# Permeable Interlocking Concrete Pavement Life-Cycle Cost Analysis Tools

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# 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.

The Federal Highway Administration (FHWA) [1] describes LCCA as "an analysis technique that builds on the well-founded principles of economic analysis to evaluate the overall long-term economic efficiency between competing alternative investment options." The comparison of life-cycle costs has become standard to not only compare different pavement types, but also evaluate different feasible rehabilitation plans over the service life of a pavement.

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.

The actual service life of the initial pavement construction and rehabilitation treatment is dependent on a variety of factors including type and composition of the traffic, timeliness of maintenance treatments, and environmental factors such as climate, temperature and precipitation. To develop comparative cost estimates to determine the whole life cost of different pavement types, it is necessary to know the timing, type and quantities of repairs and their service life. The service life of a pavement is defined as the time between initial construction and the time when the pavement reaches a minimum unacceptable level of service.

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.

As part of this project, Applied Research Associates, Inc. (ARA) developed a MS Excel based life-cycle cost analysis (LCCA) tool that quantifies and incorporates some of the stormwater management and quality benefits into the LCCA to compare permeable interlocking concrete pavements (PICP) to conventional pavements including off-road benefits.

## 2. PICP Pavement Design and Maintenance & Rehabilitation Considerations

The initial design and construction of pavements are critical factors in the life-cycle cost evaluation procedure. A pavement built for its appropriate traffic and environmental conditions will have a reasonable service life while providing a functional, safe platform for the travelling public. The service life of a pavement is established during the initial design considering the subgrade, pavement layer materials and their thicknesses, the anticipated traffic using the roadway, and the budget. This service life can be somewhat variable depending on the environmental and loading conditions. By monitoring and rating pavement performance over its service life using standard pavement management tools such as the pavement condition index (PCI), it is possible to establish typical performance curves for the pavement [2]. The PCI rating is straightforward: it rates pavement condition from 0 (non-functional) to 100 (new).

To determine the expected life of a pavement, the measured condition and a minimum acceptable level of service are used. The typical path of deterioration is monitored over the life of the pavement until the pavement reaches the typical terminal level of serviceability. For PICP, very few field data points regarding its terminal condition are available.

To generate the deterioration path, several possible techniques can be used. A common statistical technique called regression consists of selecting an appropriate form for modelling pavement condition deterioration over time and using the method of least squares to determine the best fit model. This method calculates the best-fitting line for the observed data by minimizing the sum of the squares of the vertical deviations from each data point to the line. (If a point lies on the fitted line exactly, then its vertical deviation is 0.) The terminal level of serviceability is extrapolated from the downward slope line that characterizes a deteriorating condition over time.

On-going pavement maintenance and rehabilitation costs can reverse the downward slope of the line. Maintenance and rehabilitation (M & R) activities are typically scheduled to occur at various times to improve the serviceability of the pavement. The timing of M & R activities and the cost to perform them are discounted to today's costs, then combined with initial costs to estimate the total life-cycle cost.

### 2.1 Level of Service

The minimum acceptable level of service is an important decision that must be made by a designer. The maximum state of deterioration that a pavement is expected to reach can greatly change the service life. It many cases the service level of a pavement must be maintained at a high level due to its exposure to various types of use resulting in a long service life. The level of service can be described by condition indicators such as structural capacity, ride quality or visual distress. For most municipal roadways, the visual surface condition of the pavement is typically used because it can represent the other, related factors. With the relatively low operating speed of most low-volume pavements, the impact of other functional performance factors is reduced.

A PCI rating of 60 is recommended as the trigger value for rehabilitation action. Once a pavement's condition deteriorates past this level, substantial repairs throughout a section are likely required to restore the pavement to an excellent condition level. Additional deterioration ratings below 60 generally means that M & R costs will substantially increase compared to actions taken at ratings at 60 or above.

## 2.2 Initial PICP Design

Initial design and construction costs are typically the largest expense over the life-cycle. The initial pavement design of PICP is very dependent on many factors such as traffic level, environment, and materials used. An example PICP design is as follows:

<u>30 Year Service Life Structural Design</u>

| | |
|---|---|
| 3 1/8 in. | Permeable Pavers |
| 2 in. | ASTM No 8 or ASTM No. 89 Bedding Stone |
| 4 in. | ASTM No. 57 Base |
| 32 in. | ASTM No. 2 Subbase |

## 2.3 Maintenance and Rehabilitation Plan

The maintenance and rehabilitation (M&R) plan for a pavement outlines a typical scenario to maintain the pavement in a cost-effective and serviceable manner. The plan estimates maintenance and rehabilitation activities and timing. Besides replacement and resetting of interlocking concrete pavers for permeable and mill-and-overlay for flexible pavements. PICP will also require regular vacuum sweeping to prevent clogging of the joints. In addition, jointing aggregate may sometimes require replacement after vacuuming. The amount of surface cleaning required annually is directly proportional to the amount of contributing impervious drainage area and sediment from it, as well as regular vacuum cleaning of that area. In most cases, that contributing drainage area is not vacuumed. If routine PICP vacuuming is not regularly completed to prevent clogging, then restorative vacuuming is needed with more powerful equipment. In addition, restorative cleaning requires replacing the aggregates in the joints as this vacuum operation removes the aggregate with the sediment.

A pro forma plan for maintenance and rehabilitation expected for PICP is given in **Table 2-1**. This plan should be evaluated on a project-by-project basis before implementation in the field to ensure the correct timing of activities. For the purposes of Table 2.1, preventive vacuuming is done annually.

**Table 2-1. Pro Forma Unit Costs for Maintenance and Rehabilitation**

| Year | Activity | Quantity |
|---|---|---|
| 8 | Replace Cracked Pavers | 2 percent |
| | | |
| 20 | Replace Worn/Rutted Pavers (wheelpath) | 5 percent |
| | | |
| 28 | Replace Cracked Pavers | 2 percent |
| | | |
| 35 | Replace Worn/Rutted Pavers (wheelpath) | 5 percent |
| | | |

## 2.4 Estimating Maintenance and Rehabilitation Costs

One of the key components for evaluating total costs over the pavement life-cycle is estimating maintenance and rehabilitation costs. This is typically accomplished by reviewing the potential activities throughout the service life of a pavement, their frequency and costs.

The maintenance and rehabilitation costs used in the analysis are based on current dollars. Adjustments due to inflation and discounting are considered later during the LCCA. The unit costs represent the whole cost to complete the maintenance and rehabilitation activity, including labor, equipment and materials. The estimated unit costs for the expected activities for the PICP example are given in **Table 2-2**. Each unit cost can vary significantly depending on location, size of the project, manual or machine assisted installation, availability of materials and contractors, etc.

