### **University of Central Florida BMPTRAINS Model Update**

## **BMPTRAINS Cost TECHNICAL MEMORANDUM**

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**Prepared For:** 



#### **Stormwater Management Academy**

4000 Central Florida Blvd. P.O. Box 162450 Orlando, Florida 32816-2450

Prepared By:

Geosyntec<sup>D</sup> consultants

1511 East State Road 434, Suite 1005

Winter Springs, FL 32708

Mike Hardin, PhD, PE, CFM Project Engineer



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#### 1. Introduction

The protection of surface water bodies is a priority in the United States and around the world. Stormwater discharges are identified by the USEPA as a significant source of pollution to surface water bodies (USEPA, 2009). The control of nutrients in stormwater runoff is a particular concern as it relates to the control of harmful algal blooms and dead zones in water bodies. Methods have been identified in the literature to reduce the volume of stormwater runoff generated in urban areas or reduce the pollutants in stormwater runoff before discharge (Chang, Islam, Marimon, & Wanielista, 2012; Hardin, 2006; Harper & Baker, 2007; Hood, Chopra, & Wanielista, 2013; O'Reilly, Wanielista, Chang, Xuan, & Harris, 2012; Sansalone, Kuang, & Ranieri, 2008; Wanielista, Yousef, Harper, & Dansereau, 1991). These methods are called low impact development (LID), which could be grouped into the wider classification of best management practices (BMP).

Many of these BMPs have been examined to describe their performance however, the use of this information is difficult as the information is scattered in many different sources and the studies have been done for specific regions or conditions. In an effort to address this, many state and local governments have been developing BMP manuals which attempt to gather the information on design and performance in a convenient to use manual (Burack, Walls, & Stewart, 2008; Michigan Department of Environmental Quality, 1999; Urban Drainage and Flood Control District, 2015; Seters, Graham, & Rocha, 2013; Powell, et al., 2005; Pomeroy, 2009). However, these manuals are not able to account for changes in expected efficiency due to spatial and temporal differences in site conditions nor do they provide adequate guidance on how to determine overall nutrient reduction achieved. Additionally, in many instances, the use of a single BMP is insufficient to achieve the goals of nutrient reduction and flood control in urban areas. It is for these reasons that a tool to analyze the use of several BMPs in different configurations is needed. This is called a treatment train approach.

The BMPTRAINS Model is a software modeling tool developed by the University of Central Florida Stormwater Management Academy (Client) to assess the performance of stormwater BMPs across the state of Florida. As such, the rainfall characteristics, typical event mean concentration (EMC) data for the common land uses across the state, and common BMPs are summarized and programmed into the model. The model is user friendly and the underlying methodology is accepted by all the water management districts in the State.

The work described herein is a result of the Client's desire to add features and update the model to accommodate more types of BMPs, analyze cost, and to provide for more user



flexibility and functionality of the model. This memorandum focuses on the cost component of this project. Geosyntec Consultants Inc., (Geosyntec) added two worksheets to the BMPTRAINS Model which will allow for the evaluation of cost of BMPs. A description of the methodology utilized is provided in the Methods section below.

Due to the temporal and spatial variation in price for different construction practices and products, reference cost data have not been programed into the model and is left to be a user defined input. This will ensure that the model does not need to be continuously updated with cost information and remains relevant to the practitioners. When choosing and designing BMPs for nutrient removal, it is important to consider capital cost, operating (maintenance) cost, and performance data. As a refinement of the BMPTRAINS Model, Geosyntec performed a thorough review of the literature to identify sources of reference cost (capital & operating) data for various BMPs such as street sweeping, wet detention ponds, dry retention ponds, bioretention, pervious pavements, green roofs, swales, and filter strips. This data is from both government sources as well as journal articles. Furthermore, Geosyntec identified sources to estimate land value. It is understood that this information will be provided to the Client and the Client will host this information on their website. Geosyntec will provide a button in the model which will redirect model users to the reference information. The Client will then maintain the information as they see fit.



#### 2. Methods

Version 8.0 of the BMPTRAINS model has the capability to perform a cost analysis for any given BMP design within the model. This feature allows the user to evaluate either present worth or capital cost for each design scenario considered for a project. The ability to perform the cost analysis on multiple treatment scenarios to achieve a desired TN and TP reduction goal provides the user with the economic benefits associated with each treatment option. It should be mentioned that in order for such a cost comparison analysis to be relevant, the same removal efficiency should be achieved for each scenario examined.

The cost feature was developed with the goal to find a minimum cost for a specified performance criterion, i.e. 80% removal of TN and TP. A cost function needed to be developed to make comparisons across different stormwater treatment scenarios. The expression for the general form of the equation is shown below in Equation 2-1.

#### **Equation 2-1**

$$Min \ Cost = \sum_{i=1}^{12} C_i X_i$$

Where  $C_i$  is the cost per unit size of the i<sup>th</sup> BMP brought to present value and  $X_i$  is the size of the i<sup>th</sup> BMP. The range of "i" varies from 1 to 12 since a maximum of 12 BMPs, out of the 15 available, can be analyzed within a given watershed. The maximum 12 BMPs achievable are based on a maximum of three BMPs per catchment and four catchments.

The cost component of Equation 2-1 includes the cost of constructing, operating, and maintaining the BMP. Equation 2-2 describes the components of the overall cost for the ith BMP:

#### **Equation 2-2**

$$C_i = C_{IC} + C_{OM} - C_R$$

 $C_{IC}$  is the initial capital cost of the BMP, which includes design costs, mobilization costs, land costs, construction materials and other costs.  $C_{OM}$  is the operating and maintenance cost of the BMP. The  $C_{OM}$  is a reoccurring cost, usually yearly, that is required to ensure that the BMP operates as intended.  $C_R$  is cost recovery achieved by the BMP. Some BMPs can generate revenues, such as harvesting operations, which generate water that can be utilized instead of potable supplies. This cost recovery results in a reduction of cost for the specific BMP which may lead to it having a lower present worth than a BMP that is not able to recover cost. Additionally, the protection of surface water bodies, as well as other



natural resources, should have some cost benefit associated with it. This cost benefit can be incorporated into the cost analysis by subtracting the cost benefit from the operating and maintenance cost.

Since the value of money changes with time, money spent in the future may not have the same value as money spent today. Due to this, both the  $C_{OM}$  and  $C_R$  components must be brought to present value for the desired number of periods to be included in the analysis. The equation used for present worth analysis is that presented by Park (Park, 2002) as expressed in Equation 2-3.

#### **Equation 2-3**

 $P = A \left[ \frac{(1+i)^{N} - 1}{i(1+i)^{N}} \right]$ 

Where P is present worth, A is annual cost, "*i*" is the interest rate, and N is the number of periods. The reoccurring costs,  $C_{OM}$  and  $C_R$ , would be used in Equation 2-3 above in place of *A* because each is in terms of annual cost. Life cycle cost will be defined in present worth dollars.

Furthermore, a cost analysis can be based on capital cost if the user is only interested in initial capital cost of the project. The capability of the BMPTRAINS model to perform a cost analysis is provided on the Cost Comparison Worksheet, where multiple scenarios can be selected from a drop-down menu. When examining the capital costs, the future costs associated with operation and maintenance, replacement cost, and future revenue generated are not considered. This is because, for a capital cost analysis, only the up-front costs are considered which will be useful if the user is not the owner and thus will not operate or maintain the BMP.

Since costs for various activities will vary spatially and temporally, the user is required to input all cost data. As noted previously, part of this effort is to collect and review published cost data. The results of this effort are presented in Section 3 below. The use of published cost data allows the designer to make decisions using a common cost metric and while the true cost may be different than what is presented in the literature, it can be assumed that the same difference exists for most BMPs and BMP components.

The cost analysis worksheet allows the user to select between two types of analysis options, capital cost or net present worth. The cost analysis for a net present worth evaluation would require the following information in addition to BMP specific cost information: interest rate, project duration, and cost of water (if relevant). The cost of water is only relevant for BMPs that harvest stormwater, since these BMPs will greatly reduce potable water usage. The user has the option to split the BMP cost into two



components, the fixed cost and the variable cost. An example of fixed cost is the cost of mobilization. An example of a variable cost is the cost to excavate soil. The user is required to specify the cost of land needed for the BMP, if applicable, the expected life of the BMP in years, the fixed cost portion of the BMP, the variable cost of the BMP, the estimated annual BMP maintenance cost, and the estimated future cost of replacement. The estimated cost of future replacement is only relevant if the project duration is greater than the expected life of the BMP. The model uses these inputs to calculate the net present worth for each scenario specified by the user. An illustration on the use of the cost feature is presented in the Cost Analysis Example section (Section 5) of this memo.



#### 3. Sources for BMP Cost Data

Due to the temporal and spatial variation in price for different construction practices and products, cost is a user input. This will ensure that the model does not need to be continuously updated with cost information and remains relevant to the practitioners. Reliable sources of cost data can be found in journal articles and government websites. Published cost data are presented in this section that can be used should the user not have access to site specific or other appropriate data. It should be noted that the cost data presented in this section can be used in the model, but it is recommended that, should the user have better (more recent, site specific, etc.) cost data, that be used.

