USER MANUAL

COTPP – COST OPTIMIZATION TOOL FOR PERMEABLE PAVEMENTS

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AUBURN UNIVERSITY

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"This is a free user-friendly and accessible tool for the design and cost optimization of permeable pavements"

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INTRODUCTION

Tool Description

The product described in this manual is a Tool named COTPP that helps design and optimize costs of permeable pavements. The types of permeable pavements considered are the (3) three main types: Pervious Concrete (PC), Porous Asphalt (PA), and Permeable Interlocking Concrete Pavers (PICP). It also includes other green infrastructures such as Bioretention and Infiltration Trench and conventional pavement practices such as Hot Mix Asphalt (HMA), Portland Cement Concrete (PCC), and Interlocking Concrete Pavers (ICP), only used in the cost optimization algorithm.

Benefits and Value

Value and benefits provided by the COTPP are:

- It includes the most appropriate structural and hydrological design methods among all the non-standardized industry methods for permeable pavement design.
- It helps design the (3) three main types of permeable pavements simultaneously, which reduces the need for multiple different design tools or manual design and accelerates the design process.
- It includes a cost optimization algorithm developed to help optimize the costs of permeable pavements. This will benefit municipalities, owner agencies, and design professionals in general during the planning stage by helping achieve cost optimization of permeable pavement systems for stormwater management.
- It is user-friendly and accessible because it was developed in a Microsoft Excel format, which is a computing tool that is available to most design engineers and decision makers. This will help reduce the need to invest in and learn complex modeling or optimization packages.

Platform Requirements

All the supported Windows operating systems in which Microsoft Excel can be downloaded.

Keywords

Permeable pavement, pervious concrete, porous asphalt, permeable interlocking concrete pavers, pavement design, cost optimization.

The COTPP is an Excel spreadsheet-based tool composed of six (6) different worksheet Tabs that perform various activities to achieve the design and cost optimization of permeable pavements.

Worksheet Tabs

(1) User Interface Tab: This is the main worksheet Tab of the COTPP that allows the user to enter most of the parameters required for the design and cost optimization of permeable pavements as well as to view the final results.

(2) Detailed Inputs Tab: This is the second worksheet Tab of the COTPP that allows the user to change default input values (usually fixed) to adapt to their specific project. The user can also enter construction cost data for the cost optimization process. It is the last tab where changes can be by the user.

(3) Concrete Tab: This third worksheet Tab contains the spreadsheet developed for the design of Pervious Concrete (PC).

(4) Asphalt Tab: This fourth worksheet Tab contains the spreadsheet developed for the design of Porous Asphalt (PA).

(5) PICP Tab: This fifth worksheet Tab contains the spreadsheet developed for the design of Permeable Interlocking Concrete Pavers (PICP).

(6) Optimization Tab: This sixth worksheet Tab contains the optimization algorithm Spreadsheet developed for the cost optimization of permeable pavements.

1. USER INTERFACE TAB

This worksheet represents the main Tab where the user enters all necessary inputs for the design and receives the outputs. It is one of the two worksheets that allow the user to make changes. It contains four (5) parts that only display the most important parameters needed by the designer / engineer when using the COTPP:

1-1. General Information and Permeable Pavement Inputs

This is where the user can enter general information of the project and inputs values for the design of permeable pavements. The user should click on the "Run" button to perform the design.

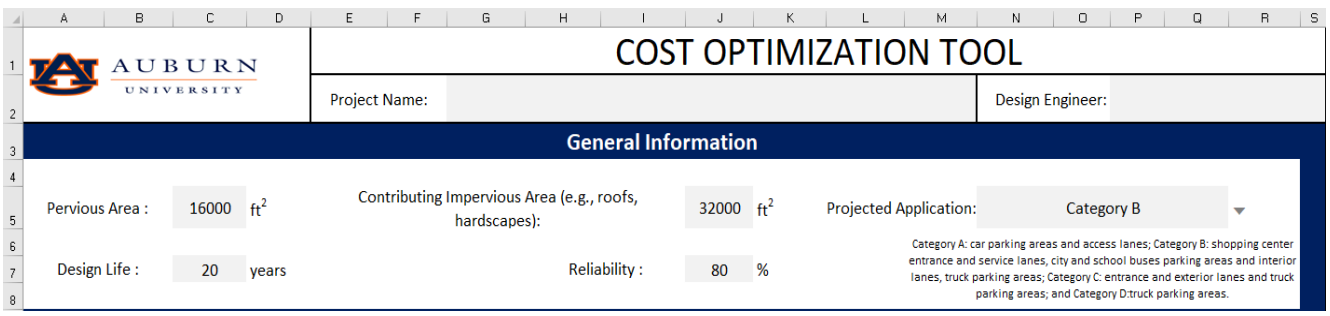
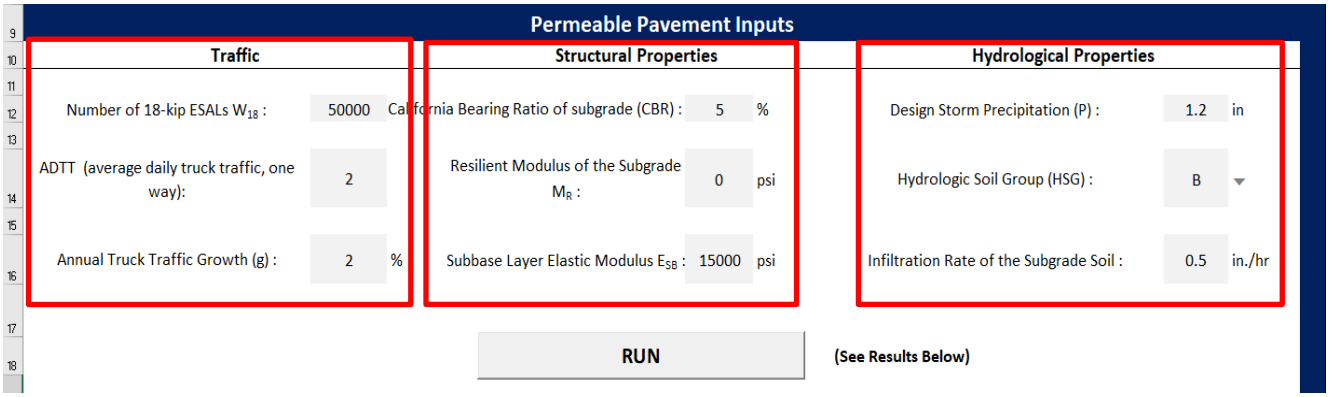


Figure 1. General Information Section

The general information section requires the following inputs:

- **Pervious area** (ft^2) – represents the total surface area of the project site intended to use as permeable pavements.
- **Contributing impervious area** (ft^2) – represents the sum of all small adjacent impervious areas such as impermeable driving lanes or rooftops from which the pervious area receives runoff.
- **Projected application** – represents the type or category of project that the design is done for. This is particularly important for the structural design of Pervious Concrete where traffic data provided by the American Concrete Institute are loaded based on the traffic category selected. The data are used for the calculations of the total number of load applications for each axle type. There are four (4) categories considered.
    - Category A: car parking areas and access lanes;
    - Category B: shopping center entrance and service lanes, city and school buses parking areas and interior lanes, truck parking areas;
    - Category C: entrance and exterior lanes and truck parking areas; and
    - Category D: truck parking areas.
- **Design life** (years) – represents the expected lifespan of the permeable pavement.
- **Reliability** (%) – represents the probability that the permeable pavement designed using the process will perform satisfactorily during the design life.



Permeable Pavement Inputs							
Traffic			Structural Properties			Hydrological Properties		
Number of 18-kip ESALs W_{18} :	50000		California Bearing Ratio of subgrade (CBR) :	5	%	Design Storm Precipitation (P) :	1.2	in
ADTT (average daily truck traffic, one way):	2		Resilient Modulus of the Subgrade M_R :	0	psi	Hydrologic Soil Group (HSG) :	B	
Annual Truck Traffic Growth (g) :	2	%	Subbase Layer Elastic Modulus E_{SB} :	15000	psi	Infiltration Rate of the Subgrade Soil :	0.5	in./hr
			RUN			(See Results Below)		

Figure 2. Permeable Pavement Inputs Section

The permeable pavement inputs section requires the following inputs:

- **Traffic**
  - **Number of 18-kip ESALs W_{18}** – represents the design traffic loading (quantified in terms of 18-kips equivalent single axle loads (ESALs)). This input is used in the structural design of PA and PICP only.
  - **ADTT (average daily truck traffic, one way)** – represents the design traffic loading used in the structural design of PC only.
  - **Annual truck traffic growth** (%) – represents the growth rate of annual truck traffic used for the estimation of future traffic for the structural design of PC only.
- **Structural properties**
  - **California bearing ratio of subgrade (CBR)** (%) – represents a measure of the strength of the subgrade. It is used to predict the subgrade resilient modulus. The minimum CBR value of 4% is recommended for the design of permeable pavement (Weiss et al., 2017).
  - **Resilient modulus of the subgrade M_R** (psi) – represents a measure of subgrade material stiffness needed for the structural design of PC, PA, and PICP.
  - **Subbase layer elastic modulus E_{SB}** (psi) – represents a measure of subbase material stiffness needed for the structural design of PC, PA, and PICP.
- **Hydrological properties**
  - **Design storm precipitation (P)** (in.) – represents the depth of rainfall uniformly distributed over the watershed area during a storm of a specific duration. The use of precipitation of 24 hours storm is recommended for the hydrological design of permeable pavement (Leming et al., 2007).
  - **Hydrologic soil group (HSG)** – represents the classification of subgrade soils in groups based on their runoff potential under similar storm conditions. There are four (4) groups (HSG A, B, C, and D). HSG A soils are well to excessively well drained while HSG D soils are poorly drained. HSG A and B are recommended for permeable pavement (NRCS, 1986). HSG C and D should be avoided (Dylewski et al., n.d.).

- **Infiltration rate of the subgrade soil** (in./hr.) – represents the velocity of water flowing into the subgrade soil. The minimum acceptable infiltration rate is 0.5 in./hr. (Dylewski et al. n. d.; City of Birmingham, 2019).

1-2. Permeable Pavement Outputs

In the permeable pavement outputs section, the design results for each type of permeable pavement are displayed. The results are provided in terms of dimensions of the surface layer, bedding layer, and base/subbase layer, rounded to the nearest 0.25 inches. The overall construction cost for each type of permeable pavement is shown and the least expensive or most economical is recommended.

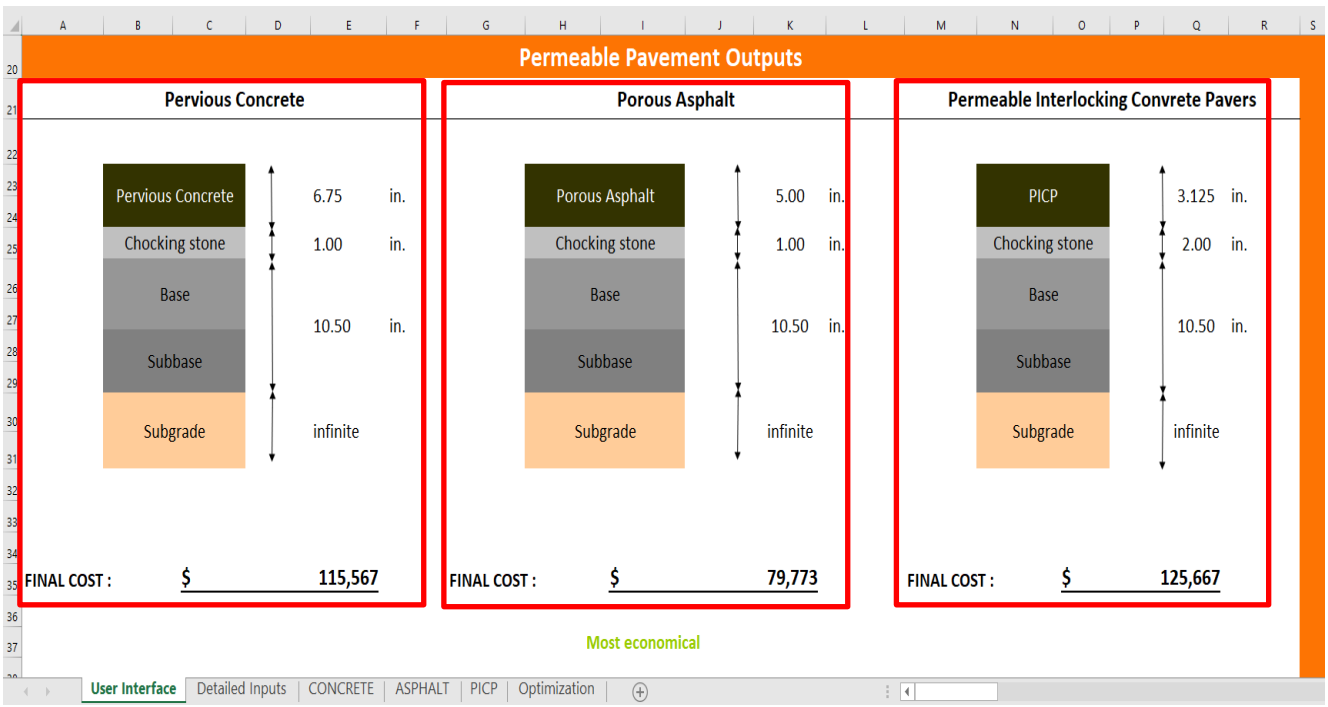


Figure 3. Permeable Pavement Outputs Section

1-3. Optimization Inputs

This section allows the user to choose the types of permeable pavement, conventional pavement, and other GI that is suitable for the optimization analysis. The optimization algorithm is similar to a heuristic search and consists of combining permeable pavements with other green infrastructures (Option A), with conventional pavements (Option B), or all three (3) together (Option C) to select the most cost-effective option. For that, certain criteria, boundaries, or design constraints must be established by the user based on their project needs for the optimization to occur. In the optimization algorithm, 10,000 trials are performed within the design boundaries specified by the user in the optimization inputs section shown below.