**Table 2-2. Unit Costs (for Maintenance and Rehabilitation)**

| Activity | Unit Cost ($) | Unit |
|---|---|---|
| Bedding and Paver Installation (machine assisted) | 6.50 | Sq. Ft |
| Granular Base | 34.20 | Cu. Yd |
| Granular Subbase | 34.20 | Cu. Yd |
| Replace Cracked Pavers | 6.00 | Sq. Ft |
| Replace Worn/Rutted Pavers (wheelpath) | 12.00 | Sq. Ft |
| Routine preventive vacuuming | 800 | Acre* |
| Restorative vacuuming of clogged surface | 8,000 | Acre** |

*$0.02/Sq. Ft 15,000 Sq. Ft minimum **$0.18/Sq. Ft 2,000 Sq. Ft minimum

# 3. Comparable Pavements

The key benefit of a LCCA is the ability to compare multiple pavement structures with different initial cross-sections and hence different maintenance strategies. Conventional (impermeable) interlocking concrete pavements and flexible pavement example designs have been provided based on the similar geometric and traffic conditions to the example PICP design.

## 3.1 Conventional Interlocking Concrete Pavement

The comparable pavement design for the interlocking concrete pavement is as follows:

<u>Interlocking Concrete Pavement Structural Design</u>

3 1/8 in. Concrete Pavers (with sand filled joints)
1 in. Bedding Sand
4 in. Base
16 in. Subbase

A typical plan for maintenance and rehabilitation expected for an interlocking concrete pavement is outlined in **Table 3-1**.

**Table 3-1. Interlocking Concrete Pavement Maintenance and Rehabilitation Plan**

| Year | Activity | Quantity (%) |
|---|---|---|
| 8 | Replace Cracked Pavers | 2 |
| 20 | Replace Worn/Rutted Pavers (wheelpath) | 5 |
| 28 | Replace Cracked Pavers | 2 |
| 35 | Replace Worn/Rutted Pavers (wheelpath) | 5 |

The estimated unit costs for the expected activities on the interlocking concrete pavements are similar to the costs for the ICP and are provided in Table 3.2.

**Table 3-2. Interlocking Concrete Pavement Unit Costs for Maintenance and Rehabilitation**

| Activity | Unit Cost ($) | Unit |
|---|---|---|
| Bedding and Paver Installation (machine assisted) | 6.50 | Sq. Ft |
| Granular Base | 34.20 | Cu. Yd |
| Granular Subbase | 34.20 | Cu. Yd |
| Replace Cracked Pavers | 6.00 | Sq. Ft |
| Replace Worn/Rutted Pavers (wheelpath) | 12.00 | Sq. Ft |

## 3.2 Conventional Flexible Asphalt Pavement

Flexible asphalt pavement structures are typically asphalt concrete surface over a granular base and subbase combination. A typical flexible pavement structure with a comparable traffic and subgrade condition to the example ICP design is as follows:

Flexible Pavement Structural Design

| | |
|---|---|
| 4 in. | Asphalt Concrete |
| 6 in. | Base |
| 14 in. | Subbase |

A typical plan for maintenance and the rehabilitation activities expected for a flexible pavement is given in **Table 3-3**.

**Table 3-3. Flexible Pavement Maintenance and Rehabilitation Plan**

| Year | Activity | Quantity (%) |
|---|---|---|
| 4 | Rout and Seal Cracks | 5 |
| 8 | Machine Patching | 5 |
| 12 | Rout and Seal Cracks | 10 |
| 12 | Machine Patch | 5 |
| 15 | Mill and Overlay (2 in.) | 100 |
| 19 | Rout and Seal Cracks | 10 |
| 22 | Machine Patching | 10 |
| 25 | Mill and Overlay (3 1/2 in.) | 100 |
| 27 | Rout and Seal Cracks | 10 |
| 30 | Machine Patching | 10 |
| 37 | Mill and Overlay (2 in.) | 100 |

This structure is typical for a municipal pavement. The estimated unit costs for the expected activities on the flexible pavement are similar to the costs for the ICP and are provided in **Table 3-4**.

**Table 3-4. Flexible Pavement Unit Costs for Maintenance and Rehabilitation**

| Activity | Unit Cost ($) | Unit |
|---|---|---|
| Asphalt Concrete Surface (45 sf/ton @ 4 in. thick) | 150.00 | ton |
| Granular Base | 34.20 | Cu. Yd |
| Granular Subbase | 34.20 | Cu. Yd |
| Rout and Seal Cracks | 2.00 | Ft |
| Asphalt Patching | 10.00 | Sq. Ft |
| Mill and Overlay Pavement | 5.00 | Sq. Ft |

# 4. Other LCCA 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.

## 4.1 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.

### *4.1.1 Stormwater Management 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. There are several issues and challenges associated with them including the following:

**Maintenance:** Routine maintenance is critical to meeting long-term stormwater management goals. Failure to properly maintain the ponds can impact water quality, threaten public safety and lead to more costly rehabilitations. Without proper maintenance, excess pollutants maybe actually become sources of water quality issues instead of improving it. Generally, many agencies do not perform routine maintenance and it the functionality of ponds and the wider drainage system.

**Land Use:** Stormwater ponds require large amounts of land.

**Health and Safety:** Increased presence of waterfowl can result in increased fecal coliform counts resulting in poor water quality and nuisance complaints by nearby residents. Health concerns regarding standing water and the presence of mosquitoes and the safety of children playing nearby are both causes for public concern.

**Habitat Impact:** The construction of large stormwater ponds has the potential to harm existing natural wetlands. For example, during large storm events a breach in the pond can result in downstream erosion. [3].

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.

### *4.1.2 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.

## 4.2 Combined Sewer System Flow Reduction

Several 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.

They must be implemented on a large-scale within a neighborhood or district to yield a system-wide reduction in stormwater runoff entering the WWTP.

#### 4.2.1 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.

#### 4.2.2 Combined Sewer Drainage Systems

Similar to Section 4.1.2 for existing urban infrastructure, eliminating stormwater flow may allow funds for CSO capital upgrades to be deferred by reducing estimated future flow rates.

#### 4.2.3 Future Plant 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.

### 4.3 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. **Table 4-1** provides a summary of benefits associated with permeable pavements and reducing and/or controlling stormwater runoff flows.

**Table 4-1. Stormwater Runoff Control**

| Consideration | Benefit |
|---|---|
| Runoff Temperature Reduction | Reduce the percentage of “heated” impervious area that surface runoff moves over. In urbanized areas, the water temperature increases as runoff moves along heated surfaces such impermeable pavements (roadways, driveways, parking lots, etc.). The heated runoff flows into receiving waters such lakes and streams and has the potential to increase the base temperature of the surface water. This is of particular concern for cold water lakes, streams and fisheries that are most sensitive to thermal changes. Increased temperatures interfere with spawning and migration patterns. [4]. |
| Freshwater/Estuarian Ecosystems | Protect and/or repair freshwater or salt marsh ecosystems, maintain fish populations, etc. |

| | |
|---|---|
| Flooding and Property Damage | Reduce the risk of property damage due to flooding therefore reducing repair costs, insurance costs, inconvenience, etc. During major storm events, flooding can pose a threat to human safety and cause expensive property damage. |
| Water Quality | Improve water quality by providing filtering capabilities and reducing runoff which transports several pollutants from impervious surfaces to various receiving waters. |
| Stormwater Management Costs (Regulatory compliance) | Reduce the costs associated with regulatory compliance. Many agencies spend millions of dollars to meet stormwater and water quality regulatory requirements. |
| Impervious Cover Fees | Reduce fees due to impermeable cover percentages or land use. |
| Urban Foliage Canopy | Improve overall urban tree health and longevity. Reduce the amount of watering required. |
| Multi-Use Systems | Permeable pavements can be combined with other systems such as recreational fields and parks to increase infiltration rates. |
| Rainwater Harvesting | Capture rainwater to be reused for municipal, commercial or residential applications, i.e. landscape watering. |

### *4.3.1 Impervious Cover Fees*

The methods used by agencies to calculate and apply impervious cover fees varies widely. For example, Washington D.C. calculates an Equivalent Runoff Unit (ERU) rate which is adjusted and applied based a tiered impervious area scale. In Minneapolis, they calculate an Equivalent Stormwater Unit (ESU) which is based on 1,530 square feet of impervious area. This is then adjusted based on the total impervious area. A monthly fee per ESU is charged to property owners. By reducing stormwater quantity and quality, property owners can receive credits of up to 100 percent of the stormwater fee. Unless fees are high due to excessive impervious cover associated with commercial land uses, the impact of the impervious cover fees for residential land uses vary widely and often do not result in a significant impact on the overall life-cycle cost of the PICP.

