Quality Preservation	• Protect drinking water sources.	Yes	Low
Winter Maintenance	• Reduce the need and cost associated with winter deicing activities.	Yes	High
Utility Cut Restoration	• Reduce cost of utility cut restoration • Service life impact	Yes	High
Roadway Paint Marking	• Reduced cost to maintain paint markings	Yes	High
Traffic Calming	• Reduce direct cost to associated with traffic calming devices • Increase driver and/or pedestrian safety	Yes	High
Urban Climate	• Reduce micro-climate temperatures via high reflectance surface and evaporative cooling	Yes	Low

4. Other LCCA Consideration Benefit Costing

To truly compare the life-cycle costs of permeable and conventional pavements, the life-cycle cost of off-road, regular BMP treatment such as stormwater management ponds and combined sewer systems need to be considered in the tradeoff analysis.

The top most feasible benefits associated with the installation of PICP include the following:

1. Elimination or reduction of stormwater management facilities;
2. Reduction in WWTP operating cost due to a stormwater flow reduction in a combined sewer overflow system;
3. Improve the water quality by achieving similar pollutant removal design efficiencies compared to WWTPs;
4. Reduction in municipal fees associated with runoff from impervious surfaces;
5. Reduce winter maintenance operations;
6. Reduce cost of utility cut restorations and service life impacts;
7. Reduce roadway paint marking maintenance costs; and
8. Reduce costs of traffic calming devices.

Table 2 provides guidance on information and costs that needs to be obtained and considered to complete a LCCA. All the considerations are costs that need to be included in the cost of conventional pavements when completing the trade-off analysis. These costs should be considered for reference only and actual costs used in the analysis should represent local conditions and experience.

Table 2. Life-Cycle Details.

Life-Cycle Consideration	Cost $ US	Frequency
1. Stormwater Management Pond		
Initial Construction		
Land Area (ha)	$ 11,675	Once
Drainage Pipes (m.)	$ 57.60	
Catch Basins (each)	$ 2,750	
Other Drainage Features	Varies	
Routine Maintenance		
Debris Removal (per visit)	$ 100	Annually
Vegetation Control (per visit)	$ 550	
Embankment/Side Slope Repair (m^2)	$ 90	
Control Structure Repair	varies	

Life-Cycle Consideration	Cost $ US	Frequency
Sediment Removal from Sediment Storage Areas (m^3)	$ 510	Every 5 years
Sediment Removal from Main Pond (event)	$ 7,600	Every 20 years
Rehabilitation		
Grading (m^2)	$ 1.80	Varied
Excavation (m^2)	$24	
Sediment Control/Site Protection (per visit)	$ 125	
2. Combined Sewer Overflow System		
Wastewater Treatment Plant Capital Cost (MLD)	$ 1.20	Annually
Treatment Plant Operating Cost (MLD)	$ 0.40	Annually
3. Pollutant Removal		
Tier 1 Pollutant Level Target(MLD)	$ 1,545	Daily
Tier 2 Pollutant Level Target(MLD)	$ 355	Daily
4. Winter Maintenance		
Snow Clearing, Salting and Sanding (lane-km)	$ 2,175	Event
Typical Cost Savings (event)	$ 1,000	Event
5. Roadway Paint Marking		
Paint (m)	$ 0.01-0.15	Year
Epoxy Paint (m)	$ 0.65-1.00	4 Years
Thermoplastic (m)	$ 0.62-0.85	6 Years
Preformed Tape (m)	$5.00-8.70	4-8 Years
Pigment Paver Cost (m)	$ 0.25	25 Years
6. Traffic Calming Devices		
Removable Rubber Speed Bumps (ea)	$ 1,500	25 Years
Installation and removal of Rubber Speed Bumps (ea)	$ 300	Seasonal
Permanent Asphalt Speed Bump with Labor (ea)	$ 3,000	25 Years
Traffic Calming for Paver Systems (ea)	$ 0	25 Years
7. Impervious Surface		
Flat Monthly Fee for Impervious Surfaces (per 100 m^2)	$ 92.90	Yearly
8. Utility Cut Restoration		
Remove and Replace Asphalt (m^2)	$ 80.00	Annually
Remove and Replaced Concrete (m^2)	$ 110.00	Annually
Remove Pavers, Clean and Re-install (m^2)	$ 50.00	Annually
Pavement degradation fee (m^2)	$ 20.00	Once

5. Estimating Total Life-Cycle Cost

Estimating total life-cycle cost combines initial and maintenance and rehabilitation costs for each alternative. The total life-cycle combines many factors for all pavement type scenarios to determine the lowest life-cycle cost. This includes the cost of traditional stormwater management and winter maintenance costs. The required inputs include:

- General inputs
  - Analysis period
  - Discount rate
  - Site description/dimensions
- Pavement Type (PICP, ICP, asphalt and concrete)
  - Unit costs
  - Initial pavement layer thickness
  - Pavement maintenance and rehabilitation plan and quantities
  - Off road considerations, costs and quantities

6. Summary

Incorporating the off-road costs such as eliminated detention ponds, associated land costs, pollutant reduction, and reduced winter maintenance activities into life-cycle costs is a key component in evaluating the use of permeable pavements. Initial construction costs of permeable pavement are typically higher than conventional pavements, however, by considering the reduced costs associated with the benefits can assist in lowering the overall life-cycle cost of a permeable pavement. This can increase the value of permeable pavement thereby justifying its use compared to other pavement types or other stormwater control measures.

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