When using published cost data, it is important to keep in mind inflation if the data is several years old. It is recommended that the *consumer price index* (CPI) be used to adjust the price of an item to current or past dollars based on inflation. There are consumer price index for different segments of the economy; however the *urban consumer price index* (*CPI–U*) is used to estimate the national inflation rate. The CPI–U is based on a typical market basket of goods and services utilized by a typical urban consumer (Park, 2002; U.S. Department of Labor Statistics, 2016). CPI-U annual average values for 2000-2016 are shown in Table 3-1. The CPI is used to calculate an average annual general inflation rate that is used to adjust the price to the desired year; the inflation calculator provided by the US Department of Labor Statistics can do the calculations for you, see Figure 3-1 (Park, 2002; US Department of Labor Statistics, 2016).



CPI-U (Average Annual)
172.20
177.10
179.90
184.00
188.90
195.30
201.60
207.30
215.30
214.54
218.06
224.94
229.59
232.96
236.74
237.02
To be determined

#### Table 3-1: United States CPI-U (U.S. Department of Labor Statistics, 2016)

The US Inflation Calculator measures the buying power of the dollar over time. Just enter any two dates between 1913 and 2016, an amount, and click 'Calculate'.

<b>Inflation Calculator</b>						
lf in	2012	(ente	r year)			
I purchased	d an item for \$		65,700.00			
then in	2016	(ente	r year)			
that same item would cost		\$6	58,143.2	21		
Cumulative rate of inflation:		3.	7%			
		CALCU	LATE			

\*Learn how this calculator works. This US Inflation Calculator uses the latest US government CPI data published on April 14, 2016 to adjust for inflation and calculate the cumulative inflation rate through March 2016. The Consumer Price Index (CPI) and inflation for April 2016 is scheduled for release by the United States government on May 17, 2016. (See a chart of recent inflation rates.)

Figure 3-1: US Department of Labor Statistics Inflation Calculator http://www.usinflationcalculator.com/ (US Department of Labor Statistics, 2016)



When determining the present value/worth of a proposed project, data can be adjusted to present worth, or any other year, by using an interest rate. The ability to bring all costs to a present worth is critical when comparing opportunity costs of different design options with varying annual operation and maintenance costs and lifespans. It is recommended to use the World Bank for information on interest rates. The World Bank provides yearly real interest rates, as well as other forms of interest rate, for various countries, including the United States (The World Bank), see Table 3-2. Real interest rate, also known as inflationfree interest rate, is an estimate of the true earning power of money once the inflation effects have been removed. Real interest rate is used in constant dollar analysis. Constant dollar analysis is used when all cash flow elements needed are provided in constant dollars and you want to compute the equivalent present worth of the constant dollars. Constant dollar analysis is commonly used in the evaluation of long-term public projects since governments do not pay income taxes (Park, 2002). When obtaining costs from journal articles and reports it can be assumed, unless otherwise stated, that the costs presented are in terms of dollars in the year the article was written/submitted. If the year the article is written or submitted is not available, then assume that the cost are in terms of the year prior to publication.

Year	2011	2012	2013	2014
Real Interest Rate (%)	1.2	1.4	1.7	1.8

The US EPA published the <u>Preliminary Data Summary of Urban Storm Water Best</u> <u>Management Practices</u> report in 1999 (Strassler, Pritts, & Strellec, 1999). This report contains performance and cost data, both capital, Table 3-3, and operational for various BMPs, Table 3-4. The cost data in Table 3-3 do not include geotechnical testing, legal fees, land costs, and other unexpected costs. Cost ranges are provided for retention and detention basins to accommodate economies of scale in design and construction (Strassler, Pritts, & Strellec, 1999).



# Table 3-3: Typical Base Capital Construction Costs for BMPs (Strassler, Pritts, &Strellec, 1999)

BMP Type	Typical Cost* (\$/cf)	Notes	Source	
Retention and Detention Basins	0.50-1.00	Cost range reflects economies of scale in designing this BMP. The lowest unit cost represents approx. 150,000 cubic feet of storage, while the highest is approx. 15,000 cubic feet. Typically, dry detention basins are the least expensive design options among retention and detention practices.	Adapted from Brown and Schueler (1997b)	
Constructed Wetland	Wetland 0.60-1.25 more expensive (because of plant selection and E		Adapted from Brown and Schueler (1997b)	
Infiltration Trench	4.00	00 Represents typical costs for a 100-foot long trench.		
Infiltration Basin	1.30	Represents typical costs for a 0.25-acre infiltration basin.	Adapted from SWRPC (1991)	
Sand Filter	3.00-6.00	The range in costs for sand filter construction is largely due to the different sand filter designs. Of the three most common options available, perimeter sand filters are moderate cost whereas surface sand filters and underground sand filters are the most expensive.	Adapted from Brown and Schueler (1997b)	
		Bioretention is relatively constant in cost, because it is usually designed as a constant fraction of the total drainage area.	Adapted from Brown and Schueler (1997b)	
Grass Swale	0.50	Based on cost per square foot, and assuming 6 inches of storage in the filter.	Adapted from SWRPC (1991)	
Filter Strip	0.00-1.30	Based on cost per square foot, and assuming 6 inches of storage in the filter strip. The lowest cost assumes that the buffer uses existing vegetation, and the highest cost assumes that sod was used to establish the filter strip.	Adapted from SWRPC (1991)	

\* Base year for all cost data: 1997



BMP	Annual Maintenance Cost (% of Construction Cost)	Source(s)	
Retention Basins and Constructed Wetlands	3%-6%	Wiegand et al, 1986 Schueler, 1987 SWRPC, 1991	
Detention Basins <sup>1</sup>	<1%	Livingston et al, 1997; Brown and Schueler, 1997b	
Constructed Wetlands <sup>1</sup>	2%	Livingston et al, 1997; Brown and Schueler, 1997b	
Infiltration Trench	5%-20%	Schueler, 1987 SWRPC, 1991	
	1%-3%		
Infiltration Basin <sup>1</sup>	5%-10%	Wiegand et al, 1986; Schueler, 1987; SWRPC, 1991	
Sand Filters <sup>1</sup>	11%-13%	Livingston et al, 1997; Brown and Schueler, 1997b	
Swales	5%-7%	SWRPC, 1991	
Bioretention	5%-7%	(Assumes the same as swales)	
Filter strips	\$320/acre (maintained)	SWRPC, 1991	

#### Table 3-4: Annual Maintenance Costs of BMPs (Strassler, Pritts, & Strellec, 1999)

1. Livingston et al (1997) reported maintenance costs from the maintenance budgets of several cities, and percentages were derived from costs in other studies

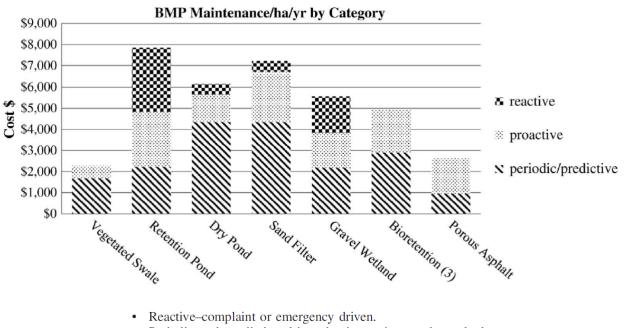
The Transportation Research Board published a document titled the <u>NCHRP REPORT 792</u>; this report is an excellent source of data for capital cost, operating cost, life span (see Table 3-5), and performance data on a cost basis for various BMPs (Taylor, et al., 2014). It is important to note that several of the tables in this report provide *Whole Life Cycle Costs*. Care must be taken when using *Whole Life Cycle Costs* with the BMPTRAINS model. Whole life cycle costs are calculated by bringing the operating costs and capital costs all to a single Present Value; this is exactly what the BMPTRAINS model Net Present Worth Analysis feature does. *Whole Life Cycle Costs* style data could be evaluated using the Capital Cost feature in the BMPTRAINS model. Care must be exercised when doing this as the assumptions must consistent between the BMPTRAINS Model and the source of the cost data.



BMP Type	Life Span	Limiting Factor		
Vegetated strips	8–60 years (depending on ecoregion)	Sediment accumulation		
Vegetated swales	d swales 10–50 years (depending on ecoregion) Sediment			
Dry detention basin	80 years	Pipe material longevity		
Bioretention	80 years	Pipe material longevity		
Retention pond	80 years	Pipe material longevity		
Sand filter	75 years	Concrete longevity		
Permeable friction course	14 years	Sediment accumulation		

#### Table 3-5: BMP expected life span (Taylor, et al., 2014)

Cost data can also be found in journals such as the ASCE Journal of Environmental Engineering. The article by Houle (Houle, Roseen, Ballestero, Puls, & Sherrard Jr., 2013), which discusses capital and maintenance costs on an area and gram of pollutant removed basis for swales, ponds, bioretention, pervious pavements, and others. A few examples of capital and maintenance costs figures and tables from the article are shown below in Figure 3-2, Table 3-6, & Table 3-7.



- Periodic and predictive-driven by inspections and standards embodied in an O&M plan; can be calendar-driven, known, or schedulable activities.
- Proactive–adaptive and applied increasingly more as familiarity with the system develops.