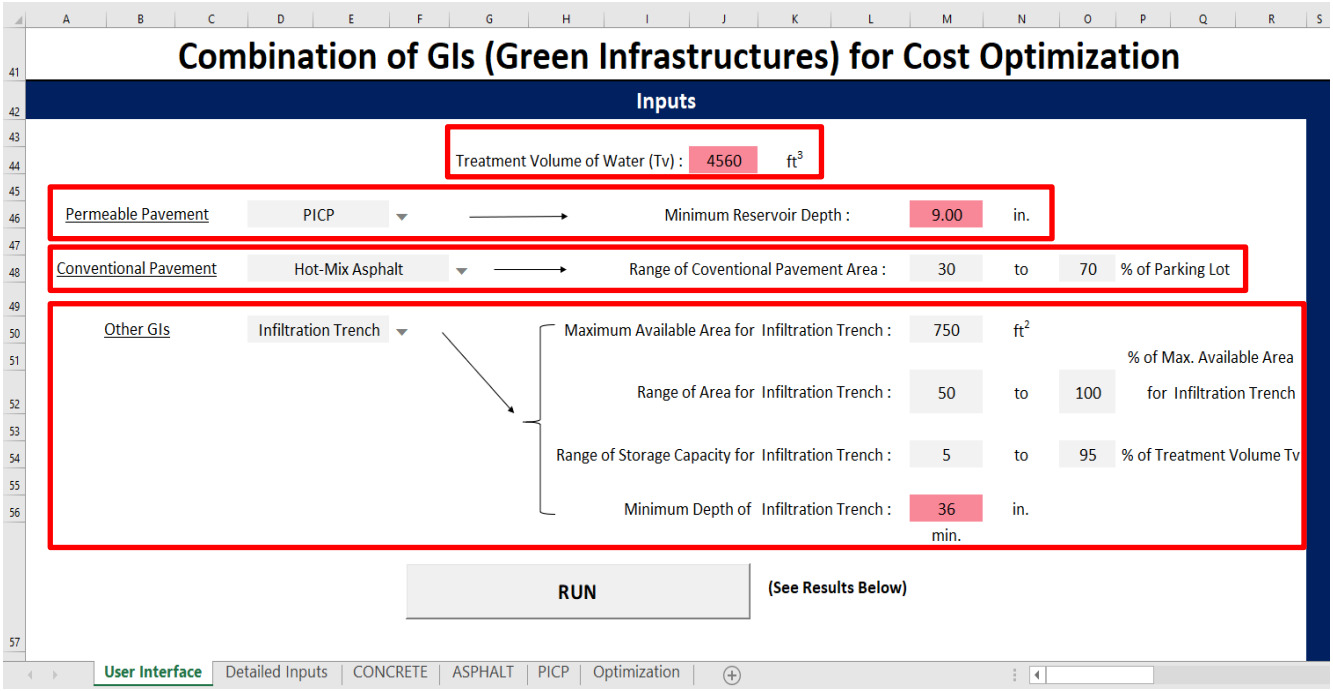


Figure 4. Optimization Inputs Section

The optimization inputs section requires the following inputs:

- **Treatment volume of water (Tv)** (ft^3) – represents the total runoff volume to be stored and treated by the permeable pavement. This value cannot be changed in this section. To modify this value, the user must change the appropriate hydrological properties in the "Permeable Pavement Inputs Section".
- **Permeable pavement** – user is asked to select a type or permeable pavement for the optimization process in Options A, B, and C. The 3 options available are PC, PA, and PICP.
    - **Minimum reservoir depth** (in) – represents the minimum thickness required for the type of permeable pavement selected. This is usually a fixed value that can only be changed in the "Structural Design Inputs Section" of the "Detailed Inputs Worksheet Tab".
- **Conventional pavement** – the user is asked to select a type or conventional pavement for the optimization process in Options A, and C. The 3 options available are HMA, PCC, and ICP.
    - **Range of conventional pavement area** (%) – user is asked to type in the range of conventional pavement surface area desired for their project as a function of the parking lot area or the initial permeable pavement surface area.
      e.g.: A user was originally planning to use an area of 16,000 ft^2 to build a fully permeable pavement parking lot. They decide to use the tool for cost optimization and desire to use between 10 and 50% of the initial permeable surface area of 16,000 ft^2 as conventional pavement.
- **Other GIs** – the user is asked to select a type or other green infrastructure for the optimization process in Options B, and C. The 2 options available are Bioretention and Infiltration Trench.
    - **Maximum available area for other GIs** (%) – user is asked to enter the maximum available area on the project site that can be occupied by the other GI selected.

e.g.: With a project site of 10,000 ft^2, the user can decide to use 8,000 ft^2 for the permeable pavement parking lot. This means that the remaining 2,000 ft^2 may be considered the maximum available area that the other GI can occupy.

- **Range of area for other GIs** (%) – user is asked to type in the desired range of area for "other GI" as a function of the maximum available area to occupy.

  e.g.: User can decide to only use between 50 and 80% of the maximum available area of 2,000 ft^2 mentioned in above example to install the other GI selected.

- **Range of storage capacity for other GIs** (%) – user is asked to enter a range of stormwater runoff storage capacity for the other GI selected as a function of the total treatment volume (Tv) calculated for the project site.

  e.g.: If the total treatment volume is 4,000 ft^3, the user can decide to store between 20% to 40% of that treatment volume in the storage of the other GI selected and the remaining will be stored in the reservoir layer of the permeable pavement selected.

- **Minimum depth of other GIs** (%) – represents the minimum storage depth required for the type of other GI selected. This is usually a fixed value, but it can be changed in the formula by double clicking in the cell.

1-4. Optimization Outputs

This is the last section of the user interface worksheet tab. In this section, the results of the optimization process are displayed. The results include the most economical design for each option (Option A, B, or C) with the recommended layer dimensions of each component and the overall construction cost. The user can compare final costs between optimization options and also compare to the cost of using only permeable pavement, which can be obtained from the "Permeable Pavement Outputs Section". The goal is to help the design professionals choose the most cost-effective design for their specific project. **NB:** since maintenance is the same for all types of permeable pavements, the COTPP only considers construction costs in the optimization algorithm. **HOWEVER, IT IS RECOMMENDED THAT, AFTER RUNNING THE COTPP, THE DESIGNER CONDUCTS A DETAILED DESIGN AND ASSESS THE MAINTENANCE COSTS OF THE OTHER PRACTICES (USED IN OPTIONS A, B, AND C) PRIOR TO MAKING A FINAL DECISION.** Some maintenance and rehabilitation costs for most components mentioned in this study can be found in the works of Rehan et al. (2018) and Olson et al. (2017). For detailed designs of the conventional pavements and the other GIs, the designer should consult the AASHTO 1993 method and the design manuals provided by the United States Environmental Protection Agency, respectively (EPA, 2023).