## 4.4 Water Quality Improvement

In addition to reducing stormwater runoff, permeable pavements are also considered an effective method for reducing pollutants from urbanized areas [5]. 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 [6].

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 [7,8,9] 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 [9] 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.

The daily life-cycle cost to achieve a total pollutant content of 1.0 mg/l and 0.1 mg/l was $1,350 and $5,850 (2018 dollars) per million gallons respectively. The costs savings in pollutant removal costs would be directly related to the quantity of water diverted from the wastewater plant. For example, if permeable pavements were able to reduce the waterflow to the plant by 10 percent, this would result in an annual per million gallons savings of $ 49,275 to achieve a total pollutant content of 1.0 mg/l and $214,525 for 0.1 mg/l.

## 4.5 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 [10]. A study from the University of New Hampshire indicates that permeable pavements require up to 75 percent less deicing than conventional pavements [11]. The reduction in costs associated with winter maintenance for permeable pavements should be considered in the LCCA.

## 4.6 Utility Cut Restoration

Utility cuts can have a significant impact on the service life of the pavement. In a 2009 study completed by ARA 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 [12].

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.

### 4.7 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.

### 4.8 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.

## 5. Other LCCA Consideration 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 5-1**.

**Table 5-1. Other LCCA Consideration Benefit Feasibility Summary**

| Benefit | Key Issue | Quantifiable | Feasibility Ranking |
|---|---|---|---|
| Stormwater Management Pond Reduction | • Reduce size or eliminate ponds.<br>• Maintenance rarely completed. Lack of maintenance results in high rehabilitation costs to restore function.<br>• May need to address existing and new development areas separately. | Yes | High |
| Stormwater Sewer System Upgrades | • Defer capital upgrades.<br>• 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.<br>• May be dependent on whether WWTP LCCA information is available. | Yes | Low |
| Combined Sewer System Pipe Sizes | • Reduce sizing. | Difficult | Low |

| Benefit | Key Issue | Quantifiable | Feasibility Ranking |
|---|---|---|---|
| | • Maybe difficult due to desire to move away from combined system instead of upgrading. | | |
| Stormwater Temperature Reduction | • Keep receiving waters at acceptable temperatures. | Difficult | Low |
| Freshwater Ecosystems | • Protect/repair systems.<br>• 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.<br>• Related to development. | Yes | Medium |
| Urban Foliage Canopy | • Reduce the need and cost for external watering of urban trees.<br>• Healthier, improved canopy and longer life spans.<br>• Improved air quality, urban micro-climate, property values, and urban character. | Difficult | Low |
| 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<br>• 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<br>• Increase driver and/or pedestrian safety | Yes | High |

| Benefit | Key Issue | Quantifiable | Feasibility Ranking |
|---|---|---|---|
| Urban Climate | • Reduce micro-climate temperatures via high reflectance surface and evaporative cooling | Yes | Low |

## 6. 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.

A description, benefits and key issues for each of the feasible elements above are provided in Appendix A.

**Table 6-1** 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. References for the cost information provided in the table are provided in the case study examples for each life-cycle consideration in Appendix A. These costs should be considered for reference only and actual costs used in the analysis should represent local conditions and experience.

**Table 6-1. Life-cycle Details**

| Life-cycle Consideration | Cost $ | Frequency |
|---|---|---|
| **1. Stormwater Management Pond** | | |
| *Initial Construction* | | |
| Land Area (acre) | $ 4,725 | Once |
| Drainage Pipes (ft.) | $ 17.55 | |
| 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 ($yd^2$) | $ 75 | |

| Life-cycle Consideration | Cost $ | Frequency |
|---|---|---|
| Control Structure Repair | varies | |
| Sediment Removal from Sediment Storage Areas ($yd^3$) | $ 390 | Every 5 years |
| Sediment Removal from Main Pond (event) | $ 7,600 | Every 20 years |
| *Rehabilitation* | | |
| Grading ($yd^2$) | $ 1.50 | Varied |
| Excavation ($yd^2$) | $20 | |
| Sediment Control/Site Protection (per visit) | $ 125 | |
| **2. Combined Sewer Overflow System** | | |
| Wastewater Treatment Plant Capital Cost (MGD) | $ 4.50 | Annually |
| Treatment Plant Operating Cost (MGD) | $ 1.50 | Annually |
| **3. Pollutant Removal** | | |
| Tier 1 Pollutant Level Target (MGD) | $ 5,850 | Daily |
| Tier 2 Pollutant Level Target (MGD) | $ 1,350 | Daily |
| **4. Winter Maintenance** | | |
| Snow Clearing, Salting and Sanding (lane-mile) | $ 3,500 | Event |
| Typical Cost Savings (event) | $ 1,000 | Event |
| **5. Roadway Paint Marking** | | |
| Paint (LF) | $ 0.03-0.05 | Year |
| Epoxy Paint (LF) | $ 0.20-0.30 | 4 Years |
| Thermoplastic (LF) | $ 0.19-0.26 | 6 Years |
| Preformed Tape (LF) | $1.50-2.65 | 4-8 Years |
| Pigment Paver Cost (LF) | $ 0.08 | 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 1,000 $ft^2$) | $ 43.91 | Yearly |
| **8. Utility Cut Restoration** | | |
| Remove and Replace Asphalt ($ft^2$) | $ 7.50 | Annually |
| Remove and Replaced Concrete ($ft^2$) | $ 10.00 | Annually |
| Remove Pavers, Clean and Re-install ($ft^2$) | $ 5.00 | Annually |
| Pavement degradation fee ($ft^2$) | $ 2.00 | Once |

## 7. 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

### 7.1 Calculations of Net Present Value

The costs distributed over the pavement are typically translated into a Net Present Value (NPV). The NPV represents the today's total cost expenditures made in the future. Such expenditures account for the interest minus inflation rate (in percent) expressed as the discount rate. The NPV of all activities each occurring in the future are summed to estimate the total maintenance and rehabilitation cost. This summation of activities is expressed as:

$$Total\ M\&R\ Cost\ = \sum_{i} \left(\frac{(M\&R\ Cost_i)}{(1 + Discount\ Rate)^{Age}}\right)$$

The discount rate typically reflects the social discount rate for public sector projects and is dependent on many factors such as current economic environment, market risk, and many other potential factors. It often reflects the difference between the prevailing (market) loan interest rate and the inflation rate. Some agencies set their discount rate for LCCA or will evaluate LCCAs with various discount rates. A discount rate of 4 percent was used for this analysis.