# Figure 3-2: Annualized maintenance costs per system per hectare of impervious cover treated per maintenance activity classification (Houle, Roseen, Ballestero,

**Puls, & Sherrard Jr., 2013)** [Based on publication date, assume that all operating costs are on a 2012 basis unless otherwise stated.] Note in Florida a detention pond is the same as the category Retention Pond listed in Figure 3-2.

Table 3-6: Capital and Maintenance Cost Data, with Normalization per Hectare ofImpervious Cover Treated (Houle, Roseen, Ballestero, Puls, & Sherrard Jr., 2013)[Thearticle from which this cost information came from was published in 2013 & written in 2012. Assume all operating costs are ona 2012 basis unless otherwise stated. The capital cost in 2012 is stated in the table. Note that 1 hectare = 2.471 acres.]

Parameter	Vegetated swale	Wet pond	Dry pond	Sand filter	Gravel wetland	Bioretention	Porous asphalt
Original capital cost (\$)	29,700	33,400	33,400	30,900	55,600	53,300	53,900
Inflated 2012 capital cost (\$)	36,200	40,700	40,700	37,700	67,800	63,200	65,700
Maintenance-capital cost comparison (year) <sup>a</sup>	15.9	5.2	6.6	5.2	12.2	12.8	24.6
Personnel (h/year)	23.5	69.2	59.3	70.4	53.6	51.1	14.8
Personnel (\$/year)	2,030	7,560	5,880	6,940	5,280	4,670	939
Materials (\$/year)	247	272	272	272	272	272	0
Subcontractor Cost (\$/year)	0	0	0	0	0	0	1,730
Annual O&M Cost (\$/year)	2,280	7,830	6,150	7,210	5,550	4,940	2,670
Annual maintenance/capital cost (%)	6	19	15	19	8	8	4

Note: Calculations based on original data with BGS units of \$/acre and h/acre.

<sup>a</sup>Number of years at which amortized maintenance costs equal capital construction costs.

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Table 3-7: Summary of Removal Performance and Comparison per kg Removed of TSS and per g Removed of TP and TN as *Dissolved Inorganic Nitrogen (DIN)* (Houle, Roseen, Ballestero, Puls, & Sherrard Jr., 2013) [The article from which this cost information came from was published in 2013 & written in 2012. Assume all capital and operating costs are on a 2012 basis unless otherwise stated.]

Parameter	Vegetated swale	d swale Wet pond Dry p		Sand filter	Gravel wetland	Bioretention	Porous asphalt
Total suspended solids performance	e-annual load of 689	9 kg					
Removal efficiency (%) <sup>a</sup>	58	68	79	51	96	92	99
Annual mass removed (kg)	399	468	544	351	662	632	682
Capital cost performance (\$/kg)	91	87	75	107	102	100	96
Operational cost (\$/kg/year)	6	17	11	21	8	8	4
Total phosphorus performance-ani	ual load of 2,950 g <sup>b</sup>	)					
Removal efficiency (%) <sup>a</sup>	0	0	0	33	58	27	60
Annual mass removed (g)	0	0	0	974	1,700	799	1,770
Capital cost performance (\$/g)	NT	NT	NT	39	40	79	37
Operational cost (\$/g/year)	NT	NT	NT	7	3	6	2
Dissolved inorganic nitrogen as to	tal nitrogen performa	ance-annual lo	ad of 26,600 g	b			
Removal efficiency (%) <sup>a</sup>	0	33	25	0	75	29	0
Annual mass removed (g)	0	8,770	6,640	0	19,900	7,740	0
Capital cost performance (\$/g)	NT	5	6	NT	3	8	NT
Operational cost (\$/g/year)	NT	0.89	0.93	NT	0.28	0.64	NT

Note: NT = No treatment; values are incalculable as lack of SCMpollutant treatment results in infinite costs.

<sup>a</sup>Values from UNHSC et al. 2012.

<sup>b</sup>Denotes change in unit mass from kg to g.

The 2012 article by Taylor and Wong discusses the life cycle costs of several types of BMPs including swales, bioretention systems, ponds, filters, and street sweeping (Taylor & Wong, 2002). Table 3-8 below compares the life cycle costs of two different types of street sweepers.

	SWEEP	ER TYPE
FEATURES	MECHANICAL	VACUUM ASSISTED
Life (years)	5	8
Purchase price (US\$)	75,000	150,000
Operation and maintenance costs (\$US/kerb km)	30	15
Annualised sweeper costs (\$US/kerb km/year)		
Weekly (sweeping frequency)	1,680	946
Bi-weekly	840	473
Monthly	388	218
Four times per year	129	73
Twice per year	65	36
Annual	32	18

#### Table 3-8: US Street Sweeping Cost Information (Taylor & Wong, 2002)

The journal article by Weiss provides the capital costs for various BMPs on a basis of volume of water treated and operating cost based on a percent of capital cost for specific BMPs (Weiss, Gulliver, & Erickson, 2007).

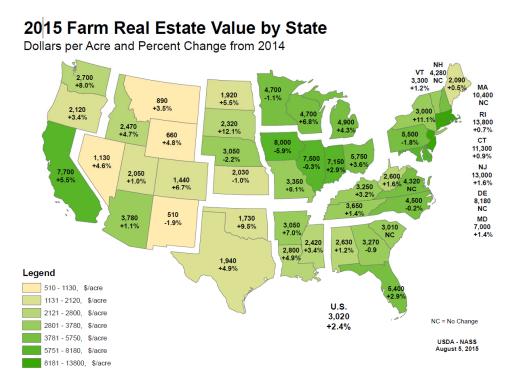
Another example of a BMP cost data source is the <u>Summary of Cost Data (2007)</u> spreadsheet published by the International Stormwater Database (Wrigth Waters Engineers, Inc. and GeoSyntec Consultants, 2007). This Excel workbook published by the International Stormwater Database, prepared by Wright Waters Engineers, Inc. and Geosyntec Consultants, contains cost estimates and the year of the estimate for ponds, green roofs, grass swales, porous pavement, infiltration basins & trenches, media filters, and other BMPs. The cost data is normalized to BMP size.

Additional cost data may be found in journal articles and government reports such as the reports by Curtis, 2002 (Curtis, 2002) and Geosyntec Consultants, 2015 (Geosyntec Consultants, 2015).



#### 4. Land Value Data

An important cost consideration when planning BMPs, especially land intensive ones such as ponds and wetlands, is land cost. For Florida agricultural, commercial, and residential land it is best to check with Florida's local county property appraisers; the Florida Department of Revenue provides a webpage with links to Florida's various county property appraiser offices (http://dor.myflorida.com/dor/property/appraisers.html) (Florida Department of Revenue, 2016). Another source that can have relevant information is www.zillow.com and similar sites. For general values of agricultural land in the United States, the United States Department of Agriculture (USDA) publishes a yearly Land Values Summary (National Agricultural Statistics Service, 2015). The values of farm land, cropland, and pasture land for the various states in the Union are presented below in Figure 4-1, Figure 4-2, and Figure 4-3.

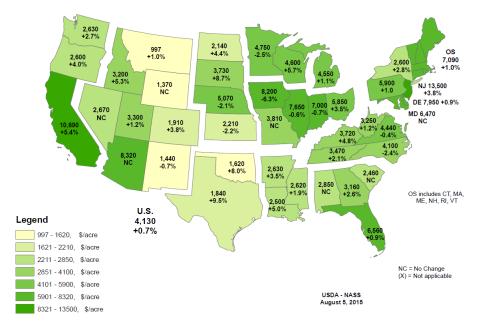


#### Figure 4-1: Farm Land Value by State (National Agricultural Statistics Service, 2015)

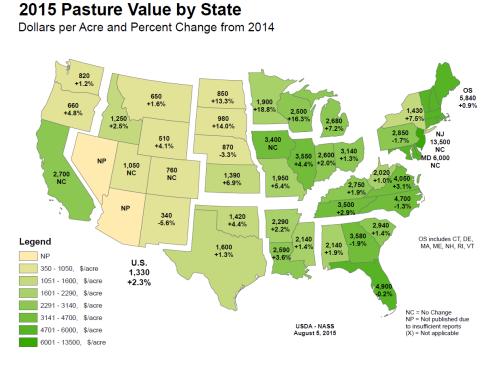


#### 2015 Cropland Value by State

Dollars per Acre and Percent Change from 2014



#### Figure 4-2: Cropland Value by State (National Agricultural Statistics Service, 2015)



## Figure 4-3: Pasture Land Value by State (National Agricultural Statistics Service, 2015)



#### 5. Cost Example

Consider a location in Jacksonville, Florida, within meteorological zone 4, with a mean average rainfall of 1270 mm (50 inches). The target removal efficiency of both TN and TP is 80%. The area of interest is a 2.0-acre single catchment. Pre-development conditions were agricultural-general land use with a non-DCIA Curve Number of 78 and no DCIA. The post-development land use condition is low-intensity commercial with a non-DCIA Curve Number of 78 and 90% DCIA. The post-development condition was assumed to consist of 40% building, 50% parking lot, and 10% green space. The green space is split, with ½ of it around the building and ½ left as natural or available for a retention basin. The two BMPs analyzed in this example were pervious concrete and a retention basin, both having an expected life of 20 years.