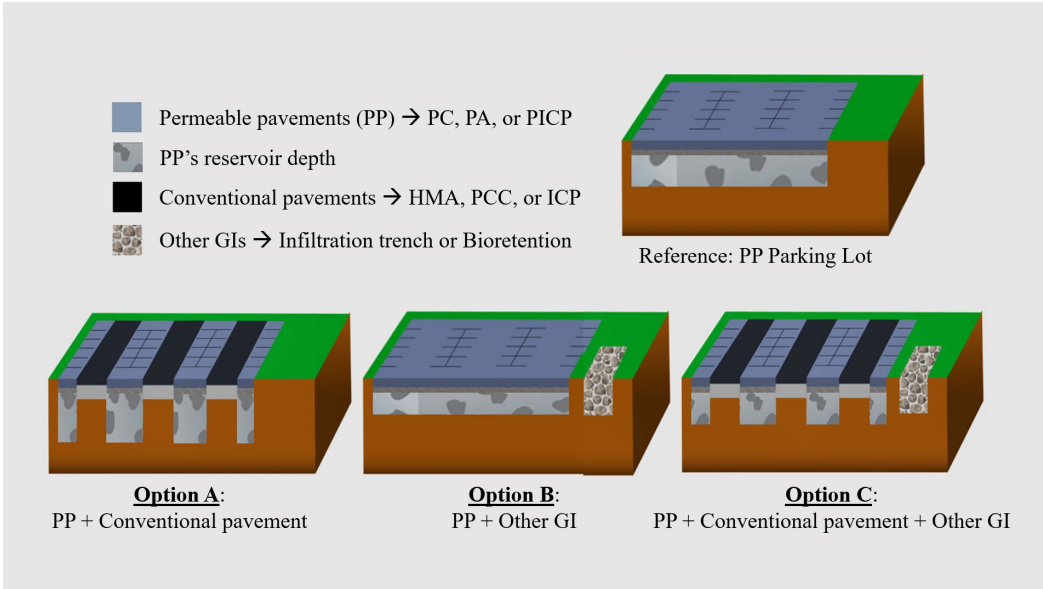


Figure 5. Options A, B and C

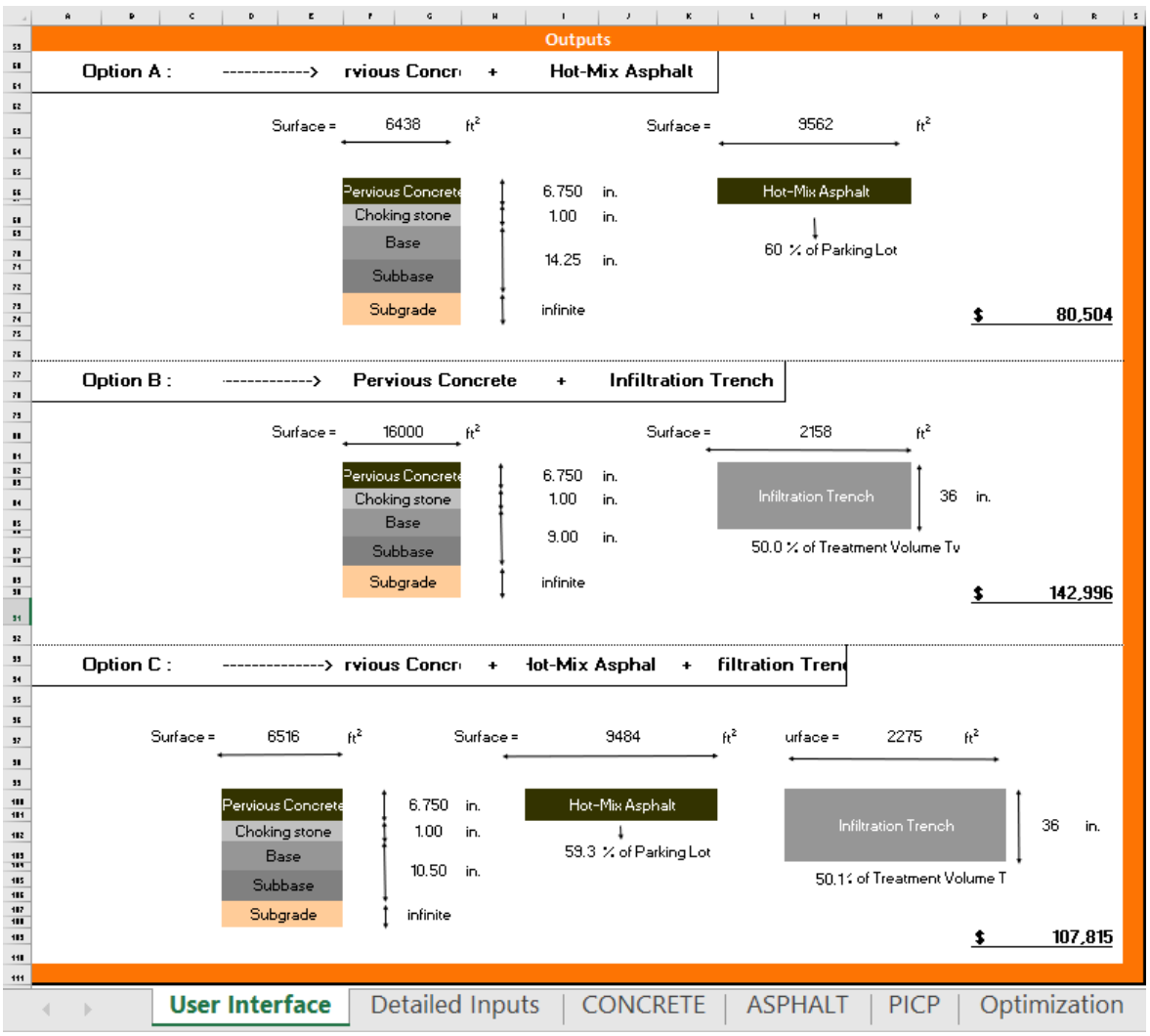


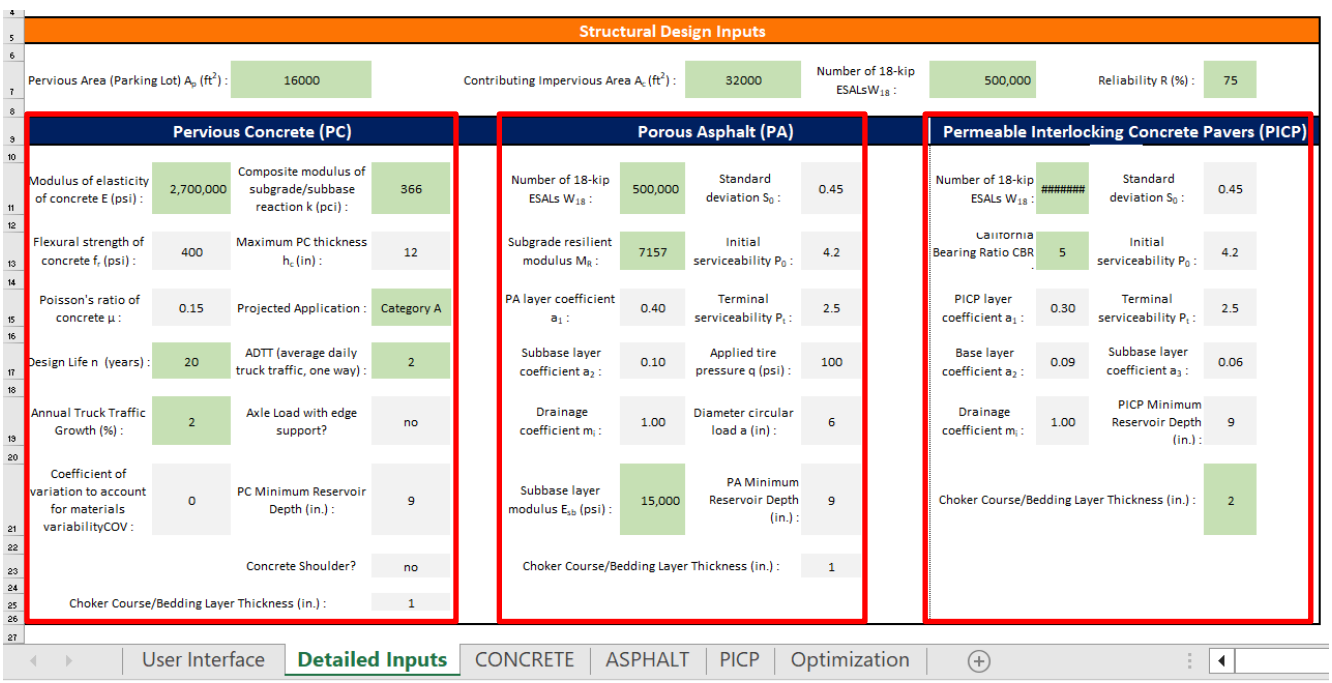
Figure 6. Optimization Outputs Section

2. DETAILED INPUTS TAB

This worksheet represents the Tab where all other secondary inputs that are not shown in the "User Interface Worksheet Tab" can be entered by the user. These inputs are default input values (usually fixed) that can be changed based on the needs of a specific project. This Tab is the last of the two worksheets that allow the user to make changes in the COTPP. It contains three (3) parts that are needed for the design of permeable pavements and construction cost calculations:

2-1. Structural Design Inputs

This first section is where the user can modify default structural design inputs used to determine the layers' thicknesses of each type of permeable pavements to support traffic loads. All the inputs highlighted in green are just duplicates of the same inputs entered in the "User Interface Worksheet Tab" sections, therefore these values should only be changed in the "User Interface Worksheet Tab".



Structural Design Inputs							
Pervious Area (Parking Lot) A_p (ft^2) :	16000	Contributing Impervious Area A_c (ft^2) :	32000	Number of 18-kip ESALs W_{18} :	500,000	Reliability R (%) :	75

Pervious Concrete (PC)				Porous Asphalt (PA)				Permeable Interlocking Concrete Pavers (PICP)			
Modulus of elasticity of concrete E (psi) :	2,700,000	Composite modulus of subgrade/subbase reaction k (pci) :	366	Number of 18-kip ESALs W_{18} :	500,000	Standard deviation S_0 :	0.45	Number of 18-kip ESALs W_{18} :	#######	Standard deviation S_0 :	0.45
Flexural strength of concrete f_r (psi) :	400	Maximum PC thickness h_c (in) :	12	Subgrade resilient modulus M_R :	7157	Initial serviceability P_0 :	4.2	California Bearing Ratio CBR	5	Initial serviceability P_0 :	4.2
Poisson's ratio of concrete μ :	0.15	Projected Application :	Category A	PA layer coefficient a_1 :	0.40	Terminal serviceability P_t :	2.5	PICP layer coefficient a_1 :	0.30	Terminal serviceability P_t :	2.5
Design Life n (years) :	20	ADTT (average daily truck traffic, one way) :	2	Subbase layer coefficient a_2 :	0.10	Applied tire pressure q (psi) :	100	Base layer coefficient a_2 :	0.09	Subbase layer coefficient a_3 :	0.06
Annual Truck Traffic Growth (%) :	2	Axle Load with edge support?	no	Drainage coefficient m_i :	1.00	Diameter circular load a (in) :	6	Drainage coefficient m_i :	1.00	PICP Minimum Reservoir Depth (in.) :	9
Coefficient of variation to account for materials variabilityCOV :	0	PC Minimum Reservoir Depth (in.) :	9	Subbase layer modulus E_{sb} (psi) :	15,000	PA Minimum Reservoir Depth (in.) :	9	Choker Course/Bedding Layer Thickness (in.) :	2		
		Concrete Shoulder?	no	Choker Course/Bedding Layer Thickness (in.) :	1						
Choker Course/Bedding Layer Thickness (in.) :	1										

User Interface | Detailed Inputs | CONCRETE | ASPHALT | PICP | Optimization

Figure 7. Structural Design Inputs Section

The inputs highlighted in green were already defined in the Chapter 2 (User Interface) of this manual. Therefore, only the inputs that are not highlighted are discussed below:

- **Pervious concrete (PC)**
  - **Flexural strength of concrete fr** (psi) – represents a measure of the tensile strength of non-reinforced concrete used in the surface layer.
  - **Poisson's ratio of concrete μ** – represents the ratio of transverse strain to longitudinal strain in concrete – typically 0.15 (Rodden and Smith, 2011).

- **Coefficient of variation to account for materials variability COV** – represents the ratio of the standard deviation to the mean to account for materials variability.
- **Maximum PC thickness h_c** (in) – represents the maximum thickness allowed for the PC surface layer – typically 12in (Rodden and Smith, 2011).
- **Axle load with edge support**? – a Yes or No question verifying the presence of edge support such as concrete shoulders or curb and gutter sections to account for the structural impact. E.g., for parking lot applications, there is usually no edge support (Rodden and Smith, 2011).
- **PC minimum reservoir depth** (in) – represents the minimum base/subbase or reservoir thickness required for PC.
- **Concrete shoulder?** – a Yes or No question verifying the presence of concrete shoulders to account for the structural impact.
- **Choker course/bedding layer thickness** (in) – represents the bedding layer thickness desired for PC – typically 1 to 2in.

- **Porous asphalt (PA)**
  - **PA layer coefficient a_1** – represents the relative strength of the material used for PA surface layer – 0.40 was recommended by the National Asphalt Pavement Association (NAPA) (Schwartz & Hall, 2018).
  - **Subbase layer coefficient a_2** – represents the relative strength of the material used for PA subbase layer – a range between 0.07 and 0.10 was recommended NAPA (Schwartz & Hall, 2018).
  - **Drainage coefficient m_i** – drainage coefficient – typically 1.0 for PA (Schwartz & Hall, 2018).
  - **Standard deviation S_0** – 0.45 is the recommended standard deviation value for PA by NAPA (Schwartz & Hall, 2018).
  - **Initial serviceability P_0** – represents the serviceability index for pavement conditions immediately after construction.
  - **Terminal serviceability P_t** – represents the lowest serviceability index for pavement conditions tolerated at the end of the pavement performance period.
  - **Applied tire pressure q** (psi) – represents the load pressure applied at the PA surface layer – 100 psi is recommended by NAPA (Schwartz & Hall, 2018).
  - **Diameter circular load a** (in) – represents the diameter of the loading tire.
  - **PA minimum reservoir depth** (in) – represents the minimum base/subbase or reservoir thickness required for PA.
  - **Choker course/bedding layer thickness** (in) – represents the bedding layer thickness desired for PC – typically 1 to 2in.
- **Permeable Interlocking Concrete Pavers (PICP)**
  - **PICP layer coefficient a_1** – represents the relative strength of the material used for PICP surface layer – a value of 0.30 was recommend by the Interlocking Concrete Pavement Institute (ICPI) (Smith, 2012).

- **Base layer coefficient a_2** – represents the relative strength of the material used for PA subbase layer – a value of 0.09 can be assumed (Smith, 2012).
- **Drainage coefficient m_i** – drainage coefficient – typically 1.0 for PICP.
- **Initial serviceability P_0** – represents the serviceability index for pavement conditions immediately after construction.
- **Terminal serviceability P_t** – represents the lowest serviceability index for pavement conditions tolerated at the end of the pavement performance period.
- **Subbase layer coefficient a_3** – represents the relative strength of the material used for PA subbase layer – a value of 0.06 can be assumed (Smith, 2012).
- **PICP minimum reservoir depth** (in) – represents the minimum base/subbase or reservoir thickness required for PICP.

2-2. Hydrological Design Inputs

This section is where the user can modify default hydrological design inputs used to determine the reservoir thickness of each type of permeable pavements to support store and treat the stormwater runoff. All the inputs highlighted in green are just duplicates of the same inputs entered in the "User Interface Worksheet Tab" sections, therefore these values should only be changed in the "User Interface Worksheet Tab".

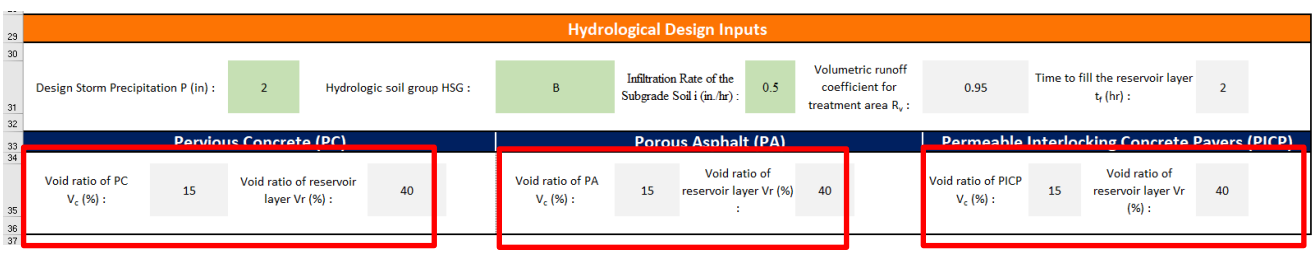


Figure 8. Hydrological Design Inputs Section

The inputs highlighted in green were already defined in the Chapter 2 (User Interface) of this manual. Therefore, only the inputs that are not highlighted are discussed below:

- **Volumetric runoff coefficient for treatment area Rv** – represents a measure of the percentage of precipitation expected to run off a specific land cover or group of land covers on an average annual basis. In this case, Rv is an important parameter to account for the runoff from the contributing impervious areas to the permeable pavement system. It is determined as a function of the land cover/HSG combination. Equation 1 from the city of Birmingham design manual shows how Rv can be calcuated. It is recommended to used Rv = 0.95 for combined impervious contributing areas such as impermeable driving lanes or rooftops (City of Birmingham, 2019).

$$Rv = \frac{(Rv_1 \times A_1) + (Rv_2 \times A_2) + \ldots (Rv_n \times A_n)}{(A_1 + A_2 + \ldots A_n)} \quad (1)$$

Where,
Rv = Rv for the combined contributing areas
Rv_n = Rv for a single land cover/HSG combination
A_n = area of a single land cover/HSG combination
The city of Birmingham design manual can be consulted to obtain Rv values for different land cover/HSG combinations.