### 7.2 Residual Value

To ensure fair comparison of the alternatives, residual value of any unused rehabilitation activity at the end of the analysis period must be included in the LCCA. The residual value is estimated by the straight-line depreciation of the last capital activity cost. The prorated life method is used in the LCCA procedure to estimate the residual value. The recoverable cost is estimated by dividing the remaining life of the last rehabilitation treatment, by the expected life of the treatment.

$$Residual\ Value = M\&R\ Cost\ \left(\frac{Service\ Life - Activity\ Age}{Service\ Life}\right)$$

To determine the salvage value, the last major rehabilitation activity is used. Based on the year of implementation of the last rehabilitation, the expected service life (from the Unit Costs table) and the activity cost, a proportion of the initial cost is estimated. This residual value at the end of the design period is then converted (discounted) to a net present value. That net present value is then subtracted from the other costs.

### 7.3 Life-cycle Cost

The total cost to construct and maintain each design option is the outcome from an LCCA. To accomplish this, the sum of all costs using an equivalent NPV is calculated for each option. The total cost for each option is thus calculated as:

$$LCC\ = Initial\ Cost + Total\ M\&R\ Cost - Residual\ Value$$

This value for each design option can be compared with other design options to determine which is has the lowest cost over the life of the pavement.

## 7.4 Life-cycle Cost Case Studies

Case studies and examples for each of the analysis items outlined in **Table 6-1** are provided in Appendix A. A summary comparison of an urban roadway, 10.5 centerline miles in length between PICP and ACP is summarized in Table 7-1. Given the complexity of the input and output data to create the summary tables, the detailed data for each analysis is provided in the MS Excel sheets accompanying this report. Based on the analysis completed herein, the summary in Table 7-1 shows that although the life-cycle cost of the permeable interlocking concrete pavement is higher than that of the asphalt concrete pavement, the impact of the other life-cycle cost consideration elements exceeds the difference of the pavement structure costs making the total life-cycle cost of the permeable pavement the lowest overall life-cycle cost.

**Table 7-1. Life-cycle Cost Comparison ($)**

| Life-Cycle Consideration Elements | PICP | | ACP | | Difference | | Net[1] |
|---|---|---|---|---|---|---|---|
| | Capital | O&M | Capital | O&M | Capital | O&M | |
| **Pavement** | 13,704,768 | 756,258 | 6,272,851 | 3,416,549 | 7,431,917 | (2,660,291) | 4,771,626 |
| **Stormwater Management Pond** | | 183,920 | 2,639,600 | 718,360 | (2,639,600) | (534,440) | (3,174,040) |
| **Combined Sewer Overflow** | | 89,235,829 | | 93,945,998 | | (4,710,169) | (4,710,169) |
| **Pollutant Removal** | | 80,312,246 | | 84,551,398 | | (4,239,152) | (4,239,152) |
| **Winter Maintenance** | | 569,338 | | 849,503 | | (280,165) | (280,165) |
| **Paint Striping** | | 10,943 | | 76,104 | | (65,161) | (65,161) |
| **Traffic Calming** | | | | 63,000 | | (63,000) | (63,000) |
| **Impervious Surface Fees** | 5,608,350 | 276,661 | 2,567,015 | 6,321,652 | 3,041,335 | (6,044,991) | (3,003,656) |
| **Utility Cut Restoration** | | 72,068 | | 93,689 | | (21,620) | (21,620) |
| | | | | **Summary Totals** | **7,833,652** | **(18,618,990)** | **(10,785,338)** |

1. Negative number indicates savings for PICP.

# 8. Life-cycle Cost Analysis Tool

A draft flow chart describing the operation of the life-cycle cost analysis tool is provided in Appendix B. An Excel spreadsheet version of the proposed tool is provided separately.

# 9. 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.

## 10. References


1. Walls, James III and Michael R. Smith. *Life-Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin*. FHWA Report FHWA-SA-98-079, September 1998.

2. Interlocking Concrete Pavement Institute*, Life-Cycle Cost Management of Interlocking Concrete Block Pavements - Methodology Report*, Washington, D.C., August 2008.

3. United States Environmental Protection Agency, *Stormwater West Pond and Wetland Management Guidebook*, Washington, D.C., 2009.

4. University of New Hampshire Stormwater Center, *Examination of Thermal Impacts from Stormwater Best Management Practices*, University of New Hampshire. Durham, NH, 2011.

5. Eck, Bradley, et al*. Water Quality of Drainage from Permeable Friction Course*, Journal of Environmental Engineering, ASCE, February 2012, pp. 174

6. North Carolina Department of Environment and Natural Resources*, Stormwater Best Practice Manual.* Raleigh, North Carolina, 2012.

7. Ohio Environmental Protection Agency, *Cost Estimate of Phosphorous Removal at Wastewater Treatment Plants*, A Technical Support Document prepared by Tetra Tech., May 2013.

8. Environmental Protection Agency, *Municipal Nutrient Removal Technologies Reference Document,* Volumes 1 and 2, Office of Wastewater Managment, Municipal Support Division, September 2008.

9. CH2MHill, *Statewide Nutrient Removal Cost Impact Study,* prepared for Utah Division of Water Quality, October 2010.

10. National Ready Mix Concrete Association, *Pervious Concrete Pavement Maintenance Guidelines,* Silver Spring, MD, 2007.

11. University of New Hampshire Stormwater Center, *Design Specifications for Porous Asphalt Pavement and Infiltration Beds*, University of New Hampshire, Durham, NH, 2009.

12. City of Toronto, *Condition and Performance Data Gathering for Pavement Degradation Study*, Applied Research Associates, Inc., Final Report, November, 2009.

*Appendix A*

# Other LCCA Consideration Fact Sheets and Examples

## 1. Storm Water Management Pond

***Description:*** Storm water management ponds are typically large permanent pools of water that are considered a Best Management Practice (BMP) to help control runoff to prevent flooding, downstream erosion and improve water quality.