The pervious concrete section consisted of seven inches of #57 stone, compacted and then topped with a six-inch layer of pervious concrete. The soils were assumed to be sandy and free draining, allowing the system to fully recover in 72 hours from a 5-year design storm event. The retention basin was assumed to have a maximum depth of 12 inches. Recently, a significant land development near the catchment has been completed, resulting in an increase in land costs. Any additional land required to construct the retention basin was assumed to be purchased at a rate of \$525,000 per acre, based on local land values from Zillow.com in 2016. The differential construction cost to build a pervious pavement BMP compared to a regular pavement was calculated at \$200,561.29 per acre-ft. of treatment provided. The cost to maintain the installed pervious concrete was \$2,017.28 per year, based on the cost of vacuum sweeping and other maintenance activities. If pervious concrete was not used as a BMP, there was no associated maintenance cost for vacuum sweeping and other activities. The cost to build the retention basin was based on a capital cost of \$0.70 per cubic ft. of water treated in 1997 dollars. This value corresponds to a total capital cost of \$45,240.53 per acre-ft. of treatment provided in 2016 dollars. The maintenance cost for the retention basin was assumed to be 3% of the capital cost per year (see Table 3-4).



The period analysis for this example was 20 years and an interest rate of 1.8% was assumed, based on the most recent values published by the World Bank in 2014. Table 5-1 shows a summary of the different BMP scenarios examined. For the first scenario, only a pervious concrete parking lot was used, while for the sixth scenario only a retention basin was used. Scenarios two through five have different combinations of the two BMPs in series.

	BMP Characteristics											
Scenario	Pervious Concrete	Retention Basin Volume	Additional Land									
Scenario	Area [ac]	[ac-ft]	Required [ac]									
1	1	0	0									
2	0.825	0.0417	0									
3	0.65	0.0833	0									
4	0.325	0.173	0.073									
5	0.15	0.221	0.121									
6	0	0.271	0.171									

#### Table 5-1 – Summary of BMP characteristics for the six scenarios evaluated

\*Assume pervious concrete has an operational porosity of 25% (Hardin, 2014).

#### Solution:

1. From the introduction page click on the *Click Here to Start* button to proceed to the **General Site Information** worksheet (see Figure 5-1).

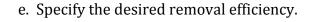
a. Select the *Reset Input for Stormwater Treatment Analysis* button to erase any existing data.

b. Enter the project name and select the meteorological zone in the **General Site Information** worksheet.

c. Indicate the mean annual rainfall amount in the **General Site Information** worksheet.



d. Select the *Specified Removal Efficiency* option from the *Type of Analysis* drop down menu in the **General Site Information** worksheet.



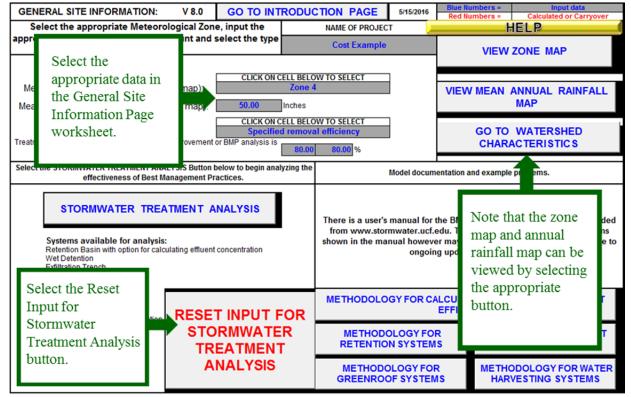


Figure 5-1 - General Site Information worksheet

#### 2. Click Watershed Characteristics.

a. In the *Click on Cell Below to Select Configuration* drop-down menu, select **A** – **Single Catchment** (see Figure 5-2).

b. Name Catchment No. 1 as **Example A** 

c. Select **Agricultural – General** in the drop-down menu for Pre-development land use.

d. Select **Low-Intensity Commercial** in the drop-down menu for Post-development land use.



e. Enter the remaining catchment area, percent DCIA, and curve numbers using the given information in the problem statement.

f. Input 0.0 acres for *Estimated BMPArea (No loading from this area)*. A value is only input here if the BMP has permanent standing water, such as a wetland or wet detention/retention pond.

WATERSHED CHA	V 8.0	GO TO S	STORMW	ATER TREATMENT ANALYSIS		Numbers = Numbers =	Input data Calculated	HELP - LAND USESIEMS				
SELECT CATCHMENT	5/15/2016	CLICK ON CE		V TO SELECT CONFIGURATION Single Catchment	VIEW CATCHMENT CONFIGURATION							
CATCHMENT N	Exampl		VIEW	Select the correct		ERWRITE D		NTRATIONS USING: POST:				
Pre-development land use: with default EMCs Post-development land use:	Agricultural - Ge CLICK ON CEL	L BELOW TO SE eneral: TN=2.800 TP=0. L BELOW TO SE mercial: TN=1.13 TP=	487 LECT		Catchment Configuration.			mg/L mg/L	mg/L mg/L			
with default EMCs Total pre-development catchr			2.00 Indicate land use				USE DEFAULT CONCENTRATIONS					
Total post-development catch Pre-development Non DCIA C Pre-development DCIA perce	CN:	rea:	2.00 78.00 0.00		and enter the give	n	e: ne (note no E .oading - Nitr		0.970 ac-ft/year 6.270 ac-ft/year 3.350 kg/year			
Post-development Non DCIA Post-development DCIA perc Estimated BMPArea (No load		78.00 90.00 0.00		information.	ou mus.	oading - Pho Loading - Ni Loading - Ph	trogen:	0.583 kg/year 8.738 kg/year 1.454 kg/year				

Figure 5-2 – Watershed Characteristics Worksheet

#### Scenario 1

The pervious concrete area, retention basin volume, and additional land required for Scenario 1 is presented in Table 5-2.

#### Table 5-2 - Scenario 1

	BMP Characteristics											
Camparia	Pervious Concrete	<b>Retention Basin Volume</b>	Additional Land									
Scenario	Area [ac]	[ac-ft]	Required [ac]									
1	1	0	0									

#### 3. Click Go to Stormwater Treatment Analysis.

a. Select the **Pervious Pavement** tab (see Figure 5-3).

- b. Enter **Pervious Concrete** in the *Pvmt Name* cell (see Figure 5-4).
- c. Enter **6.0** in the *Pervious Concrete Thickness (in)* cell (see Figure 5-4).
- d. Enter **25.0** in the *Pervious Concrete Operational Porosity (%)* cell (see Figure 5-4).



- e. Enter **7.0** in the *#57 rock Thickness (in)* cell (see Figure 5-4).
- f. Enter **1.0** in the *Area of the pervious pavement* cell (see Figure 5-4).

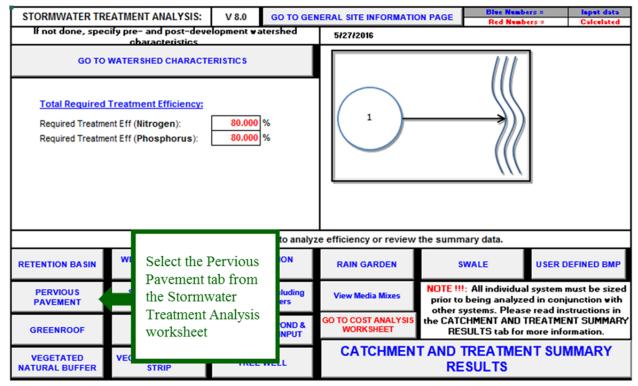


Figure 5-3 – Stormwater Treatment Analysis worksheet



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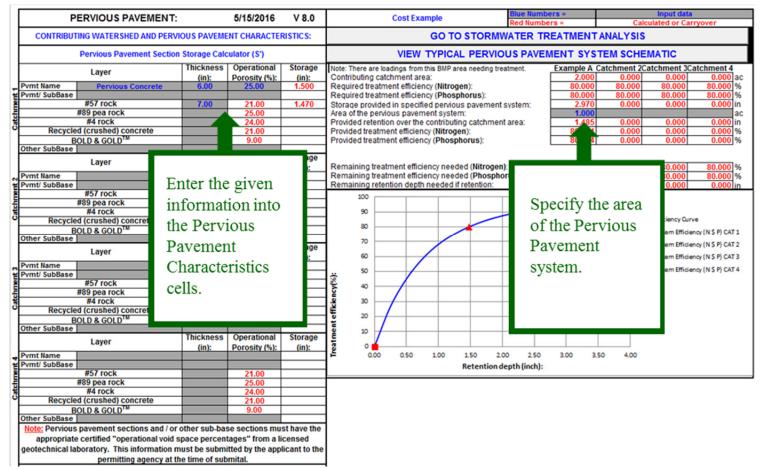


Figure 5-4 - Pervious Pavement BMP tab

4. Click Go to Stormwater Treatment Analysis to return to the Stormwater Treatment Analysis worksheet.



# a. Click **Catchments and Treatment Summary Results** tab to see if the design meets criteria (see Figure 5-5).

b. If it does not pass, go back and adjust the BMP inputs until it passes.