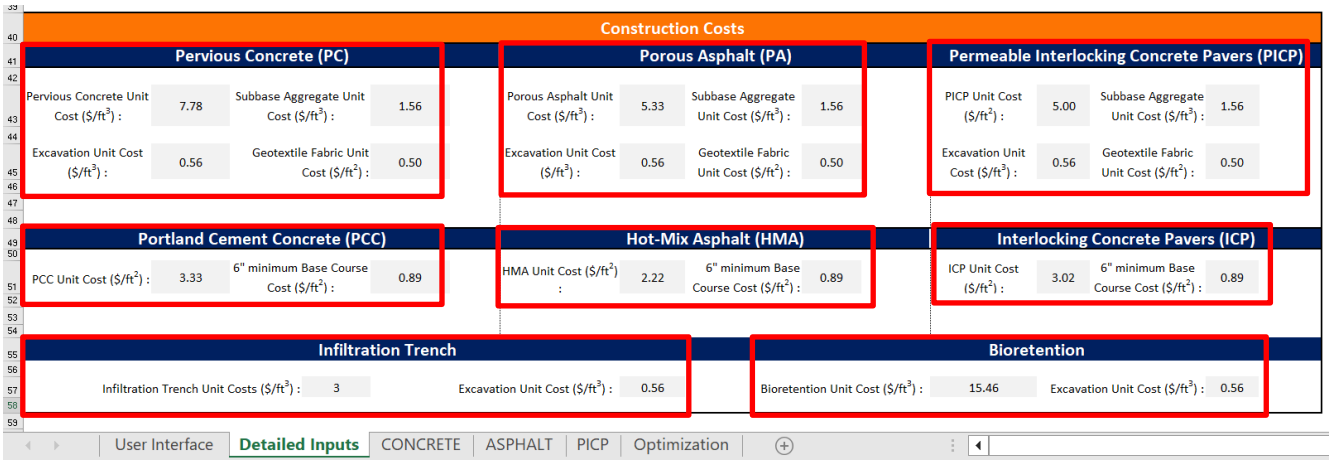
- **Time to fill the reservoir layer t_f** (hr) – represents the time desired for the runoff to fill the reservoir layer of the permeable pavement system – typically 2 hours or 0.083 day (City of Birmingham, 2019).
- **Pervious concrete (PC)**
  - **Void ratio of PC Vc** (%) – represents the ratio of the volume of voids in the PC surface layer to volume of solids – a range between 15 and 25% for PC (Dylewski et al., n.d.).
  - **Void ratio of reservoir layer Vr** (%) – represents the ratio of the volume of voids in the reservoir layer to volume of solids – typically 40% (City of Birmingham, 2019).
- **Porous asphalt (PA)**
  - **Void ratio of PA Vc** (%) – represents the ratio of the volume of voids in the PC surface layer to volume of solids – a range between 15 and 20% for PA (Dylewski et al., n.d.).
  - **Void ratio of reservoir layer Vr** (%) – represents the ratio of the volume of voids in the reservoir layer to volume of solids – typically 40% (City of Birmingham, 2019).
- **Permeable interlocking concrete pavers (PICP)**
  - **Void ratio of PICP Vc** (%) – represents the ratio of the volume of voids in the PC surface layer to volume of solids – a range between 8 and 20% for PICP (Dylewski et al., n.d.).
  - **Void ratio of reservoir layer Vr** (%) – represents the ratio of the volume of voids in the reservoir layer to volume of solids – typically 40% (City of Birmingham, 2019).

2-3. Construction Costs

This section is where the user can enter the unit costs of all the components used in the design and cost optimization process of the COTPP. For a more efficient optimization process, the user must obtain the most recent unit costs of each type of permeable pavements, conventional pavements, and other GIs. If the most recent costs are unknown, the user can use the costs provided by Biessan (2021), which are in dollars of previous years, and adjust them to dollars of the current year. This adjustment can be done for inflation using Equation 2 with the 20-city average value of Engineering News Record (ENR) Construction Cost Index (CCI) and for location to account for regional differences in construction costs (i.e., materials and labor) using Equation 3 with the most recent regional factors. The ENR CCI values for recent years can be found on the Engineering News Record website (ENR, 2023).

$$\text{Cost (present)} = \text{Cost (base year)} \times \frac{\text{ENRCCI (present)}}{\text{ENRCCI (base year)}} \qquad (2)$$

$$\text{Cost (regional)} = \text{Cost (national)} \times \frac{\text{ENRCCI (regional)}}{\text{ENRCCI (national)}} \qquad (3)$$



Construction Costs

Pervious Concrete (PC)			
Pervious Concrete Unit Cost ($/ft^3) :	7.78	Subbase Aggregate Unit Cost ($/ft^3) :	1.56
Excavation Unit Cost ($/ft^3) :	0.56	Geotextile Fabric Unit Cost ($/ft^2) :	0.50

Porous Asphalt (PA)			
Porous Asphalt Unit Cost ($/ft^3) :	5.33	Subbase Aggregate Unit Cost ($/ft^3) :	1.56
Excavation Unit Cost ($/ft^3) :	0.56	Geotextile Fabric Unit Cost ($/ft^2) :	0.50

Permeable Interlocking Concrete Pavers (PICP)			
PICP Unit Cost ($/ft^2) :	5.00	Subbase Aggregate Unit Cost ($/ft^3) :	1.56
Excavation Unit Cost ($/ft^3) :	0.56	Geotextile Fabric Unit Cost ($/ft^2) :	0.50

Portland Cement Concrete (PCC)			
PCC Unit Cost ($/ft^2) :	3.33	6" minimum Base Course Cost ($/ft^2) :	0.89

Hot-Mix Asphalt (HMA)			
HMA Unit Cost ($/ft^2) :	2.22	6" minimum Base Course Cost ($/ft^2) :	0.89

Interlocking Concrete Pavers (ICP)			
ICP Unit Cost ($/ft^2) :	3.02	6" minimum Base Course Cost ($/ft^2) :	0.89

Infiltration Trench			
Infiltration Trench Unit Costs ($/ft^3) :	3	Excavation Unit Cost ($/ft^3) :	0.56

Bioretention			
Bioretention Unit Cost ($/ft^3) :	15.46	Excavation Unit Cost ($/ft^3) :	0.56

User Interface | Detailed Inputs | CONCRETE | ASPHALT | PICP | Optimization

Figure 9. Construction Costs Section

The construction costs section requires the following inputs:

- **Pervious concrete (PC)**
  - **Pervious concrete unit cost** ($/ft^3) – represents cost per cubic foot of PC surface layer.
  - **Excavation unit cost** ($/ft^3) – represents cost per cubic foot of excavated soil.
  - **Subbase aggregate unit cost** ($/ft^3) – represents cost per cubic foot of PC subbase or reservoir layer.
  - **Geotextile fabric unit cost** ($/ft^2) – represents cost per square foot of geotextile fabric.
- **Porous asphalt (PA)**
  - **Porous asphalt unit cost** ($/ft^3) – represents cost per cubic foot of PA surface layer.
  - **Excavation unit cost** ($/ft^3) – represents cost per cubic foot of excavated soil.
  - **Subbase aggregate unit cost** ($/ft^3) – represents cost per cubic foot of PA subbase or reservoir layer.
  - **Geotextile fabric unit cost** ($/ft^2) – represents cost per square foot of geotextile fabric.
- **Permeable interlocking concrete pavers (PICP)**
  - **PICP unit cost** ($/ft^2) – represents cost per square foot of PICP surface layer because PICP have usually a fixed thickness of approximately 3.125in.
  - **Excavation unit cost** ($/ft^3) – represents cost per cubic foot of excavated soil.
  - **Subbase aggregate unit cost** ($/ft^3) – represents cost per cubic foot of PICP subbase or reservoir layer.
  - **Geotextile fabric unit cost** ($/ft^2) – represents cost per square foot of geotextile fabric.
- **Portland cement concrete (PCC)**
  - **PCC unit cost** ($/ft^2) – represents cost per square foot of PCC surface layer.

- **6" minimum base course cost** ($/ft^2) – represents cost per square foot of PCC base layer. The assumed thickness is 6in.

- **Hot-mix asphalt (HMA)**
  - **HMA unit cost** ($/ft^2) – represents cost per square foot of HMA surface layer.
  - **6" minimum base course cost** ($/ft^2) – represents cost per square foot of HMA base layer. The assumed thickness is 6in.
- **Interlocking concrete pavers (ICP)**
  - **ICP unit cost** ($/ft^2) – represents cost per square foot of HMA surface layer.
  - **6" minimum base course cost** ($/ft^2) – represents cost per square foot of ICP base layer. The assumed thickness is 6in.
- **Infiltration trench**
  - **Infiltration trench unit cost** ($/ft^3) – represents cost per cubic foot of infiltration trench storage or reservoir layer.
  - **Excavation unit cost** ($/ft^3) – represents cost per cubic foot of excavated soil.
- **Bioretention**
  - **Bioretention unit cost** ($/ft^3) – represents cost per cubic foot of bioretention storage or reservoir layer.
  - **Excavation unit cost** ($/ft^3) – represents cost per cubic foot of excavated soil.

3. CONCRETE TAB

This worksheet represents the Tab where the structural and hydrological designs of PC are performed using the inputs from the “User Interface” and “Detailed Inputs” worksheet tabs. The design process followed for calculations is provided by Biessan (2021). This worksheet is locked and can only be unlocked with a password created by the developer.

Pervious Concrete (PC)

CONSTRAINTS

Not intended to treat sites with high sediment of trash/debris loads
Setbacks: Water supply wells require 100' and Septic systems require 50'
Underdrain required when bedrock is less than 2' beneath the pavement surface
Site Topography: Slope should not be greater than 2%
Soils Requirement: HSG C or D requires an underdrain
Utility Requirement: Consider clearance for all utilities. Min. 5' from down-gradient wet utility lines
Water Table Requirement: Minimum of 2' separation from base layer
Soil infiltration rate should be greater than 0.5 in./hr
For design purposes, the native soil infiltration rate (I) shall be the field-tested soil infiltration rate divided by a factor of safety of 2. The minimum acceptable native soil infiltration rate is 0.5 inches/hr.