***Benefit:*** Permeable pavers offer an alternative or additional storm water control measures that could potentially minimize or eliminate the use of storm water ponds

***Key Issues:*** Land use, maintenance

| | Cost (USD) | Unit | Frequency |
|---|---|---|---|
| *Initial Construction* | | | |
| Land (Minnesota) | $4,725 | /acre | Once |
| Excavation 8' Depth | $10.00 | Sq,yd | Once |
| Hauling Off-Site 8' Depth | $10.00 | Sq.yd | Once |
| Grading | $1.50 | Sq.yd | Once |
| Sod | 4.50 | Sq.yd | Once |
| Inlet Structure | $2,000 | each | Once |
| Overflow Structure | $3,500 | each | Once |
| Corrugated Metal Pipe: 8-72' | $17.55-241.00 | Each/LF | Once |
| Reinforced Concrete Pipe: 12-96' | $29.50-550.00 | Each/LF | Once |
| *Maintenance* | | | |
| Debris Removal | $100 | /visit | Annually |
| Inspection | $125 | /visit | Annually |
| Sod | $4.50 | Sq.yd | Annually |
| Remove Invasive Plants | $500 | /visit | Annually |
| Mowing | $150 | /visit | 8 times a year |
| Sediment Removal from Pond | $ 390 | /Cu.yd | Every 20 years |
| Sediment Removal Setup | $ 7,600 | /visit | Every 20 years |
| *Rehabilitation* | | | |
| Erosion | $75.00 | Sq.yd | Varied |
| Site Protection/Sediment Control | $125.00 | /visit | Varied |
| Soil Preparation | $5.00 | Sq.yd | Varied |

***Relevant for:*** Small, Medium, Large Storm Water Ponds, Urban, Rural, Old/New municipalities, New Developments

### References:

1. U.S Environmental Protection Agency, *Urban Storm Water Preliminary Data Summary*, https://www3.epa.gov/npdes/pubs/usw_d.pdf.
2. Meersman, T. *Study: Median price of Minnesota farmland continues to slide*. Star Tribune January 13th 2017, Retrieved from: http://www.startribune.com/study-median-price-of-minnesota-farmland-continues-to-slide/410683005/.
3. U.S. Environmental Protection Agency, *Stormwater Wet Pond and Wetland Management Guidebook,* Retrieved from: https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf.

## Example of Use

The use of permeable pavements may permit the reduction or elimination of stormwater ponds. This may provide land for other uses such as increased development or recreational use, reduce drainage system elements and costs and reduce the long-term operation and maintenance costs.

**Existing Features:**

- Approximately 10.5 miles of roadway (1,330,560 sq. ft) of pavement
- Discount rate of 5 percent
- Current municipal design would require a 4-acre stormwater management (SWM) pond
- Excavation requirement of 8 ft

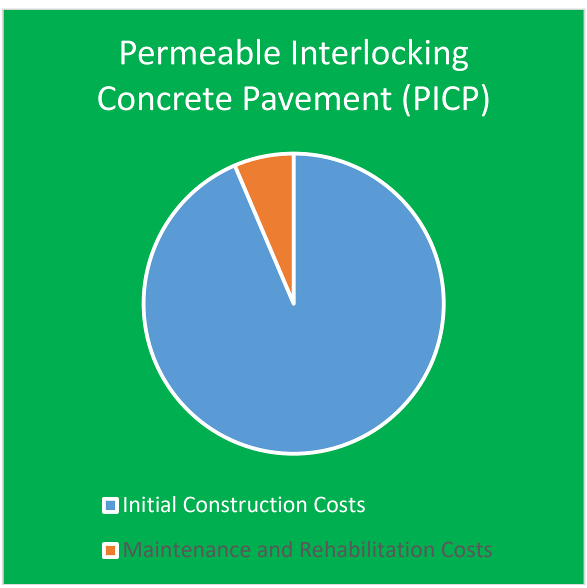
**PICP LCCA Example Assumption:**

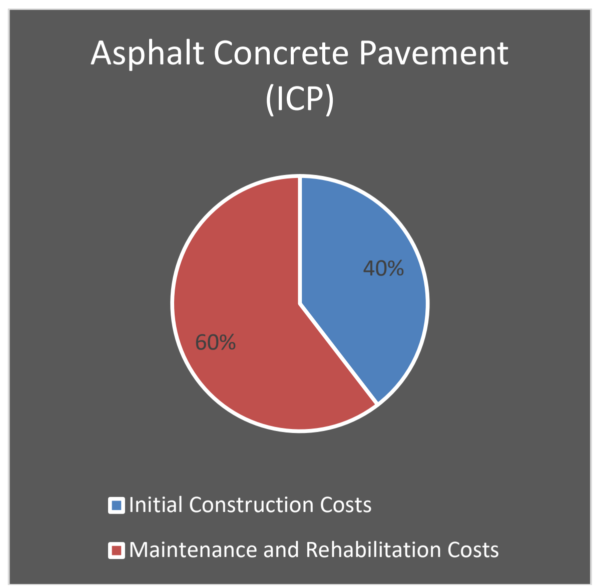
1. 40-year LCCA between the feasibility of PICP versus conventional asphalt concrete
    a. PICP Pavement (PICP) Layers
        i. 3 1/8 in pavers + 2 in bedding
        ii. 4 in ASTM No. 57 base
        iii. 32 in ASTM No. 2 subbase
    b. Asphalt Concrete Pavement (ACP) Layers
        i. 4 in asphalt concrete
        ii. 6 in dense graded base
        iii. 14 in dense graded subbase
2. LCCA completed prior to any construction (assume green field construction, not retro-fit).
3. PICP Alternative includes PICP installed for all roadways.
    a. Vacuum sweeping required for roadway in Year 15 followed by additional treatments every 10 years.
4. ACP alternative includes:
    a. Estimated concrete pipe length = 60,000 ft
    b. Estimated number of catch basins = 230
5. Installation of PICP would eliminate the catch basins and underground piping.
6. Installation of PICP would eliminate the stormwater management pond.
7. Estimated SWM Pond Area = 4 acres (19,360 $yd^2$).
8. SWM Pond excavation depth = 8 ft.
9. Inspection of SWM Pond once per year.
10. Erosion protection of 500 square yards every 10 years.

11. Sediment removal of 500 cubic yards every 5 years.
12. The available land not used by the SWM pond would be used for a graded and sodded park space. Land value retained as park space is $4,725 per acre.
    a. Park space requires annual maintenance. (Assumed mowing 3 times annually).

**Life-cycle Cost Analysis Results (Pavement and Off-Road Considerations):**

| Element | Life-cycle Cost |
|---|---|
| **Asphalt Concrete Pavement** | |
| Capital Costs | $ 8,912,453 |
| Operation and Maintenance Cost | $ 4,134,909 |
| **Life-Cycle Cost** | **$ 14,644,946** |
| | |
| **Permeable Interlocking Concrete Pavement** | |
| Capital Costs | $ 13,704,768 |
| Operation and Maintenance Cost | $ 940,178 |
| **Life-Cycle Cost** | **$ 13,047,362** |
| | |
| **Life-Cycle Cost Savings (Asphalt Concrete Pavement)** | **$ 1,597,584** |



## 2. Combined Sewer System

***Description:*** A system designed to collect rainwater runoff, domestic sewage and industrial wastewater in the same pipe whereby it passes through a waste water treatment plant and discharged to a water body.

***Benefit:*** Permeable pavements offer a reduced flow rate within this system to potentially decrease the management and operating costs of the plants.