CATCHMENTS	AND TREATMEN	T SUMMARY RE	SULTS	V 8.0	Blue Numb Red Numb		Input data Calculated or Car	ryover	
CALCULATION METHODS: 1. The effectiveness of each BMP 2. Certain BMP treatment train co	-	GO TO STORMWATER TREATMENT ANALYSIS							
an example is a greenroof folk 3. Wet detention is last when use	owing a tree well.	GO TO	WATER	RSHED CHARACTER	ISTICS				
PROJECT TITLE Cos	t Example	Optional Identification	Catabaset 2	Catabaset 4	Thank yo	u for us	sing this BMPTRAI	VS model.	
BMP Name	Example A Pervious Pavement	Catchment 2	Catchment 3	Catchment 4					
BMP Name					NOTE: are 1			hment: tion	
BMP Name					purpos	Dro	ceed to the	es use	
S	ummary Perform	ance of Entire W	atershed		mul <sup>.</sup> maxim	Cost Analysis		e a iment.	
с со				2016 NS MODEL	<b>GO TO</b>	WO	rksheet.	PAGE	
The treatment objective of 8		Treatment Objectives							
Ph objective of 8 Te removal of Th Ter TP has been r		or Target	$\frown$		HEL	P - 3	СА СНМ	ENTS	
Targ Prov Prov							O COST ANALYSI	S	
Uliconarged Load, ir (kgyr α Discnarged Lögö, ν (kgyr & Ibbr/) Load Removed, N (kg/yr & Ib/yr):	1.73 0.29 7.00	3.82 0.64 15.43	$\smile$						
Load Removed, P (kg/yr & lb/yr):	1.17	2.57							

**Figure 5-5 – Catchments and Treatment Summary Results** 

#### Scenario 1, Costs

#### 5. Click Go to Cost Analysis Worksheet.

a. Table 5-3 provides capital and operating costs for pervious pavement. Use these values and adjust the cost to be on a per acre of impervious area treated basis.

#### Table 5-3 - Costs for pervious pavement per acre

Capital cost per hectare of impervious area in 2012 dollars	Annual operating and maintenance cost per hectare of impervious area in 2012 dollars	Capital cost per acre of impervious area in 2012 dollars	Annual operating and maintenance cost per acre of impervious area in 2012 dollars
\$65,700.00	\$2,670.00	\$26,588.43	\$1,080.53



b. The literature is providing the cost data on a basis of cost per acre of impervious area, however the model needs the BMP Cost input on a basis of (\$/acre-ft) for capital cost and 0 & M cost on a basis of (\$/year) so some modifications are needed. For the basis of this conversion, consider the rainfall on the pavement to all be treated; the buildings will also be considered to translate all the rainfall to runoff. Recall that the site is 2 acres with 40% building and 50% parking lot, thus 90% shall be considered as the Effective Impervious Area which is 1.8 acres (see Table 5-4).

#### Table 5-4 - Costs for pervious pavement in 2012 dollars

Capital cost per acre of impervious area in 2012 dollars	Annual operating and maintenance cost per acre of impervious area in 2012 dollars	Acres contributing to the BMP	Capital cost in 2012 dollars	Annual operating and maintenance cost in 2012 dollars
\$26,588.43	\$1,080.53	1.8	\$47,859.17	\$1,944.96

c. Convert values to 2016 dollars using inflation calculator (see Table 5-5).

#### Table 5-5 - Costs for pervious pavement in 2016 dollars

po in are	pital cost er acre of pervious ea in 2016 dollars	Annual operating and maintenance cost per acre of impervious area in 2016 dollars	Acres contributing to the BMP	Capital cost in 2016 dollars	Annual operating and maintenance cost in 2016 dollars
\$2	27,577.18	\$1,120.71	1.8	\$49,638.92	\$2,017.28

d. The model is in terms of \$/acre-ft of water treated thus a volume calculation needs to be made. The area used for this calculation is the actual area of pervious pavement, 1 acre. The depth used is the "Storage provided in specified pervious pavement system" from the *Pervious Pavement worksheet* (2.970 inches).

Storage provided in specified pervious pavement system [inches] \*  $\frac{1 ft}{12 inches}$ \* area of pervious pavement [acre] = volume [acre - feet]

2.970 inches \* 
$$\frac{1ft}{12 \text{ inches}}$$
 \* 1acre = 0.2475 acre – feet

Convert capital cost to \$/(Acre-ft) in 2016 dollars

$$\frac{\$49,638.92}{0.2475 \ acre - ft} = \frac{\$200,561.29}{acre - ft}$$

e. Enter capital cost and operating cost data into model.

6. Fill in the remaining fields in the **Life Cycle Cost Comparison Worksheet** (see Figure 5-6).

a. For What type of analysis would you like to perform select Net Present Worth

b. The most recent interest rate value published by the World Bank is for the year 2014 so we will use this value, which is 1.8%.

c. Problem statement gave life span as 20 years; assume the project duration is the same since not otherwise stated.

d. Leave *BMP Fixed Cost* blank since the source cost data had the *Fixed Data* and *BMP Cost* combined into a single value.

e. Leave *Estimated Future Cost of Replacement* blank since the Project Duration and Expected Lifespan are the same.

f. Leave *Cost Land needed for BMP* blank because according to the data for scenario1, no additional land is needed.

- g. Enter the Scenario #
- h. Click Perform Cost Analysis

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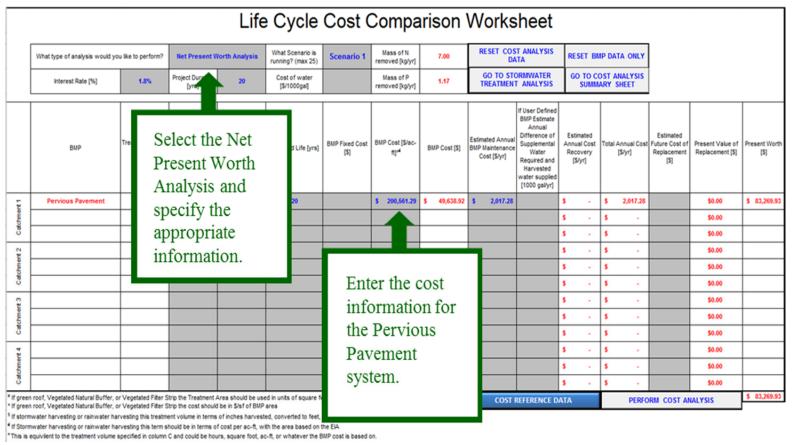


Figure 5-6 - Life Cycle Cost Comparison Worksheet

7. The resulting **Life Cycle Cost Analysis Summary Capital Cost** and **Life Cycle Cost of N and P Removed** figures and table will be created for Scenario 1 (see Figure 5-7).

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	GO TO COST ANALYSIS WORKSHEET						Lif	fe (	Сус	le (	Cos	st A	٨na	lys	is	Su	m	mai	ry	Ca	pita	al C	osi	t [\$	\$]		
	Life Cyc	le Cost Analy	sis Summar	у		\$90,000.00	Γ																				
	Net Present Worth [\$]	Cost of N Removed [\$/kg vr]	Cost of P Removed [\$/kg- vr]	TN Removed [kg/yr]	TP Removed [kg/yr]	\$80,000.00 \$70,000.00 \$60,000.00																					
Scenario 1 Scenario 2 Scenario 3 Scenario 4 Scenario 5 Scenario 7 Scenario 7 Scenario 9 Scenario 10	\$ 83,269.93	\$ 11,887.91	\$ 71,453.90	7.00	1.17	\$50,000.00 \$40,000.00 \$30,000.00 \$20,000.00 \$10,000.00 \$-	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 7	Scenario 8	Scenario 9	scenario 10	Scenario 11	Scenario 12 Scenario 13	Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18	Scenario 20	Scenario 21	Scenario 22	Scenario 23	scenario 24 Scenario 25
Scenario 11 Scenario 12 Scenario 13 Scenario 14								Lif		-			t o	f N	ar	nd	PF	Ren	no	ve	d [\$	5/k	g-y				
Scenario 15 Scenario 16 Scenario 17 Scenario 18 Scenario 20 Scenario 21 Scenario 22 Scenario 23						\$80,000.00 \$70,000.00 \$60,000.00 \$50,000.00 \$40,000.00 \$30,000.00 \$20,000.00 \$10,000.00																					
Scenario 24 Scenario 25						\$-	Scenario 1	Scenario 2	Scenario 3		Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18 Scenario 19	Scenario 20	Scenario 21	Scenario 22	Scenario 23	scenario 24 Scenario 25

#### Figure 5-7 – Life Cycle Cost Analysis Summary

8. Return to the **Stormwater Treatment Analysis** worksheet.



#### Scenario 2

The pervious concrete area, retention basin volume, and additional land required for Scenario 2 is presented in Table 5-6.