STRUCTURAL DESIGN

INPUTS

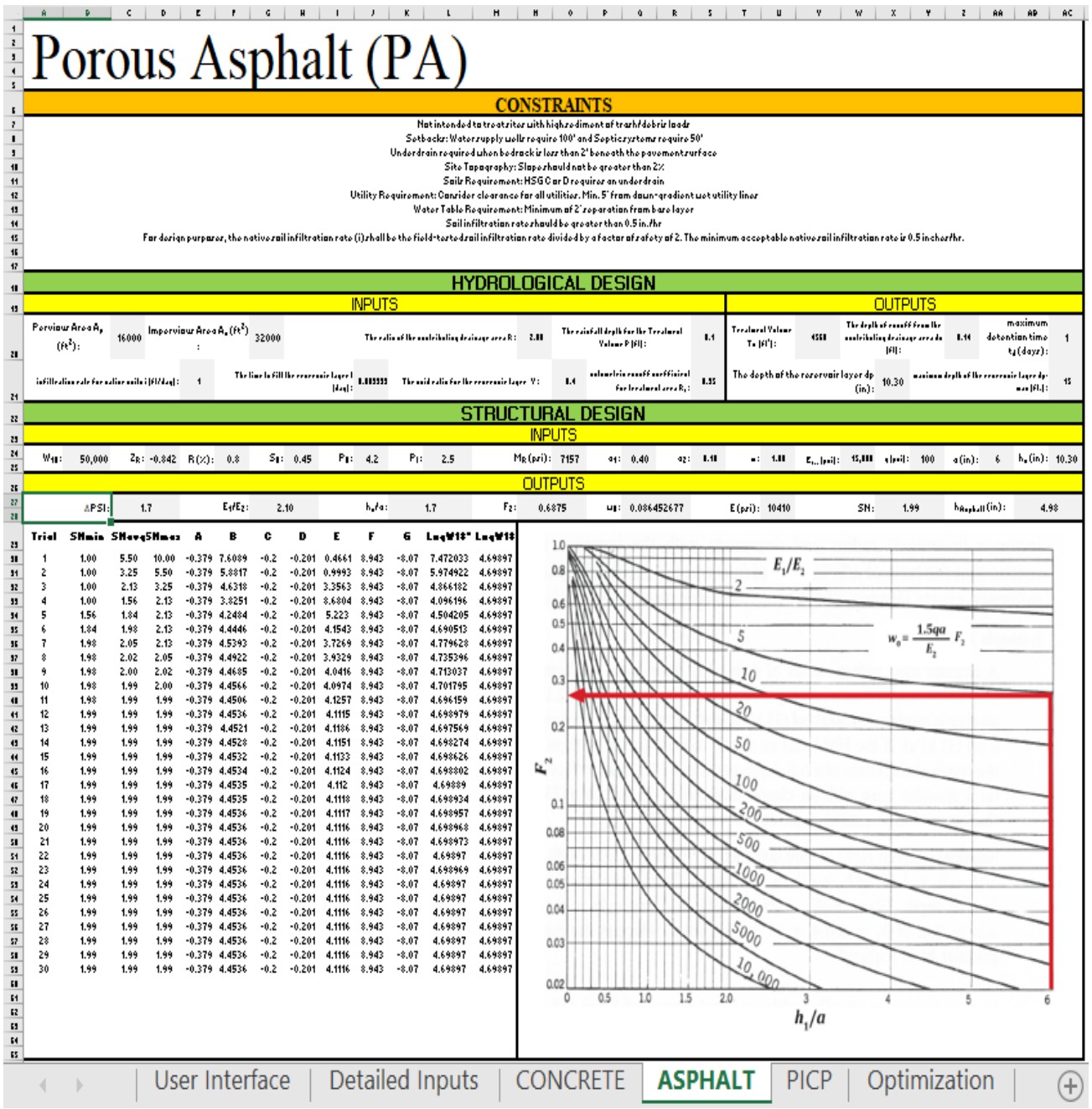
modulus of elasticity of the concrete E (psi):	2700000	Flexural Strength of the concrete f_c (psi):	400	composite modulus of subgrade/subbase reaction k (pci):	344	Poisson's ratio of the concrete:	0.15	Max. concrete pavement thickness h_p (in):	12	Reliability R (%):	0.8	coefficient of variation COV ?:	0	ADTT (average daily truc traffic, one way):	2	Percent Traffic on Design Section (%):	100	Annual Truck Traffic Growth (%):	2	Projected Application:	Category B	Concrete Shoulder?	no	Axle Load with edge support?	no					
												Design Life (years):	20					Growth Factor:	24.3	Design Traffic:	17737.1									

OUTPUTS

Radius of relative stiffness L (in)	percent slabs cracked at the end of pavement's life SC (assumed 15%)	Probability of Failure P (%)	Adjustment factor for the effect of axle loads and contact area I_1: SAL I_1	TAL I_1	TRAL I_1	Adjustment factor for a slab with no concrete shoulder I_2	adjustment factor to account for the effect of truck (wheel) placement at the slab edge (assumed for 6 percent trucks at the slab edge) I_3	adjustment factor to account for approximately 23.5% increase in concrete strength with age after the 28th day and reduction of one coefficient of variation (COV) to account for materials variability I_4	Equivalent Moment M_e (psi): for SAL	for TAL	for TRAL	Equivalent Stress σ_{eq} (psi): For SAL	For TAL	For TRAL	Stress Ratio SR: For SAL	For TAL	For TRAL	Allowable Load Applications to Failure N_f: For SAL	For TAL	For TRAL	Fatigue Damage FD: For SAL	For TAL	For TRAL	hc_{min}	hc_{avg}	hc_{max}	SUM	
23.05	0.15	0.998	1.23	1.02	0.98	0.96	0.894	0.81	2512.36	2034.53	1945.00	228.99	153.56	141.68	0.57	0.38	0.35	1.91E+11	2.60E+27	6.08E+32	3.11E-04	3.88E-21	0.00E+00	3.00	7.50	12.00	0.00	1.00
17.64	0.15	0.998	1.23	1.02	0.98	0.96	0.894	0.81	2041.95	1669.70	1700.45	379.82	257.19	252.79	0.95	0.64	0.63	4.62E+03	5.20E+08	1.14E+09	1.29E+04	1.95E-02	0.00E+00	3.00	5.25	7.50	12669.72	1.00
20.41	0.15	0.998	1.23	1.02	0.98	0.96	0.894	0.81	2230.64	1945.16	1831.99	288.97	192.75	184.71	0.72	0.48	0.46	5.34E+06	3.43E+16	1.54E+18	1.11E+01	2.30E-10	0.00E+00	5.25	6.38	7.50	11.13	1.00
21.74	0.15	0.998	1.23	1.02	0.98	0.96	0.894	0.81	2404.30	1938.52	1890.46	256.11	171.00	160.95	0.64	0.43	0.40	6.27E+08	3.88E+21	4.97E+24	9.45E-02	2.62E-15	0.00E+00	6.38	6.94	7.50	0.09	1.00
21.12	0.15	0.998	1.23	1.02	0.98	0.96	0.894	0.81	2351.58	1894.22	1863.47	270.76	180.61	171.48	0.68	0.45	0.43	5.95E+07	1.31E+19	2.82E+21	1.00E+00	7.73E-13	0.00E+00	6.67	6.67	6.67	1.00

4. ASPHALT TAB

This worksheet represents the Tab where the structural and hydrological designs of PA are performed using the inputs from the “User Interface” and “Detailed Inputs” worksheet tabs. The design process followed for calculations is provided by Biessan (2021). This worksheet is locked and can only be unlocked with a password created by the developer.



Porous Asphalt (PA)

CONSTRAINTS

Not intended to treat sites with high sediment or trash/debris loads
Setbacks: Water supply wells require 100' and Septic systems require 50'
Underdrain required when bedrock is less than 2' beneath the pavement surface
Site Topography: Slope should not be greater than 2%
Soils Requirement: HSG C or D require an underdrain
Utility Requirement: Consider clearance for all utilities. Min. 5' from down-gradient wet utility lines
Water Table Requirement: Minimum of 2' separation from bare layer
Soil infiltration rate should be greater than 0.5 in./hr
For design purposes, the native soil infiltration rate (i) shall be the field-tested soil infiltration rate divided by a factor of safety of 2. The minimum acceptable native soil infiltration rate is 0.5 inches/hr.

HYDROLOGICAL DESIGN

INPUTS

Pervious Area A_p (ft^2):	16000	Impervious Area A_a (ft^2):	32000	The ratio of the underlying drainage area R:	2.00	The rainfall depth for the Treatment Volume P [ft]:	0.1		
infiltration rate for native soils i [ft/day]:	1	The time to fill the reservoir layer t [day]:	0.000555	The void ratio for the reservoir layer V:	0.4	volumetric runoff coefficient for treatment area R_v:	0.95		

OUTPUTS

Treatment Volume T_v [ft^3]:	4560	The depth of runoff from the underlying drainage area d_u [ft]:	0.14	maximum detention time t_d (days):	1
The depth of the reservoir layer d_p (in):	10.20	maximum depth of the reservoir layer $d_{p,max}$ [ft.]:	15		

STRUCTURAL DESIGN

INPUTS

W_{18}:	50,000	Z_R:	-0.842	R (%):	0.8	S_0:	0.45	P_t:	4.2	P_i:	2.5	M_R (psi):	7157	α_1:	0.40	α_2:	0.10	m:	1.00	$E_{s,}$ [psi]:	15,000	γ [pci]:	100	a (in):	6	h_a (in):	10.20

OUTPUTS

ΔPSI:	1.7	E_1/E_2:	2.10	h_a/a:	1.7	F_2:	0.6875	w_0:	0.086452677	E (psi):	10410	SN:	1.99	$h_{Asphalt}$ (in):	4.98				

Trial	SNmin	SNavg	SNmax	A	B	C	D	E	F	G	LogW18*	LogW18
1	1.00	5.50	10.00	-0.379	7.6089	-0.2	-0.201	0.4661	8.943	-8.07	7.472033	4.69897
2	1.00	3.25	5.50	-0.379	5.8817	-0.2	-0.201	0.9993	8.943	-8.07	5.974922	4.69897
3	1.00	2.13	3.25	-0.379	4.6318	-0.2	-0.201	3.3563	8.943	-8.07	4.866182	4.69897
4	1.00	1.56	2.13	-0.379	3.8251	-0.2	-0.201	8.6804	8.943	-8.07	4.096196	4.69897
5	1.56	1.84	2.13	-0.379	4.2484	-0.2	-0.201	5.223	8.943	-8.07	4.504205	4.69897
6	1.84	1.98	2.13	-0.379	4.4446	-0.2	-0.201	4.1543	8.943	-8.07	4.690513	4.69897
7	1.98	2.05	2.13	-0.379	4.5393	-0.2	-0.201	3.7269	8.943	-8.07	4.779628	4.69897
8	1.98	2.02	2.05	-0.379	4.4922	-0.2	-0.201	3.9329	8.943	-8.07	4.735396	4.69897
9	1.98	2.00	2.02	-0.379	4.4685	-0.2	-0.201	4.0416	8.943	-8.07	4.712037	4.69897
10	1.98	1.99	2.00	-0.379	4.4566	-0.2	-0.201	4.0974	8.943	-8.07	4.701795	4.69897
11	1.98	1.99	1.99	-0.379	4.4506	-0.2	-0.201	4.1257	8.943	-8.07	4.696159	4.69897
12	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1115	8.943	-8.07	4.698979	4.69897
13	1.99	1.99	1.99	-0.379	4.4521	-0.2	-0.201	4.1186	8.943	-8.07	4.697569	4.69897
14	1.99	1.99	1.99	-0.379	4.4528	-0.2	-0.201	4.1151	8.943	-8.07	4.698274	4.69897
15	1.99	1.99	1.99	-0.379	4.4532	-0.2	-0.201	4.1133	8.943	-8.07	4.698626	4.69897
16	1.99	1.99	1.99	-0.379	4.4534	-0.2	-0.201	4.1124	8.943	-8.07	4.698802	4.69897
17	1.99	1.99	1.99	-0.379	4.4535	-0.2	-0.201	4.112	8.943	-8.07	4.69889	4.69897
18	1.99	1.99	1.99	-0.379	4.4535	-0.2	-0.201	4.1118	8.943	-8.07	4.698934	4.69897
19	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1117	8.943	-8.07	4.698957	4.69897
20	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.698968	4.69897
21	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.698973	4.69897
22	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.69897	4.69897
23	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.698969	4.69897
24	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.69897	4.69897
25	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.69897	4.69897
26	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.69897	4.69897
27	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.69897	4.69897
28	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.69897	4.69897
29	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.69897	4.69897
30	1.99	1.99	1.99	-0.379	4.4536	-0.2	-0.201	4.1116	8.943	-8.07	4.69897	4.69897

5. PICP TAB

This worksheet represents the Tab where the structural and hydrological designs of PICP are performed using the inputs from the “User Interface” and “Detailed Inputs” worksheet tabs. The design process followed for calculations is provided by Biessan (2021). This worksheet is locked and can only be unlocked with a password created by the developer.