***Key Issues:*** Land use, Age of Infrastructure, Operating Costs, Flow Rates, Disposal, Energy

| | Cost (USD) | Unit | Frequency |
|---|---|---|---|
| Treatment plant capital cost | $ 4.50 | Gallons/day | Depends on growth |
| Operating cost | $ 1.50 | 1,000 Gallons | |
| Typical treatment plant capacity | | | |
| Small | | Gallons | 2 Million/Day |
| Medium | | Gallons | 15 to 25 Million/day |
| Large | | Gallons | 100 Million/Day |
| | | | |
| | | | |

***Relevant for:*** Urban, Rural, Old/New municipalities, New Developments, Cities within proximity of large bodies of water, Infrastructure (old/new)

***References:***


1. Reilly, J., and Gottlieb, P., New Jersey Office of State Planning and Princeton University, *Estimating Costs for Wastewater Collection and Treatment Under various Growth Scenarios*, Third International Conference on Computers in Urban Planning and Urban Management, Atlanta, Georgia, July 1993, https://pdfs.semanticscholar.org/a1d0/2bbf49840a384bd673ffe0b0243330ba7d8e.pdf
2. City of Toronto, *Ashbridges Bay, Wastewater Treatment Plan, 2015 Annual Report*, Retrieved from: https://www.toronto.ca/wp-content/uploads/2017/11/97d1-ashbridges-bay-annual-report-2015-AODA.pdf.
3. California Waterboards, Waste Water Treatment Plant Classification, Retrieved from: https://www.waterboards.ca.gov/water_issues/programs/operator_certification/docs-wwtp_classification_brochure.pdf.

## *Example of Use*

The use of permeable pavements will reduce the flow of stormwater in a treatment plant. This may result in reduced capital and operating costs for the treatment of stormwater.

**Existing Features:**

- Small size community stormwater plant. Capacity = 10 million gallons per day.

**PICP LCCA Example Assumption:**

1. Typical plant operation period = 25 years
2. Plant capital cost remains the same for both alternatives
3. Capital cost for plant $4.50/gallon treated (one time cost)
4. Operating cost of $1.50/1,000 gallons treated
5. 365 days per year for operating period
6. Permeable pavements reduce plant water volume by 5 percent annually (from 3,650 MG/yr to 3,467 MG/yr.
7. Discount rate = 5 percent

**Life-cycle Cost Analysis Results:**

| Element | Life-cycle Cost |
| --- | --- |
| **Asphalt Concrete Pavement** | |
| Capital Costs (same for both alternatives) | |
| Operation and Maintenance Cost | $ 93,945,998 |
| **Life-Cycle Cost** | **$ 93,645,998** |
| | |
| **Permeable Interlocking Concrete Pavement** | |
| Capital Costs | |
| Operation and Maintenance Cost | $ 89,235,829 |
| **Life-Cycle Cost** | **$ 89,235,829** |
| | |
| **Life-Cycle Cost Savings (Permeable Pavement)** | **$ 4,239,152** |

## 3. Pollutant Removal

***Description:*** Achieve similar design pollutant removal efficiencies for total suspended solids (TSS), total phosphorus, total nitrogen, metals, and/or oils.

***Benefit:*** Provides and alternative method for removal of pollutants and achieving water quality requirements.

***Key Issues:*** Removal of suspended solids, other chemicals and heavy metals.

| | Cost (USD) | Unit | Frequency |
|---|---|---|---|
| Tier 1 Pollutant Level Target (0.1 mg/l) | $ 5,850 | M Gallons | Day |
| Tier 2 Pollutant Level Target (1 mg/l) | $ 1,350 | M Gallons | Day |
| | | | |
| | | | |

***Relevant for:*** Urban, Rural, Old/New municipalities, New Developments, Cities within proximity of large bodies of water, Infrastructure (old/new)

***References:***


1. Ohio Environmental Protection Agency, *Cost Estimate of Phosphorous Removal at Wastewater Treatment Plants*, A Technical Support Document prepared by Tetra Tech., May 2013. http://epa.ohio.gov/Portals/35/wqs/nutrient_tag/OhioTSDNutrientRemovalCostEstimate_05_06_13.pdf.


### *Example of Use*

Water flow reductions to the wastewater treatment plant will reduce the cost of achieving the desired effluent pollutant level targets.

**Existing Features:**

- Small size community stormwater plant. Capacity = 10 million gallons per day.

**PICP LCCA Example Assumption:**

1. Typical plant operation period = 25 years
2. Permeable pavements reduce plant water volume by 5 percent annually.
3. Tier 2 pollutant level target operating cost savings of $1,350/M gallons treated
4. Discount rate = 5 percent

**Life-cycle Cost Analysis Results:**

| Element | Life-cycle Cost |
|---|---|
| **Asphalt Concrete Pavement** | |
| Capital Costs (same for both alternatives) | $ 0 |
| Operation and Maintenance Cost | $ 84,551,398 |
| **Life-Cycle Cost** | **$ 84,551,398** |
| | |
| **Permeable Interlocking Concrete Pavement** | |
| Capital Costs | $ 0 |
| Operation and Maintenance Cost | $ 80,312,246 |
| **Life-Cycle Cost** | **$ 80,312,246** |
| | |
| **Life-Cycle Cost Savings (Permeable Pavement)** | **$ 4,239,152** |

## 4. Winter Maintenance

***Description:*** Yearly practice of deicing, sanding and plowing operations associated with snowfall, icing during freezing temperatures.

***Benefit:*** Permeable pavers offer a potential savings in reduced winter maintenance costs compared to conventional pavements.

***Key Issues:*** Land use, Maintenance

| | Units | Cost (USD) | Frequency |
|---|---|---|---|
| Snow clearing, salting and sanding | Per 2 lane mile | $ 4,715 | Annual |

***Relevant for:*** Urban, Rural, Old/New municipalities, New Developments, Old/New Infrastructure

***References:***


1. City of Minnesota. *Winter Maintenance Report at a Glance, Transportation Services.* 2016 Retrieved from https://www.dot.state.mn.us/maintenance/pdf/AtaGlance2016.pdf.
2. Transport Canada, *Representative Annualized Capital and Maintenance Costs of Roads by Functional Class*, Applied Research Associates, Inc., March 2006. http://lexcellenceaunprix.org/wp-content/uploads/01_Revised_final_report-Transport-Canada.pdf.
3. Minnesota Department of Natural Resources. *Historical Climate Data.* https://www.dnr.state.mn.us/climate/twin_cities/snow_event_counts.html.


### *Example of Use*

The use of permeable pavements may reduce the frequency of snow removal events and requirement for deicing chemicals.

**Existing Features:**

- 2 lane urban low volume roadway, 10.5 miles in length

**PICP LCCA Example Assumption:**

1. No capital costs
2. Reduced snow removal events requiring salting/sanding/plowing from to 12 to 8 (reduction in maintenance of one third.
3. Discount rate = 5 percent

**Life-cycle Cost Analysis Results:**

| Element | Life-cycle Cost |
|---|---|
| **Asphalt Concrete Pavement** | |
| Capital Costs | $ 0 |
| Operation and Maintenance Cost | $ 849,503 |
| **Life-Cycle Cost** | **$ 849,503** |
| | |
| **Permeable Interlocking Concrete Pavement** | |
| Capital Costs | $ 0 |
| Operation and Maintenance Cost | $ 569,338 |
| **Life-Cycle Cost** | **$ 569,338** |
| | |
| **Life-Cycle Cost Savings (Permeable Pavement)** | **$ 280,165** |

## 5. Roadway Paint Marking

**Description:** Process of repainting and or replacing lanes marking and other safety markings in order to sustain the safety and awareness of commuters.