#### Table 5-6 – Scenario 2

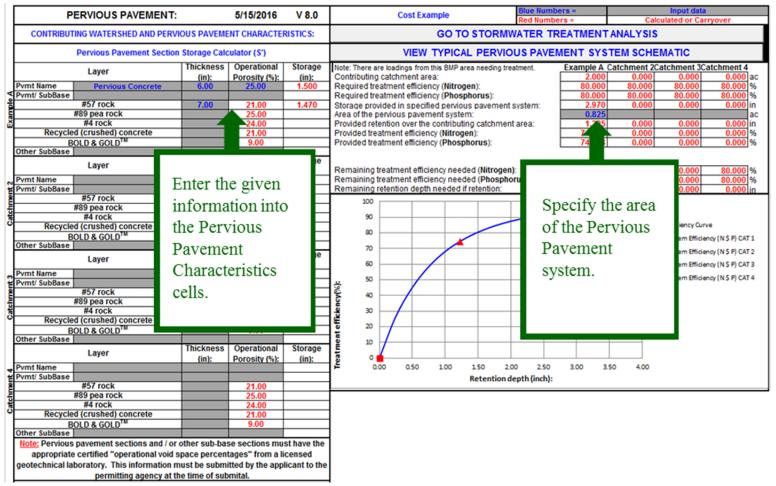
BMP Characteristics											
Campanio	Pervious Concrete	<b>Retention Basin Volume</b>	Additional Land								
Scenario	Area [ac]	[ac-ft]	Required [ac]								
2	0.825	0.0417	0								

9. Select the BMP from the list and enter the information into the tab as you did in Step 3; however, this time you will also have to enter information for the retention basin.

a. The information you previously entered for Pervious Pavement should still be in the cells and you will only need to change the value for *Area of the pervious pavement system*. If the values are not in the cells, re-enter them as you did in Step 3 (using the new area value) (see Figure 5-8).

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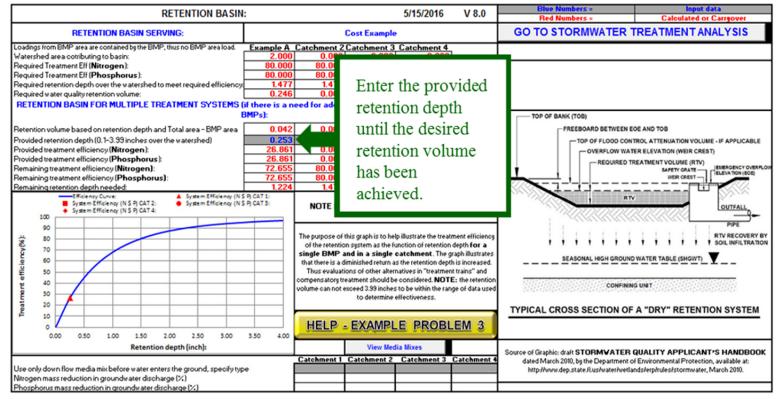
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**Figure 5-8 - Pervious Pavement BMP tab** 

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#### **Figure 5-9 – Retention Basin BMP tab**

\*The problem stated that the provided retention volume for this scenario is 0.0417 acre-ft  $\approx$  0.042 acre-ft. Use an iterative guess and check approach by entering in a *Provided retention depth* and seeing if the *Retention volume based on retention depth* and *Total area –BMP area* becomes the desired value of 0.042 ac-ft. (see Figure 5-9).



10. Click **Catchments and Treatment Summary Results** to see if the design meets criteria. If it does not pass, then go back and adjust the BMP inputs until it passes (see Figure 5-10).

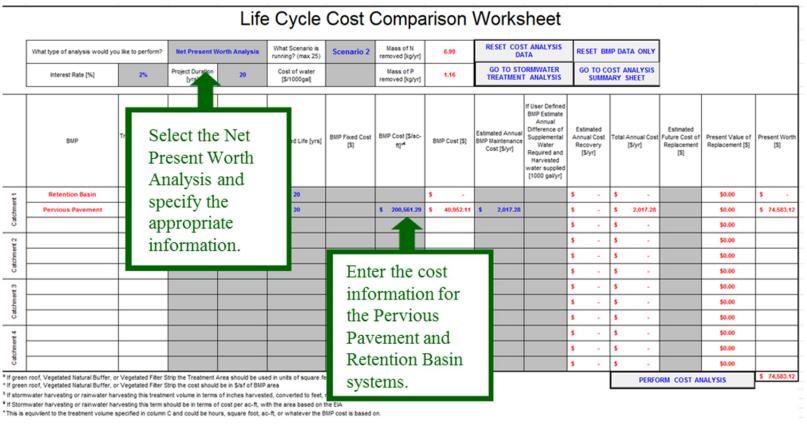
CATCHMENTS	AND TREATMEN	T SUMMARY RE	SULTS	V 8.0	Blue Numb Red Numb		over	
CALCULATION METHODS: 1. The effectiveness of each BMF 2. Certain BMP treatment train co		GO TO STORMWATER TREATMENT ANALYSIS						
an example is a greenroof foll 3. Wet detention is last when use	owing a tree well.	GO TO	WATERSHED CHARACTERIS	STICS				
PROJECT TITLE Cos	t Example	Optional Identification		and a second d	Thank yo		odel.	
BMP Name	Example A	Catchment 2	Catchment 3	Catchment 4				
	Retention Basin				NOTE: I		ment	
BMP Name	Pervious Pavement				are tr	-	<b>n</b>	
BMP Name					purpose	Proceed to the	s use	
	ummany Porform	ance of Entire W	atorshod		multi maximu	Cost Analysis	a ent.	
-	uninary Periorin	ance of Entire W				worksheet.		
H		-		/2016 NS MODEL	GO TO (		AGE	
The treatment		Treatment						
The treatment objective of 80 removal of TN TP has been m		Objectives		///				
		or Target		111				
<ul> <li>removal of TN</li> </ul>	and	MET	$\square$		HELP	P - 3 CAICHME	NTS	
TP has been m	net.	1	$\left  \right\rangle$					
		4		<b>&gt;</b> ))		GO TO COST ANALYSIS		
Pr		{				WORKSHEET		
Discharged Load, it (kg/yr a	1.75	3.85						
Discharged Load, P (Kg/yr &	0.29	0.64		(((				
Load Removed, N (kg/yr & lb/yr):		15.40		~~~~				
Load Removed, P (kg/yr & lb/yr):	1.16	2.56						

**Figure 5-10 – Catchments and Treatment Summary Results** 

#### Scenario 2, Costs

11. Click Go to Cost Analysis Worksheet.

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#### Figure 5-11 - Life Cycle Cost Comparison Worksheet

\*For pervious pavement, use the *BMP Cost* [\$/acre-ft] and *Estimated Annual BMP Maintenance Cost* determined in Scenario 1 for Scenario 2; both of these are based on the area of impervious area being treated and as stated in Scenario 1 the entire paved and building covered area is being considered impervious for the purpose of cost estimate.



a. Table 5-7 provides capital cost data on a volumetric basis (cubic feet) of water treated for retention basins, the operating cost can be calculated as a percentage of capital cost.

- Capital cost of \$0.7/cubic ft (1997 dollars)
- Operating cost of 3% of capital cost.
- 1 acre-foot = 43559.9 ft<sup>3</sup>
- From Cost sheet: Treatment Volume = 0.0422
- Use the Inflation Calculator to adjust to 2016 dollars.
- b. Calculate the Capital and operating costs.

Table 5-7 - Retention basin costs

Capital cost per cubic foot of treated water in 1997	of treated water in 1997	Capital cost per acre-foot of treated water in 2016
dollars	dollars	dollars
\$0.70	\$30,491.93	\$45,240.53

c. Enter capital cost and operating cost data into model. The best way to calculate and enter the operating cost is in the model cell for *Estimated Annual BMP Maintenance Cost*; create a formula to multiply the *BMP capital Cost* by 3% (see Figure 5-11).

12. Fill in the remaining fields (see Figure 5-12).

a. For What type of analysis would you like to perform select Net Present Worth

b. The most recent interest rate value published by the World Bank is for the year 2014 so we will use this value, which is 1.8%.

c. Problem statement gave life span as 20 years; assume the project duration is the same since not otherwise stated.

d. Leave *BMP Fixed Cost* blank since the source cost data had the *Fixed Data* and *BMP Cost* combined into a single value.

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- e. Leave *Estimated Future Cost of Replacement* blank since the Project Duration and Expected Lifespan are the same.
- f. Leave *Cost Land needed for BMP* blank because according to the data for scenario 2, no additional land is needed.
- g. Enter the Scenario #

				Life	e Cycle	Cost (	Compa	arison	Works	heet						
	What type of analysis would you	like to perform?	Net Present W	forth Analysis	What Scenario is running? (max 25)	Scenario 2	Mass of N removed [kg/yr]	6.99		t analysis Ta	RESET B	MP DAT	TA ONLY			
	Interest Rate [%]	1.8%	Project Duration	20	Cost of water [\$/1000gal]		Mass of P removed [kg/yr]	1.16		ORMWATER ANALYSIS		COST AI	NALYSIS SHEET			
	BMP	Pre	ect the sent Wa	orth	cted Life (yrs)	BMP Fixed Cost [\$]	BMP Cost (\$/ac- ମ୍ବ <sup>4</sup>	BMP Cost [\$]	Estimated Annual BMP Maintenance Cost [\$/yr]	If User Defined BMP Estimate Annual Difference of Supplemental Water Required and Harvested water supplied [1000 gallyr]	Estimated Annual Cost Recovery [\$/yr]		Annual Cost [\$/yr]	Estimated Future Cost of Replacement [\$]	Present Value of Replacement [\$]	Present Worth [5]
۷,	Retention Basin		-		20		\$ 45,240.53	\$ 1,907.64	\$ 57.23		\$ -	\$	57.23		\$0.00	\$ 2,861.75
Example	Pervious Pavement	-	cify the		20		\$ 200,561.29	\$ 40,952.11	\$ 2,017.28		<b>\$</b> -	\$	2,017.28		\$0.00	\$ 74,583.12
		app	ropriat	e							s -	5			\$0.00	
ort 2			ormatio								s -	5			\$0.00	
Catchine			Jinano	·11.							s -	5			\$0.00	
c						Enter	the co	st			s -	5			\$0.00	
113											s	5			\$0.00	
Ē						infor	mation	IOT			s -	5			\$0.00	
Catch						the P	ervious	s			s -	\$	-		\$0.00	
514 4						Dove	ment a	nd			s -	\$			\$0.00	
Ĕ.											s -	5			\$0.00	
Catch						Reter	ntion B	asin			s -	\$	-		\$0.00	
If green	roof, Vegetated Natural Buffer, or roof, Vegetated Natural Buffer, or water harvesting or rainwater harv	Vegetated Filter S	trip the cost should	be in \$/sf of BMP	area	syste	ms.		COST	REFERENCE D	ATA		PERFO	RM COST A	NALYSIS	\$ 77,444.87

\* This is equivient to the treatment volume specified in column C and could be hours, square foot, ac-ft, or whatever the BMP cost is based on.