Permeable Interlocking Concrete Pavers (PICP)

CONSTRAINTS

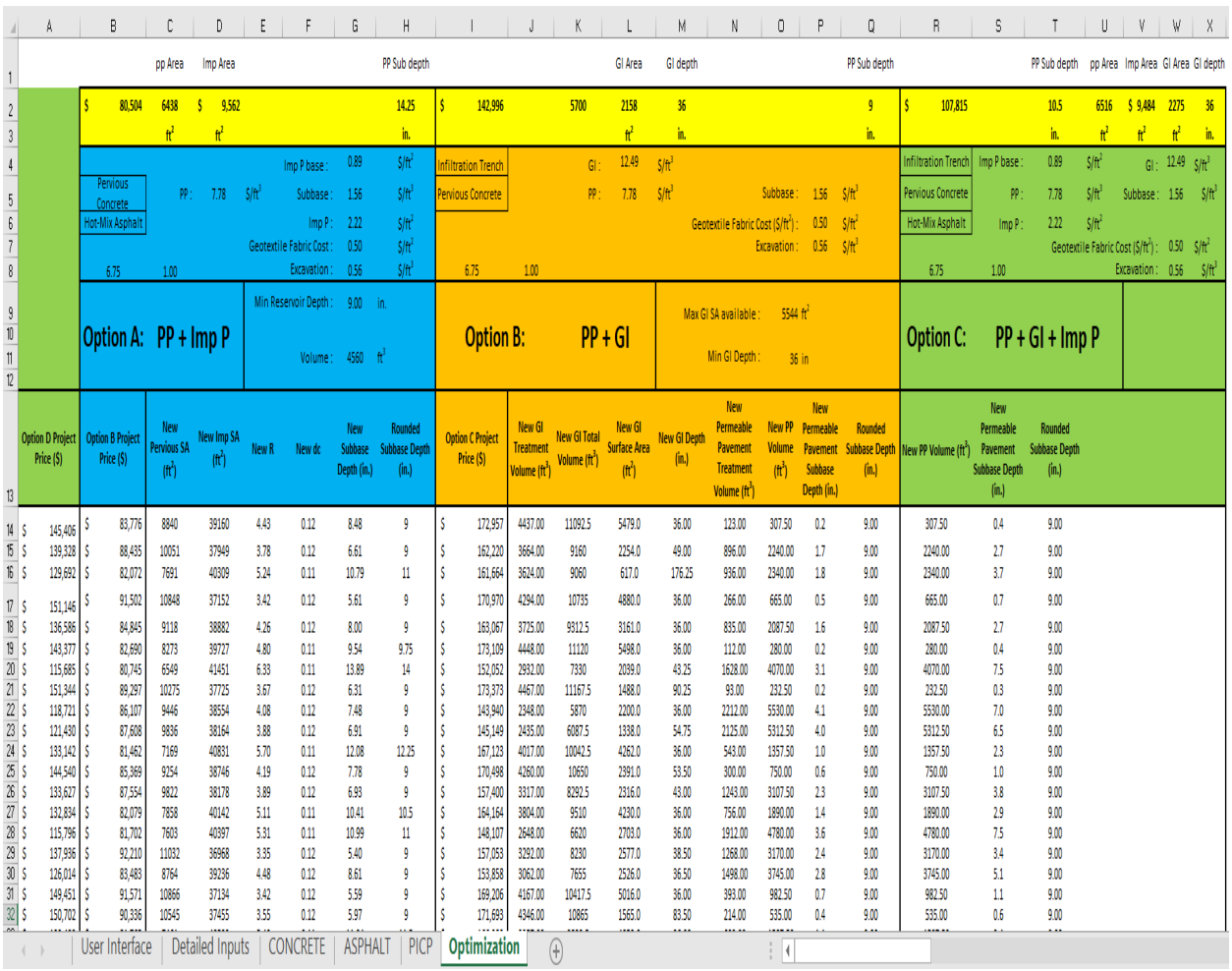
Setbacks: Water supply wells require 100' and Septic systems require 50'
Underdrain required when bedrock is less than 2' beneath the pavement surface
Site Topography: Slope should not be greater than 2%
Soils Requirement: HSG C or D requires an underdrain
Utility Requirement: Consider clearance for all utilities. Min. 5' from down-gradient wet utility lines
Water Table Requirement: Minimum of 2' separation from base layer
All soils should have a minimum CBR of 4%

STRUCTURAL DESIGN

INPUTS

6. OPTIMIZATION TAB

This worksheet represents the Tab where the optimization algorithm is implemented using the inputs from the “User Interface” and “Detailed Inputs” worksheet tabs. The design and cost calculations are done for each optimization option (Option A, B, or C). The detailed process followed for calculations is provided by Biessan (2021). This worksheet is locked and can only be unlocked with a password created by the developer.

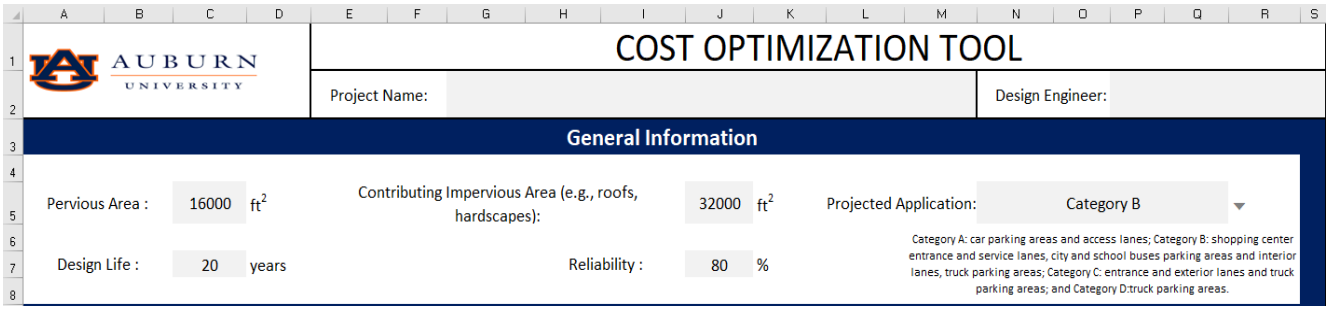


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1			pp Area	Imp Area				PP Sub depth				GI Area	GI depth				PP Sub depth			PP Sub depth	pp Area	Imp Area	GI Area	GI depth
2		$ 80,504	6438	$ 9,562				14.25	$ 142,996		5700	2158	36				9	$ 107,815		10.5	6516	$ 9,484	2275	36
3			ft^2	ft^2				in.				ft^2	in.				in.			in.	ft^2	ft^2	ft^2	in.
4						Imp P base :	0.89	$/ft^2$	Infiltration Trench		GI :	12.49	$/ft^2$					Infiltration Trench	Imp P base :	0.89	$/ft^2$	GI :	12.49	$/ft^2$
5		Pervious Concrete	PP :	7.78	$/ft^2$	Subbase :	1.56	$/ft^2$	Pervious Concrete		PP :	7.78	$/ft^2$		Subbase :	1.56	$/ft^2$	Pervious Concrete	PP :	7.78	$/ft^2$	Subbase :	1.56	$/ft^2$
6		Hot-Mix Asphalt				Imp P :	2.22	$/ft^2$						Geotextile Fabric Cost ($/ft^2) :		0.50	$/ft^2$	Hot-Mix Asphalt	Imp P :	2.22	$/ft^2$			
7						Geotextile Fabric Cost :	0.50	$/ft^2$						Excavation :		0.56	$/ft^2$					Geotextile Fabric Cost ($/ft^2) :	0.50	$/ft^2$
8		6.75	1.00			Excavation :	0.56	$/ft^2$	6.75	1.00								6.75	1.00			Excavation :	0.56	$/ft^2$
9–12		Option A: PP + Imp P			Min Reservoir Depth :	9.00	in.		Option B: PP + GI				Max GI SA available :	5544 ft^2				Option C: PP + GI + Imp P						
						Volume :	4560	ft^2					Min GI Depth :	36 in										
13	Option D Project Price ($)	Option B Project Price ($)	New Pervious SA (ft^2)	New Imp SA (ft^2)	New R	New dc	New Subbase Depth (in.)	Rounded Subbase Depth (in.)	Option C Project Price ($)	New GI Treatment Volume (ft^3)	New GI Total Volume (ft^3)	New GI Surface Area (ft^2)	New GI Depth (in.)	New Permeable Pavement Treatment Volume (ft^3)	New PP Volume (ft^3)	New Permeable Pavement Subbase Depth (in.)	Rounded Subbase Depth (in.)	New PP Volume (ft^3)	New Permeable Pavement Subbase Depth (in.)	Rounded Subbase Depth (in.)				
14	$ 145,406	$ 83,776	8840	39160	4.43	0.12	8.48	9	$ 172,957	4437.00	11092.5	5479.0	36.00	123.00	307.50	0.2	9.00	307.50	0.4	9.00				
15	$ 139,328	$ 88,435	10051	37949	3.78	0.12	6.61	9	$ 162,220	3664.00	9160	2254.0	49.00	896.00	2240.00	1.7	9.00	2240.00	2.7	9.00				
16	$ 129,692	$ 82,072	7691	40309	5.24	0.11	10.79	11	$ 161,664	3624.00	9060	617.0	176.25	936.00	2340.00	1.8	9.00	2340.00	3.7	9.00				
17	$ 151,146	$ 91,502	10848	37152	3.42	0.12	5.61	9	$ 170,970	4294.00	10735	4880.0	36.00	266.00	665.00	0.5	9.00	665.00	0.7	9.00				
18	$ 136,586	$ 84,845	9118	38882	4.26	0.12	8.00	9	$ 163,067	3725.00	9312.5	3161.0	36.00	835.00	2087.50	1.6	9.00	2087.50	2.7	9.00				
19	$ 143,377	$ 82,690	8273	39727	4.80	0.11	9.54	9.75	$ 173,109	4448.00	11120	5498.0	36.00	112.00	280.00	0.2	9.00	280.00	0.4	9.00				
20	$ 115,685	$ 80,745	6549	41451	6.33	0.11	13.89	14	$ 152,052	2932.00	7330	2039.0	43.25	1628.00	4070.00	3.1	9.00	4070.00	7.5	9.00				
21	$ 151,344	$ 89,297	10275	37725	3.67	0.12	6.31	9	$ 173,373	4467.00	11167.5	1488.0	90.25	93.00	232.50	0.2	9.00	232.50	0.3	9.00				
22	$ 118,721	$ 86,107	9446	38554	4.08	0.12	7.48	9	$ 143,940	2348.00	5870	2200.0	36.00	2212.00	5530.00	4.1	9.00	5530.00	7.0	9.00				
23	$ 121,430	$ 87,608	9836	38164	3.88	0.12	6.91	9	$ 145,149	2435.00	6087.5	1338.0	54.75	2125.00	5312.50	4.0	9.00	5312.50	6.5	9.00				
24	$ 133,142	$ 81,462	7169	40831	5.70	0.11	12.08	12.25	$ 167,123	4017.00	10042.5	4262.0	36.00	543.00	1357.50	1.0	9.00	1357.50	2.3	9.00				
25	$ 144,540	$ 85,369	9254	38746	4.19	0.12	7.78	9	$ 170,498	4260.00	10650	2391.0	53.50	300.00	750.00	0.6	9.00	750.00	1.0	9.00				
26	$ 133,627	$ 87,554	9822	38178	3.89	0.12	6.93	9	$ 157,400	3317.00	8292.5	2316.0	43.00	1243.00	3107.50	2.3	9.00	3107.50	3.8	9.00				
27	$ 132,834	$ 82,079	7858	40142	5.11	0.11	10.41	10.5	$ 164,164	3804.00	9510	4230.0	36.00	756.00	1890.00	1.4	9.00	1890.00	2.9	9.00				
28	$ 115,796	$ 81,702	7603	40397	5.31	0.11	10.99	11	$ 148,107	2648.00	6620	2703.0	36.00	1912.00	4780.00	3.6	9.00	4780.00	7.5	9.00				
29	$ 137,936	$ 92,210	11032	36968	3.35	0.12	5.40	9	$ 157,053	3292.00	8230	2577.0	38.50	1268.00	3170.00	2.4	9.00	3170.00	3.4	9.00				
30	$ 126,014	$ 83,483	8764	39236	4.48	0.12	8.61	9	$ 153,858	3062.00	7655	2526.0	36.50	1498.00	3745.00	2.8	9.00	3745.00	5.1	9.00				
31	$ 149,451	$ 91,571	10866	37134	3.42	0.12	5.59	9	$ 169,206	4167.00	10417.5	5016.0	36.00	393.00	982.50	0.7	9.00	982.50	1.1	9.00				
32	$ 150,702	$ 90,336	10545	37455	3.55	0.12	5.97	9	$ 171,693	4346.00	10865	1565.0	83.50	214.00	535.00	0.4	9.00	535.00	0.6	9.00				

User Interface | Detailed Inputs | CONCRETE | ASPHALT | PICP | Optimization

A. DESIGN STEPS

Step 1: Enter all general information about the project.