**Benefit:** Permeable pavers offer potential to reduce maintenance costs for pavement and crosswalks as colored pavers can be used in lieu of paint or thermoplastic markings/

**Key Issues:** Maintenance, operating costs

| | Cost (USD) | Unit | Frequency (years) |
|---|---|---|---|
| *Material* | | | |
| Paint | $0.03-$0.05 | LF | 1 |
| Epoxy Paint | $0.20-$0.30 | LF | 4 |
| Thermoplastic | $0.19-$0.26 | LF | 6 (depending on seasons) |
| Preformed Tape | $1.50-$2.65 | LF | 4-8 |
| Incremental Color Paver Cost | $ 0.08 | LF | 25 |

**Relevant for:** Urban, Rural; Old/New municipalities, New Developments, Old/New Infrastructure

**References:**


1. Montebello, P.E. and Schroeder, MP. *Cost of Pavement Marking Materials*. Minnesota Department of Transportation. March 2000. https://www.lrrb.org/pdf/200011.pdf.


### Example of Use

The use of colored pavers provides "permanent" paving markings which results in reduced operations and maintenance costs. The incremental cost for pavers assumes that the cost of paver replacement is included under the pavement maintenance item and that only the incremental cost for pigment is included in this item.

**Existing Features:**

- Road, 10.5 centerline miles in length.
- Centerline no passing solid double line.

**PICP LCCA Example Assumption:**

1. Double solid line stripping on ACP and colored pavers for PICP.
2. Annual painting frequency for conventional roadway lane marking.
3. Painting yearly for ACP
4. 25 year life for colored pavers.
5. Discount rate = 5 percent

**Life-cycle Cost Analysis Results:**

| Element | Life-cycle Cost |
|---|---|
| **Asphalt Concrete Pavement** | |
| Capital Costs | $ 0 |
| Operation and Maintenance Cost | $ 76,104 |
| **Life-Cycle Cost** | **$ 76,104** |
| | |
| **Permeable Interlocking Concrete Pavement** | |
| Capital Costs | $ 10,943 |
| Operation and Maintenance Cost | $ 0 |
| **Life-Cycle Cost** | **$ 10,943** |
| | |
| **Life-Cycle Cost Savings (Permeable Pavement)** | **$ 67,624** |

## 6. Traffic Calming Devices

| | |
|---|---|
| ***Description:*** Physical objects or designs that enhance safety of all commuters and reduction of traffic flow. |  |
| ***Benefit:*** Removal of annual cost of maintenance to traffic calming devices. | |
| ***Key Issues:*** Maintenance | |

| | Cost(USD) | Unit | Lifespan |
|---|---|---|---|
| *Material* | | | |
| Cost for Removable Rubber Speedbump | $ 2,000 | Per | 25 years |
| Install and Remove Rubber Speedbump | $300 | per | Seasonal |
| Permanent Asphalt Speed Bump w/labor | $3,000 | per | 25 years |
| Cost for Traffic Calming for Paver Systems | $ 0 | per | 25 years |

***Relevant for:*** Arterial and Local roads

***References:***


1. City of Toronto. *Traffic Calming Guide for Toronto*, Transportation Services. 2016. Retrieved from: https://www.toronto.ca/legdocs/mmis/2016/pw/bgrd/backgroundfile-94207.pdf.


### *Example of Use*

The use of colored pavers provides "permanent" paving markings which results in reduced operations and maintenance costs.

**Existing Features:**

- 10.5 mile low volume urban roadway.
- 2 asphalt speed bumps/mile.

**PICP LCCA Example Assumption:**

1. No damage to speed bump over 25-year life-cycle.
2. Paver surface provides required traffic calming.
3. No maintenance costs.
4. Discount rate = 5 percent.

**Life-cycle Cost Analysis Results:**

| Element | Life-cycle Cost |
|---|---|
| **Asphalt Concrete Pavement** | |
| Capital Costs | $ 63,000 |
| Operation and Maintenance Cost | $ 0 |
| **Life-Cycle Cost** | **$ 63,000** |
| | |
| **Permeable Interlocking Concrete Pavement** | |
| Capital Costs | $ 0 |
| Operation and Maintenance Cost | $ 0 |
| **Life-Cycle Cost** | **$ 0** |
| | |
| **Life-Cycle Cost Savings (Permeable Pavement)** | **$ 63,000** |

## 7. Impervious Surface Fee

***Description:*** The amount of impervious surfaces on a land mass whereby a fee is taken to compensate for runoff water treatment

***Benefit:*** Permeable pavers offer a system of permeability that would reduce the cost of impervious surface fees as this can be substituted for paved driveways and patios.

***Key Issues:*** runoff to limited capacity for storm sewers

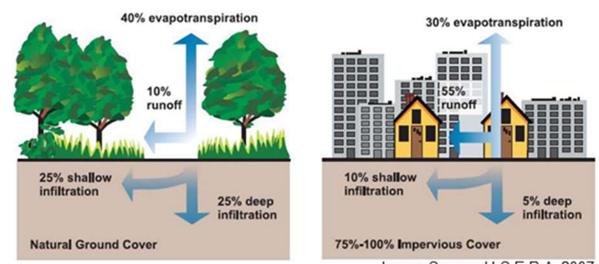


Image Source: U.S E.P.A, 2007

| | Cost(USD) | Unit | Frequency |
|---|---|---|---|
| *Flat Monthly Fee for Impervious Surfaces (varies on location)* | $43.91 | Per 1,000 sq ft. | Month |

***Relevant for:*** large, medium & small building, land coverage, runoff water

***References:***


1. City of Marysville. Surface Water Billing, Water Management. January 2018. Retrieved from http://marysvillewa.gov/296/Surface-Water-Billing-FAQ.
2. U.S. Shopping-Center Classification and Characteristics, ICSC Research and CoStar Realty Information, Inc. https://www.icsc.org/uploads/research/general/US_CENTER_CLASSIFICATION.pdf


### *Example of Use*

Many agencies are charging an impervious surface fee to compensate for runoff water treatment.

**Existing Features:**

- Average regional shopping mall complex area, 50 acres.
- Parking area, 50 % of overall land area.
- 50 percent of parking area (544,500 $ft^2$) is constructed as a permeable pavement. The remaining area has an asphalt concrete surface.

**PICP LCCA Example Assumption:**

1. Discount rate = 5 percent.
2.

**Life-cycle Cost Analysis Results:**

| **Element** | **Life-cycle Cost** |
|---|---|
| **Asphalt Concrete Pavement** | |
| Capital Costs | $ 2,567,015 |
| Pavement Operation and Maintenance Cost | $ 1,398,574 |
| Pervious Surface Fees | $ 4,923,078 |
| **Life-Cycle Cost** | **$ 8,888,667** |
| | |
| **Permeable Interlocking Concrete Pavement** | |
| Capital Costs | $ 5,608,350 |
| Pavement Operation and Maintenance Cost | $ 276,661 |
| Pervious Surface Fees | $ 0 |
| **Life-Cycle Cost** | **$ 5,885,011** |
| | |
| **Life-Cycle Cost Savings (Permeable Pavement)** | **$ 3,003,656** |

## 8. Utility Cut Restoration

| | |
|---|---|
| ***Description:*** Necessary cuts into road surfaces to repair install or remove telecommunications, hydro and water lines which then requires a patch followed by a permanent repair. |  |
| ***Benefit:*** Many agencies have documented the reduction in pavement service life caused by utility cuts in the pavement no matter how well the pavement is restored. The pavement surface related cost of the utility cut includes the cost to remove and replace the pavement surface and dispose of the removed materials. For interlocking concrete pavements, the pavement surface related cost includes only the removal, cleaning and replacement of the interlocking concrete pavement. For other materials, the cost includes removal and disposal of the pavement surface followed by the placement of new material to replace that removed. | |
| ***Key Issues:*** Degradation, maintenance, | |

| | Cost(USD) | Unit | Measurements |
|---|---|---|---|
| *Pavement Degradation Fee* | $2.00 | Per Sq.ft | Once |
| | | | |

***Relevant for:*** road, sidewalks, urban, rural

***References:***


1. City of Toronto. *Improvements to the Utility Cut Management Process.* Transportation Services. February 2010.Retrieved from: https://www.toronto.ca/legdocs/mmis/2010/pw/bgrd/backgroundfile-27579.pdf.