Figure 5-12 - Updated Life Cycle Cost Comparison Worksheet



j		T ANALYSIS SHEET					Life	Сус	le	Cos	st A	٩na	lys	is S	Sur	nm	nar	уC	ар	ita	l Co	ost	[\$]	]		
	Life Cyc	le Cost Analy	/sis Summar	у		\$84,000.00	T																			
	Net Present Worth [\$]	Cost of N Removed [\$/kg yr]	Cost of P Removed [\$/kg yr]	TN Removed [kg/yr]	TP Removed [kg/yr]	\$83,000.00 \$82,000.00 \$81,000.00																				
Scenario 1	\$ 83,269.93	\$ 11,887.91	\$ 71,453.90	7.00	1.17	\$80,000.00																				
Scenario 2	\$ 77,444.86	\$ 11,076.28	\$ 66,575.54	6.99	1.16	\$79,000.00																				
Scenario 3						\$78,000.00																				
Scenario 4						\$77,000.00																				
Scenario 5						\$76,000.00																				
Scenario 6						\$75,000.00																				
Scenario 7						\$74,000.00	- N	່ຕ່	4 1	o' 0	~	~	പ്	- '-			4	<b>n</b>			<u>_</u>		- '	~ ~	- <del>-</del>	
Scenario 8						]			ê.	2 2	10	ę	ę	0 10	010	013	o 14	010	0 1	013	0 10	0 2(	0 2	2 0	0 24	0 2
Scenario 9							Scenario Scenario	Scenario	Scenario	Scenario Scenario	Scenario 7	Scenario 8	Scenario	Scenario 10 Scenario 11	Scenario 12	Scenario 13	Scenario	Scenario 15	Scenario 16 Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22 Scenario 23	Scenario	scenario 25
Scenario 10							S S	S	S .	y y	S	S	S,	Sce Sce	Sce	Sce	Sce	Sce	Sce Sce	Sce	Sce	Sce	Sce	ξ, ζ	Sce	Sce
Scenario 11																										
Scenario 12							Lif	fe (	Vc	le C	os	t of	fΝ	an	d F	R	em	ιov	/ed	ſŚ.	/kg	z-vi	rl –			
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#### Figure 5-13 – Life Cycle Cost Analysis Summary

13. Return to the **Stormwater Treatment Analysis** worksheet (see Figure 5-13).



#### Scenario 3

The pervious concrete area, retention basin volume, and additional land required for Scenario 3 is presented in Table 5-8.

#### Table 5-8 – Scenario 3

	Е	MP Characteristics	
Sconorio	Pervious Concrete	<b>Retention Basin Volume</b>	Additional Land
Scenario	Area [ac]	[ac-ft]	Required [ac]
3	0.65	0.0833	0

14. Select the BMP from the list and enter the information into the tab as you did in Step 3; however, this time you will also have to enter information for the retention basin.



a. The information you previously entered for Pervious Pavement should still be in the cells and you will only need to change the value for *Area of the pervious pavement system*. If the values are not in the cells, re-enter them as you did in Step 3 (using the new area value) (see Figure 5-14).

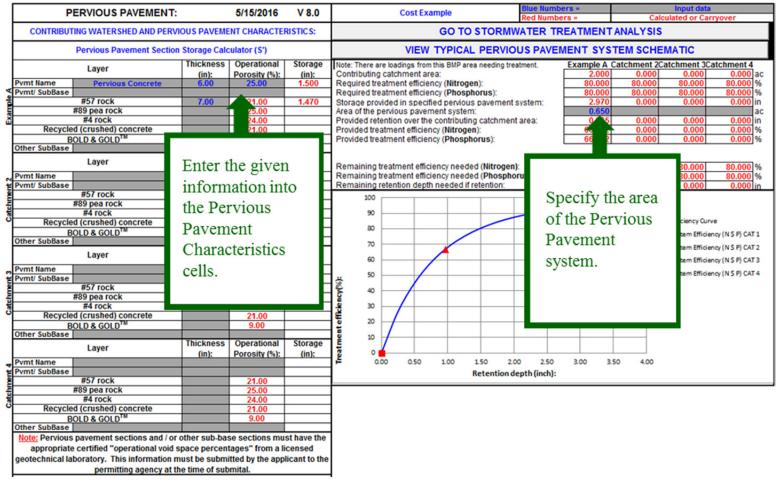


Figure 5-14 – Pervious Pavement BMP tab



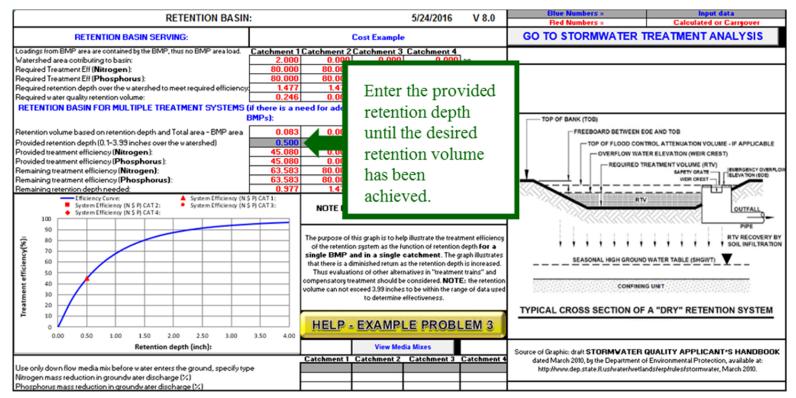


Figure 5-15 - Retention Basin BMP tab

\*The problem stated that the provided retention volume for this scenario is 0.083 acre-ft. Use an iterative guess and check approach by entering in a *Provided retention depth* and seeing if the *Retention volume based on retention depth and Total area* – *BMP area* becomes the desired value (see Figure 5-15).



#### 15. Click Catchment and Treatment Summary Results

a. As seen in the **Catchment and Treatment Summary Results**, the *Treatment Objectives or Target* was not met. We will have to go back and adjust the parameters for one or both of the BMPs.

b. Return to the **Stormwater Treatment Analysis** worksheet and click the *Retention Basin* Tab. Increase the *Provided retention depth* to 0.515 in. This results in a corresponding *Retention volume based on retention depth and total area – BMP area* of 0.086 ac-ft.

c. Return to the **Stormwater Treatment Analysis** worksheet and click **Catchment and Treatment Summary Results**. The Treatment Objectives have now been met (see Figure 5-16).

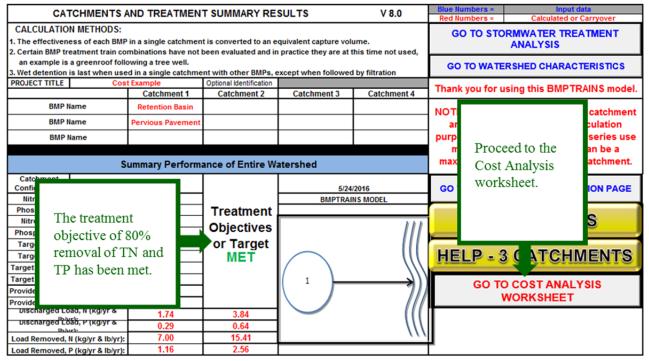


Figure 5-16 - Catchments and Treatment Summary Results

#### Scenario 3, Costs

16. Table 5-7 provides capital cost data on a volumetric basis (cubic feet) of water treated for retention basins, the operating cost can be calculated as a percentage of capital cost.



a. For the retention basin use the same *BMP Cost per acre-ft* used in Scenario 2, no further data entry is need for capital cost. Additionally, just as in Scenario 2, multiply the formula for *Estimated Annual BMP Maintenance Cost* is still 3% of the capital *BMP Cost*.

b. For pervious pavement, use the *BMP Cost* [\$/acre-ft] and *Estimated Annual BMP Maintenance Cost* determined in Scenario 1 for Scenario 3; both of these are based on the area of impervious area being treated and as stated in Scenario 1 the entire paved and building covered area is being considered impervious for the purpose of cost estimate.