AUBURN UNIVERSITY

COST OPTIMIZATION TOOL

Project Name: | Design Engineer:

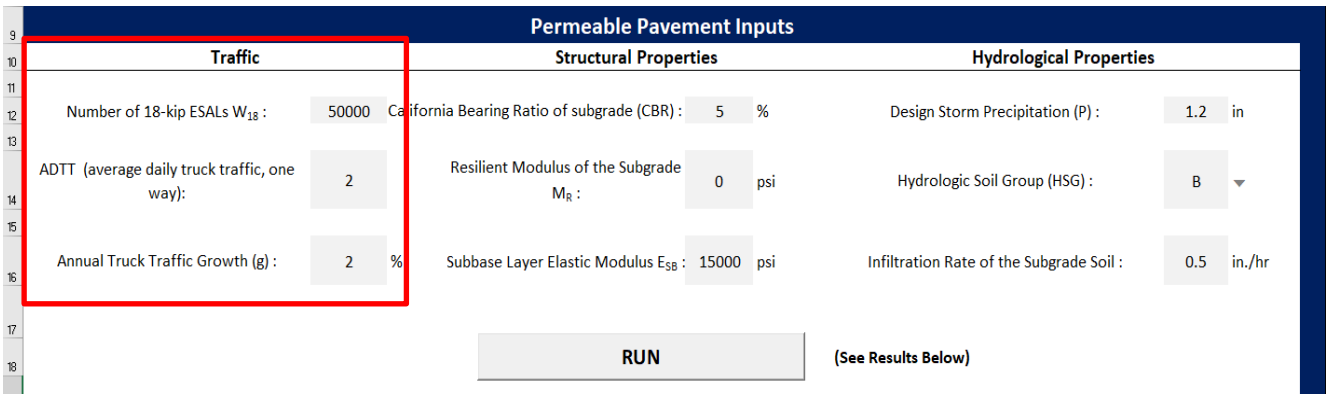
General Information

Pervious Area :	16000	ft^2	Contributing Impervious Area (e.g., roofs, hardscapes):	32000	ft^2	Projected Application:	Category B
Design Life :	20	years	Reliability :	80	%		

Category A: car parking areas and access lanes; Category B: shopping center entrance and service lanes, city and school buses parking areas and interior lanes, truck parking areas; Category C: entrance and exterior lanes and truck parking areas; and Category D:truck parking areas.

Step 2: Enter the traffic inputs

- **For PA and PICP** – only the number of 18-kip ESALs W18 is needed
- **For PC** – only the ADTT and the annual truck traffic growth are needed

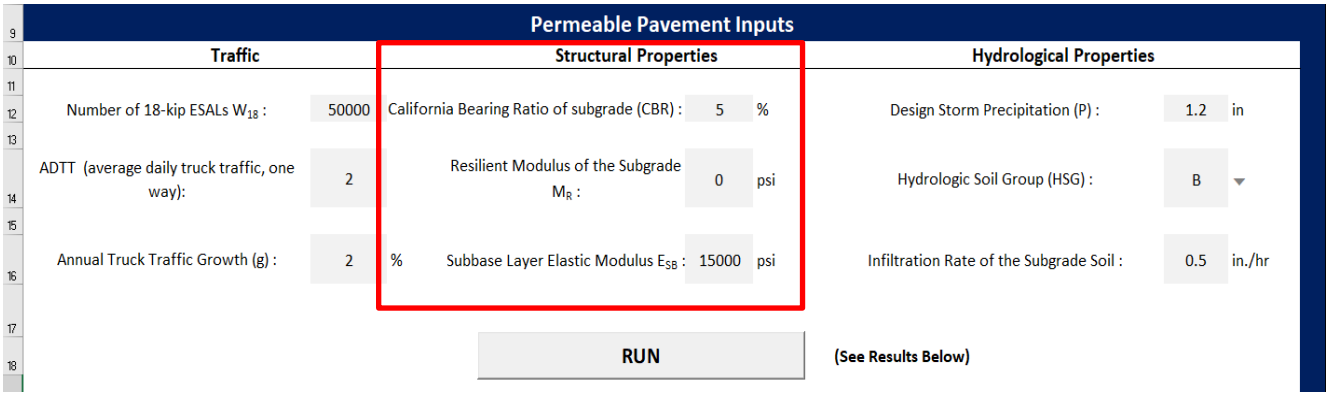


Permeable Pavement Inputs

Traffic			Structural Properties			Hydrological Properties		
Number of 18-kip ESALs W_{18} :	50000		California Bearing Ratio of subgrade (CBR) :	5	%	Design Storm Precipitation (P) :	1.2	in
ADTT (average daily truck traffic, one way):	2		Resilient Modulus of the Subgrade M_R :	0	psi	Hydrologic Soil Group (HSG) :	B	
Annual Truck Traffic Growth (g) :	2	%	Subbase Layer Elastic Modulus E_{SB} :	15000	psi	Infiltration Rate of the Subgrade Soil :	0.5	in./hr

RUN (See Results Below)

Step 3: Enter the structural properties required for PC, PA, and PICP.



Permeable Pavement Inputs

Traffic			Structural Properties			Hydrological Properties		
Number of 18-kip ESALs W_{18} :	50000		California Bearing Ratio of subgrade (CBR) :	5	%	Design Storm Precipitation (P) :	1.2	in
ADTT (average daily truck traffic, one way):	2		Resilient Modulus of the Subgrade M_R :	0	psi	Hydrologic Soil Group (HSG) :	B	
Annual Truck Traffic Growth (g) :	2	%	Subbase Layer Elastic Modulus E_{SB} :	15000	psi	Infiltration Rate of the Subgrade Soil :	0.5	in./hr

RUN (See Results Below)

Step 4: Enter the hydrological properties for PC, PA, PICP.

Permeable Pavement Inputs							
Traffic			**Structural Properties**			**Hydrological Properties**	
Number of 18-kip ESALs W_{18} :	50000		California Bearing Ratio of subgrade (CBR) :	5	%	Design Storm Precipitation (P) :	1.2 in
ADTT (average daily truck traffic, one way):	2		Resilient Modulus of the Subgrade M_R :	0	psi	Hydrologic Soil Group (HSG) :	B
Annual Truck Traffic Growth (g) :	2	%	Subbase Layer Elastic Modulus E_{SB} :	15000	psi	Infiltration Rate of the Subgrade Soil :	0.5 in./hr
			RUN			(See Results Below)	

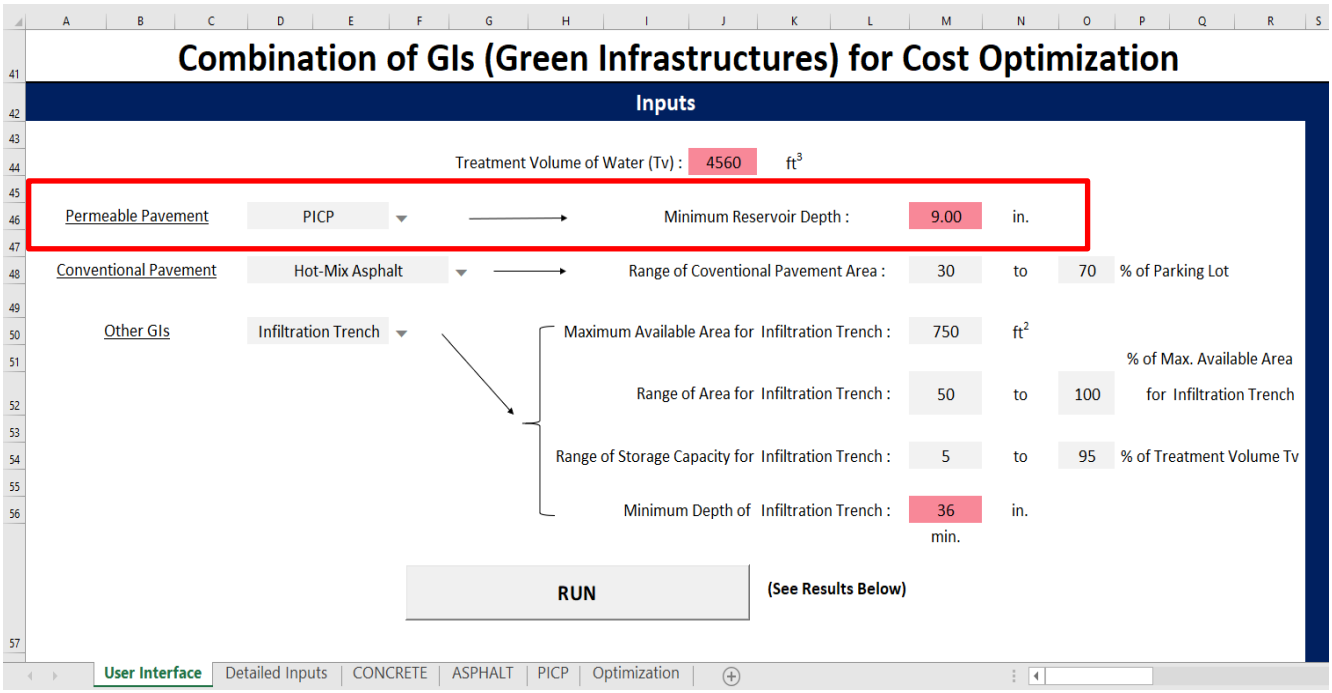
Step 5: Verify that all the default inputs in the "Detailed Inputs" worksheet Tab are appropriate for the specific project.

Step 6: Click "Run" to obtain the results.

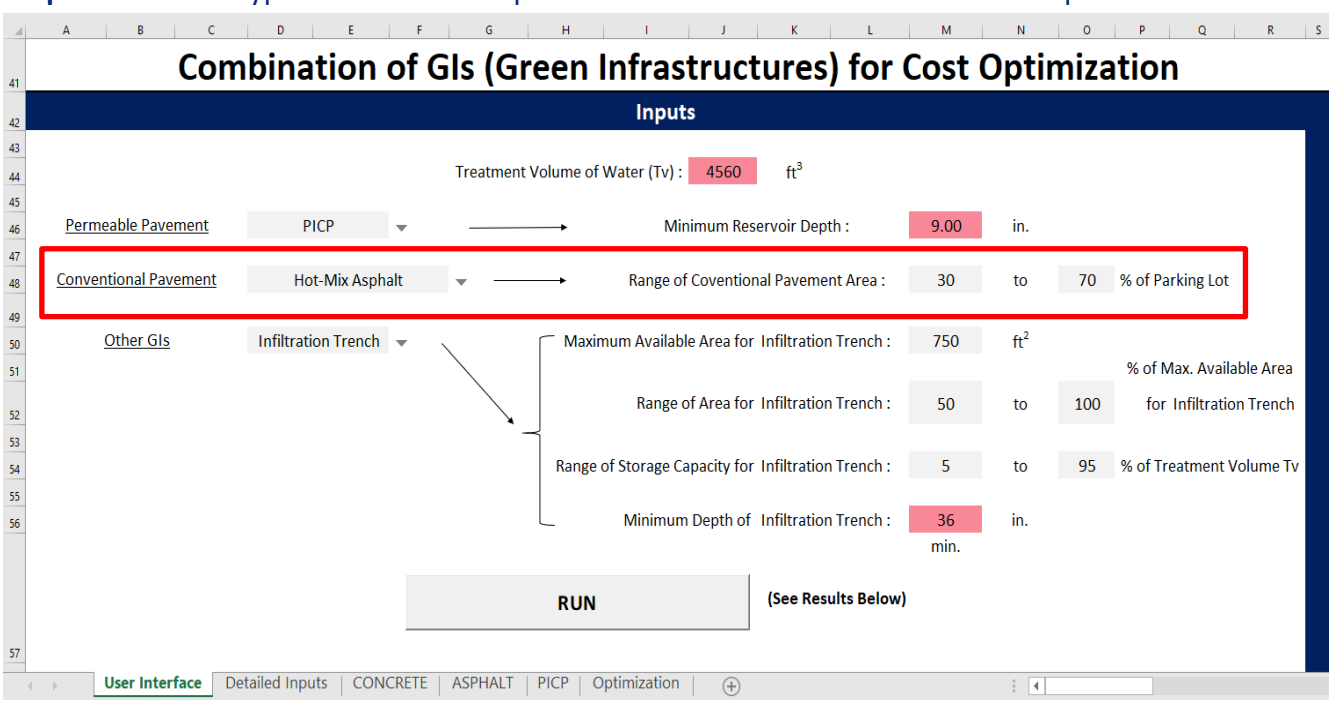
Permeable Pavement Inputs							
Traffic			**Structural Properties**			**Hydrological Properties**	
Number of 18-kip ESALs W_{18} :	50000		California Bearing Ratio of subgrade (CBR) :	5	%	Design Storm Precipitation (P) :	1.2 in
ADTT (average daily truck traffic, one way):	2		Resilient Modulus of the Subgrade M_R :	0	psi	Hydrologic Soil Group (HSG) :	B
Annual Truck Traffic Growth (g) :	2	%	Subbase Layer Elastic Modulus E_{SB} :	15000	psi	Infiltration Rate of the Subgrade Soil :	0.5 in./hr
			RUN			(See Results Below)	