### *Example of Use*

Utility cuts for conventional pavements result and a reduced quality of pavement surface which will reduce the overall life span of the pavement. Many agencies have instituted a pavement degradation fee which is intended to account for this reduction in pavement life. Access to utilities for paver surfaced pavements can be achieved by removing the pavers, accessing the utility re-using and/or replacing the pavers with no resulting degradation to pavement life.

**Existing Features:**

- Road, 10.5 centerline miles in length.

**PICP LCCA Example Assumption:**

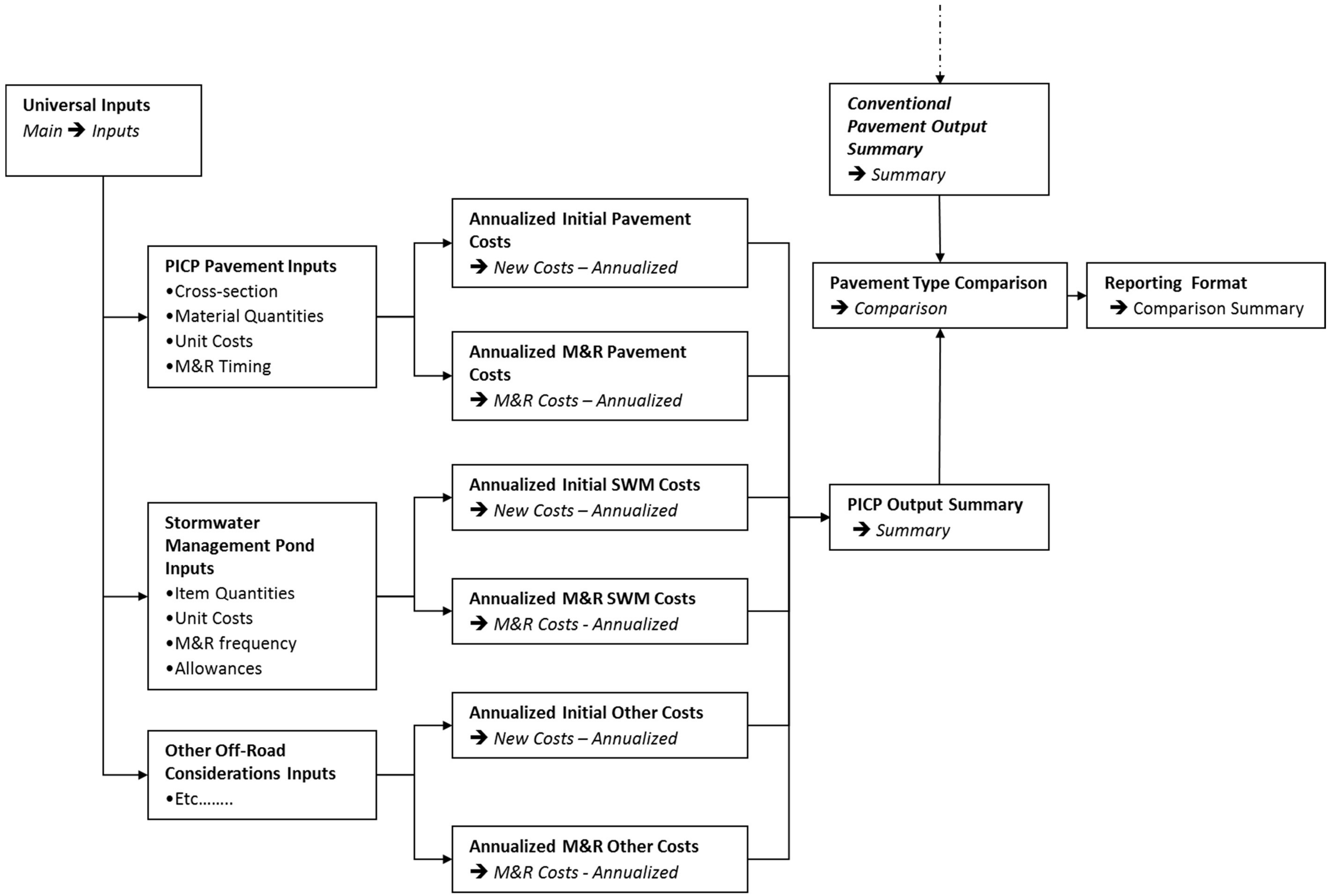
1. Discount rate = 5 percent.
2. Urban roadway.
3. 2 utility cuts/year per mile per year.
4. 40 $ft^2$ average utility cut size.
5. Surface removed, disposed of and replaced with new asphalt for ACP.
6. Surface removed, pavers cleaned and reinstalled for PICP.
7. Pavement degradation fee of \$2/$ft^2$ for ACP only.

**Life-cycle Cost Analysis Results:**

| Element | Life-cycle Cost |
|---|---|
| **Asphalt Concrete Pavement** | |
| Capital Costs | $ 0 |
| Operation and Maintenance Cost | $ 93,689 |
| **Life-Cycle Cost** | **$ 93,689** |
| | |
| **Permeable Interlocking Concrete Pavement** | |
| Capital Costs | $ 0 |
| Operation and Maintenance Cost | $ 72,068 |
| **Life-Cycle Cost** | **$ 72,068** |
| | |
| **Life-Cycle Cost Savings (Permeable Pavement)** | **$ 21,620** |

*Appendix B*

# Life-Cycle Cost Analysis Flow Chart


Universal Inputs
Main ➔ Inputs
PICP Pavement Inputs
•Cross-section
•Material Quantities
•Unit Costs
•M&R Timing
Stormwater Management Pond Inputs
•Item Quantities
•Unit Costs
•M&R frequency
•Allowances
Other Off-Road Considerations Inputs
•Etc……..
Annualized Initial Pavement Costs
➔ New Costs – Annualized
Annualized M&R Pavement Costs
➔ M&R Costs – Annualized
Annualized Initial SWM Costs
➔ New Costs – Annualized
Annualized M&R SWM Costs
➔ M&R Costs - Annualized
Annualized Initial Other Costs
➔ New Costs – Annualized
Annualized M&R Other Costs
➔ M&R Costs - Annualized
Conventional Pavement Output Summary
➔ Summary
Pavement Type Comparison
➔ Comparison
Reporting Format
➔ Comparison Summary
PICP Output Summary
➔ Summary