B. OPTIMIZATION STEPS

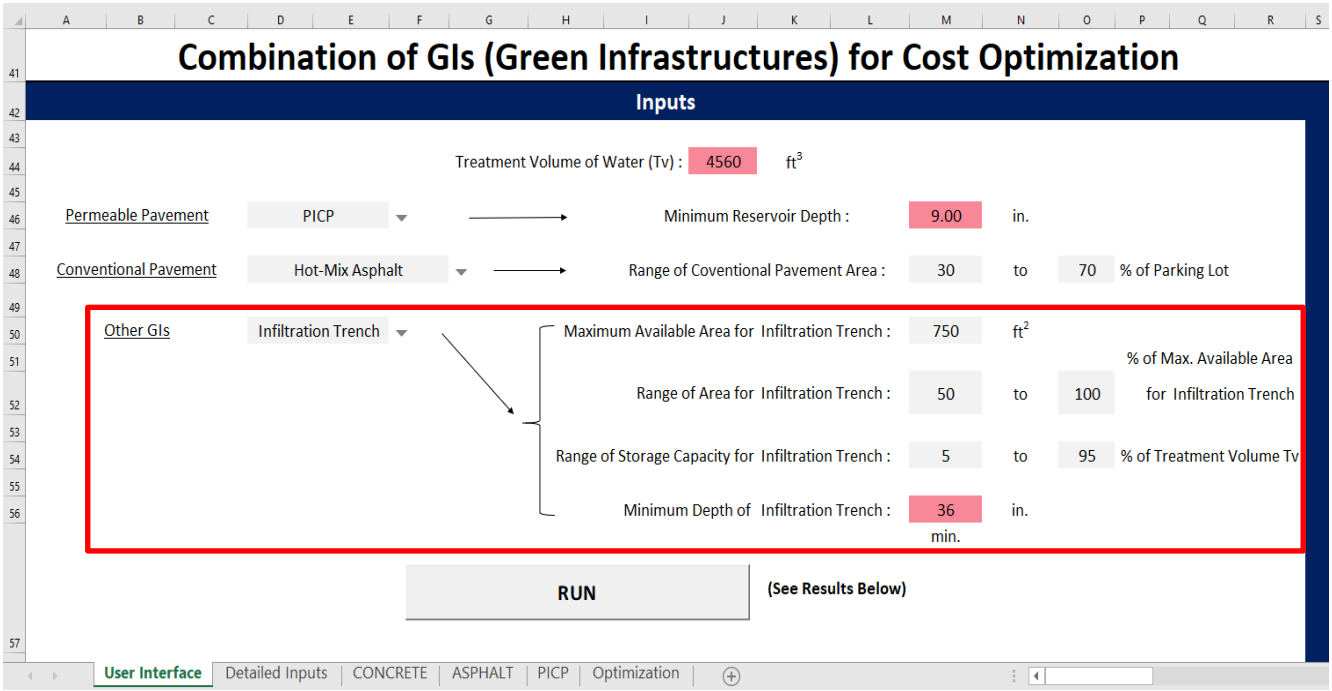
Step 1: Select the type of permeable pavement desired.



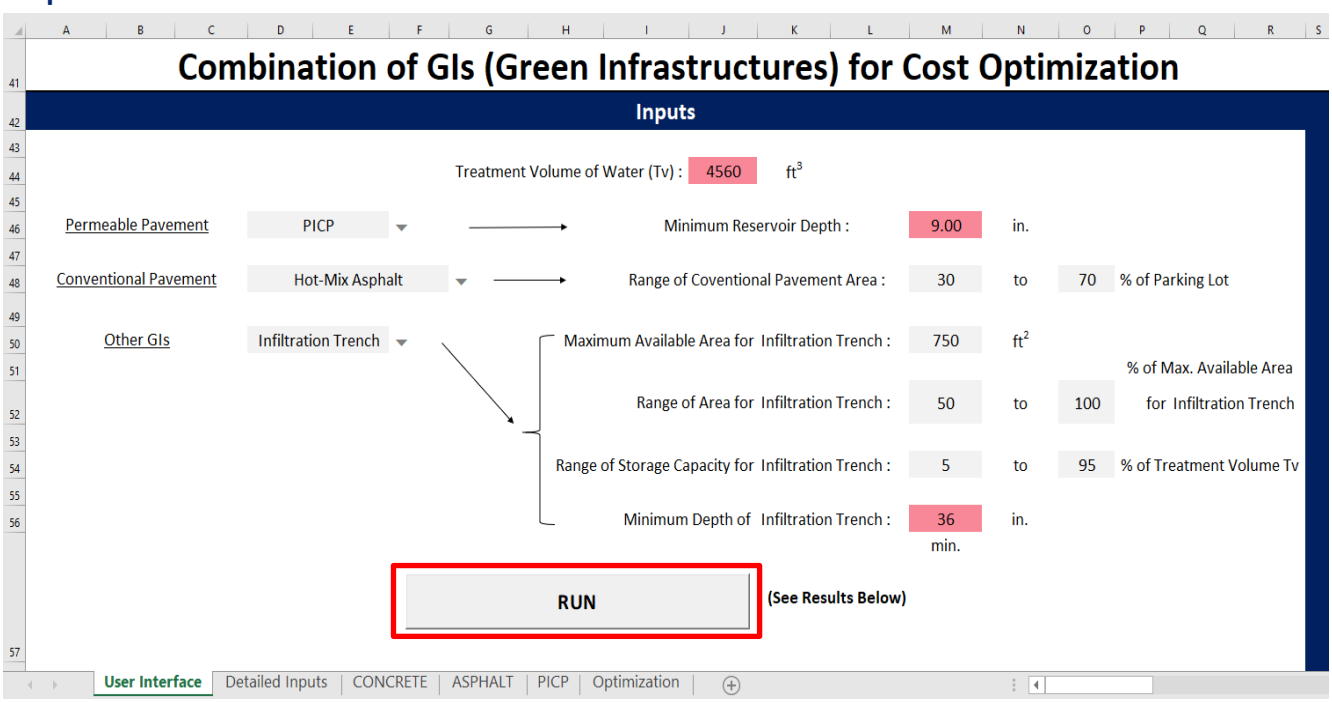
Step 2: Select the type of conventional pavement and the constraint desired for optimization.



Step 3: Select the type of other GI and the constraints desired for optimization



Step 4: Click "Run" to obtain the results.



C. CONSTRAINTS TO CONSIDER

In the "User Interface" worksheet tab, the information shown below is displayed to on the right side of the design and cost optimization results. This section is just a reminder for the user to consider certain constraints during the design and optimization process of PP. All other constraints not displayed in the "User Interface" worksheet tab are discussed in the papers recommended below.

Constraints to consider for PP reservoir layers:

Calculated Detention time (t_d) of Time to drain the reservoir layers of all 3 types of PP:

t_d = 6 hrs.

Maximum Detention time recommended is:

1 to 2 days therefore 24 hrs. to 48 hrs.

User should verify that the calculated detention time is not greater than the maximum desired detention time. If it is greater, then possible solutions are: an increase of the pervious area, an increase of the infiltration rate of the subgrade soil, or a decrease of the rainfall depth.

Calculated Maximum depth of PPs reservoir layers $d_{p\text{-}max}$:

For t_d = 24 hrs. .---> $d_{p\text{-}max}$ = 30 in. For t_d = 48 hrs. .---> $d_{p\text{-}max}$ = 60 in.

User should verify that the depths of the PP reservoir layers obtained in design results (on the left) are not greater than the calcuated maximum depth or the desired maximum depth of PP reservoir layer. If they are greater, then possible solutions are: an increase of the infiltratio rate of the subgrade soil, a decrease of the rainfall depth, or just the use of underdrain.

User should know and consider the depths of the ground water table and bedrock, and all other design constraints discussed in related papers mentioned in Section C of the User Manual.

The following thesis and peer reviewed journal paper are important papers related to the development of the COTPP. Those papers provide:

- The adapted detailed version of the steps used in the COTPP for the structural and hydrological design of all three types of PPs.
- The design constraints that must be considered during the design and optimization process.
- Suggested unit costs and their corresponding adjustment methods for the components considered in the COTPP.

Thesis:

Biessan, D. G. V. V. Developing a Tool for the Design and Cost Optimization of Permeable Pavements in the Planning Stage of Stormwater Management. M.S. Thesis, Auburn University, Auburn, AL, 2021.

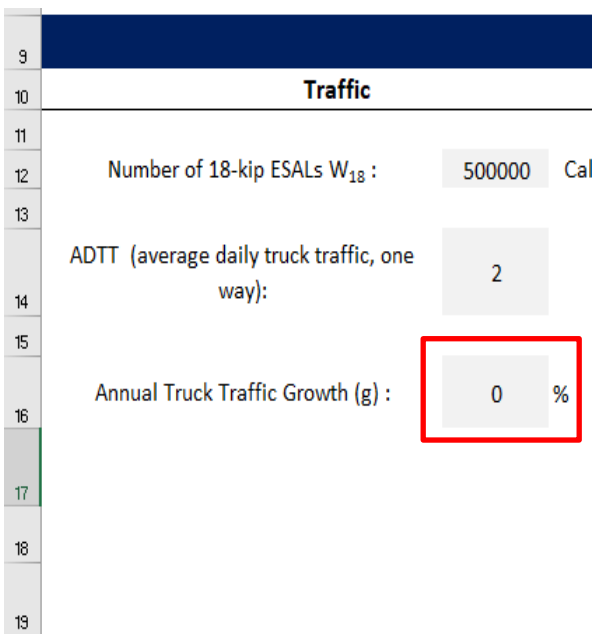
Journal paper:

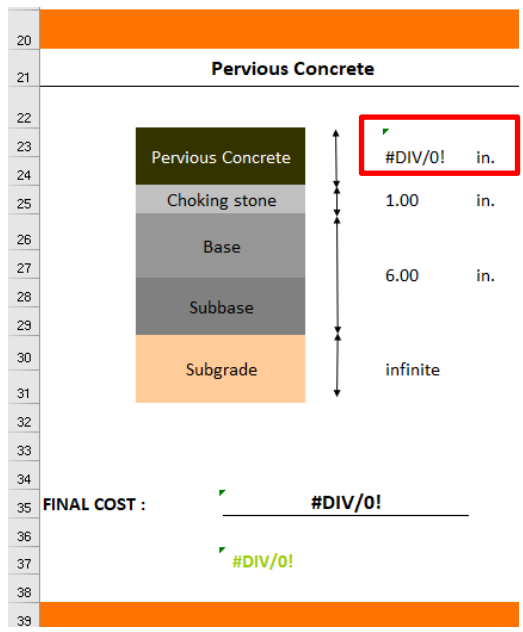
Biessan, D. G. V. V. et al. Practical Tool for the Design and Cost Optimization of Permeable Pavements in the Planning Stage of Stormwater Management. Transportation Research Records. 2023.

D. TROUBLESHOOTING

While using the COTPP, Microsoft Excel may show some error messages based on the type of inputs entered by the user that may lead to incorrect or illogical results. It is recommended to consult the "HELP" window of Microsoft Excel to understand the meaning of the error message and find solutions. The two most common error messages that are encountered in the COTPP are explained below:

(1) #DIV/0! Error: this error message is shown when a number is divided by zero (0). It usually happens when a value of 0 is entered as an input, which is used in a formula that divides another number by that input. One example is shown below where a value of 0 is entered for the annual truck traffic growth (usually ≠ 0). Since this value is used in the growth factor formula as a denominator, this leads to the result shown on the right with a #DIV/0! Error message.





(2) #NUM Error: this error means impossible calculation. It usually happens when a non-valid value is entered as an input using a data type or number format not supported in the argument of a formula or function. One example is shown below where a value of 0 is entered for the CBR of the subgrade soil. This is not a valid input because subgrade soils should have a minimum strength that is used in the algorithm calculations of the COTPP. To avoid this type of errors, it is recommended that the user consider the ranges provided in the COTPP and the constraints discussed in Section C of this User Manual.

Permeable Pavement Inputs

Structural Properties

California Bearing Ratio of subgrade (CBR) :	0	%
Resilient Modulus of the Subgrade M_R :	0	psi
% Subbase Layer Elastic Modulus E_{SB} :	15000	psi

RUN

Permeable Pavement Outputs

Pervious Concrete		Porous Asphalt		Permeable Interlocking Convrete Pavers	
Pervious Concrete	#NUM! in.	Porous Asphalt	#NUM! in.	PICP	3.125 in.
Choking stone	1.00 in.	Choking stone	1.00 in.	Choking stone	2.00 in.
Base	9.00 in.	Base	9.00 in.	Base	#NUM! in.
Subbase		Subbase		Subbase	
Subgrade	infinite	Subgrade	infinite	Subgrade	infinite
FINAL COST :	#NUM!	FINAL COST :	#NUM!	FINAL COST :	#NUM!
	#NUM!		#NUM!		#NUM!

E. REFERENCES

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