17. Fill in the remaining fields (see Figure 5-17).

a. For What type of analysis would you like to perform select "Net Present Worth"

b. The most recent interest rate value published by the World Bank is for the year 2014 so we will use this value, which is 1.8%.

c. Problem statement gave life span as 20 years; assume the project duration is the same since not otherwise stated.

d. Leave *BMP Fixed Cost* blank since the source cost data had the *Fixed Data* and *BMP Cost* combined into a single value.

e. Leave *Estimated Future Cost of Replacement* blank since the Project Duration and Expected Lifespan are the same.

f. Leave *Cost Land needed for BMP* blank because according to the data for scenario3, no additional land is needed.

g. Enter the Scenario #

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Life Cycle Cost Comparison Worksheet RESET COST ANALYSIS DATA What Scenario is Mass of N RESET BMP DATA ONLY What type of analysis would you like to perform? Net Present Worth Analysis Scenario 3 7.00 running? (max 25) emoved [kg/yr] GO TO STORMWATER TREATMENT ANALYSIS GO TO COST ANALYSIS SUMMARY SHEET Cost of water Mass of P Project C Interest Rate [%] 1.8% 1.16 20 [\$/1000gal] emoved [kg/yr] If User Defined **BMP Estimate** Annual Select the Net Difference of Estimated Estimated Estimated Annual **BMP Fixed Cost** BMP Cost [\$/acotal Annual Cost Future Cost of Present Value of Supplemental Annual Cost Present Worth ed Life [yrs] BMP Cost [\$] **BMP Maintenance** ft]\*\* Recovery [\$/vr1 Replacement Replacement [\$] [\$] Water [\$] Present Worth Cost [\$/yr] Required and [\$/yr] [\$] Harvested water supplie Analysis and [1000 gal/yr] 45,240.53 3,883.1 116.49 \$ 5,825.20 **Retention Basin** 116.49 \$0.00 specify the Example **Pervious Pavement** \$ 200,561.29 32,265.30 • 2,017.28 2,017.28 \$0.00 \$ 65,896.31 appropriate \$0.00 information. ent 2 \$0.00 Catchine \$0.00 Enter the cost \$0.00 ent 3 \$0.00 information for \$ Catchme \$0.00 the Pervious \$0.00 \$ ert 4 Pavement and \$0.00 \$0.00 **Retention Basin** \$0.00 \* If green roof, Vegetated Natural Buffer, or Vegetated Filter Strip the Treatment Area should be used in units of square \$ 71,721.52 systems. COST REFERENCE DATA PERFORM COST ANALYSIS \* If green roof, Vegetated Natural Buffer, or Vegetated Filter Strip the cost should be in \$/sf of BMP area <sup>8</sup> If stormwater harvesting or rainwater harvesting this treatment volume in terms of inches harvested, converted to fee <sup>4</sup> If Stormwater harvesting or rainwater harvesting this term should be in terms of cost per ac-ft, with the area based on the EIA \*This is equivilent to the treatment volume specified in column C and could be hours, square foot, ac-ft, or whatever the BMP cost is based on

Figure 5-17 – Life Cycle Cost Comparison Worksheet

18. Perform the Cost Analysis (see Figure 5-18).

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Figure 5-18 – Life Cycle Cost Analysis Summary

19. Return to the **Stormwater Treatment Analysis** worksheet.



#### Scenario 4

The pervious concrete area, retention basin volume, and additional land required for Scenario 4 is presented in Table 5-9.

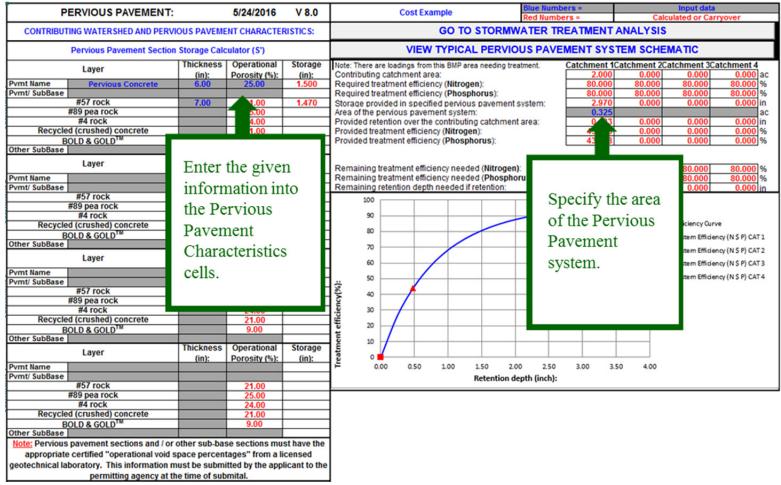
#### Table 5-9 – Scenario 4

	E	SMP Characteristics	
Scenario	Pervious Concrete	Retention Basin Volume	Additional Land
Scenario	Area [ac]	[ac-ft]	Required [ac]
4	0.325	0.173	0.073

20. Select the BMP from the list and enter the information into the tab as you did in Step 3; however, this time you will also have to enter information for the retention basin.

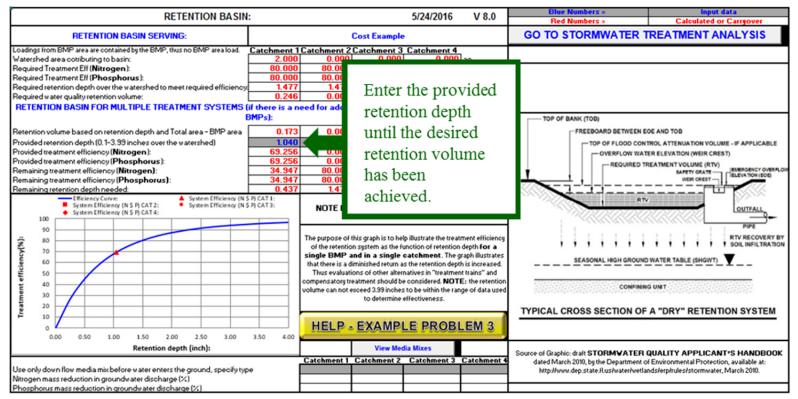


a. The information you previously entered for Pervious Pavement should still be in the cells and you will only need to change the value for *Area of the pervious pavement system*. If the values are not in the cells, re-enter them as you did in Step 3 (using the new area value) (see Figure 5-19).



**Figure 5-19 – Pervious Pavement BMP tab** 





#### Figure 5-20 - Retention Basin BMP tab

\*The problem stated that the provided retention volume for this scenario is 0.173 acre-ft. Use an iterative guess and check approach by entering in a *Provided retention depth* and seeing if the *Retention volume based on retention depth and Total area* – *BMP area* becomes the desired value (see Figure 5-20).



# 21. Return to the **Stormwater Treatment Analysis** worksheet and click **Catchment and Treatment Summary Results** (see Figure 5-21).

a. If the treatment objectives are not met, adjust the BMP inputs until it passes.

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Figure 5-21 - Catchments and Treatment Summary Results

#### Scenario 4, Costs

22. This Scenario requires additional land.

a. Based on Zillow, May 2016, 1 acre of land costs about \$525,000. For this scenario, the cost to purchase additional land would be \$38,325.

b. For the retention basin use the same *BMP Cost per acre-ft* used in Scenario 2, no further data entry is need for capital cost. Additionally, just as in Scenario 2, multiply the formula for *Estimated Annual BMP Maintenance Cost* is still 3% of the capital *BMP Cost*.

c. For pervious pavement, use the *BMP Cost* [\$/acre-ft] and *Estimated Annual BMP Maintenance Cost* determined in Scenario 1 for the current Scenario; both of these



are based on the area of impervious area being treated and as stated in Scenario 1 the entire paved and building covered area is being considered impervious for the purpose of cost estimate.

23. Fill in the remaining fields (see Figure 5-22).

a. For What type of analysis would you like to perform select "Net Present Worth"

b. The most recent value published by the World Bank is for the year 2014 so we will use this value, which is 1.8%.

c. Problem statement gave life span as 20 years; assume the project duration is the same since not otherwise stated.

d. Leave *BMP Fixed Cost* blank since the source cost data had the *Fixed Data* and *BMP Cost* combined into a single value.

e. Leave *Estimated Future Cost of Replacement* blank since the Project Duration and Expected Lifespan are the same.

f. Leave *Cost Land needed for BMP* blank because according to the data for scenario3, no additional land is needed.

g. Enter the Scenario #

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#### Figure 5-22 - Life Cycle Cost Comparison Worksheet

24. Perform Cost Analysis (see Figure 5-23).

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#### Figure 5-23 – Life Cycle Cost Analysis Summary

25. Return to **Stormwater Treatment Analysis** worksheet.



#### Scenario 5

The pervious concrete area, retention basin volume, and additional land required for Scenario 5 is presented in Table 5-10.

#### Table 5-10 – Scenario 5

	E	MP Characteristics	
Campania	Pervious Concrete	<b>Retention Basin Volume</b>	Additional Land
Scenario	Area [ac]	[ac-ft]	Required [ac]
5	0.15	0.221	0.12

26. Select the BMP from the list and enter the information into the tab as you did in Step 3; however, this time you will also have to enter information for the retention basin.



a. The information you previously entered for Pervious Pavement should still be in the cells and you will only need to change the value for *Area of the pervious pavement system*. If the values are not in the cells, re-enter them as you did in Step 3 (using the new area value) (see Figure 5-24).

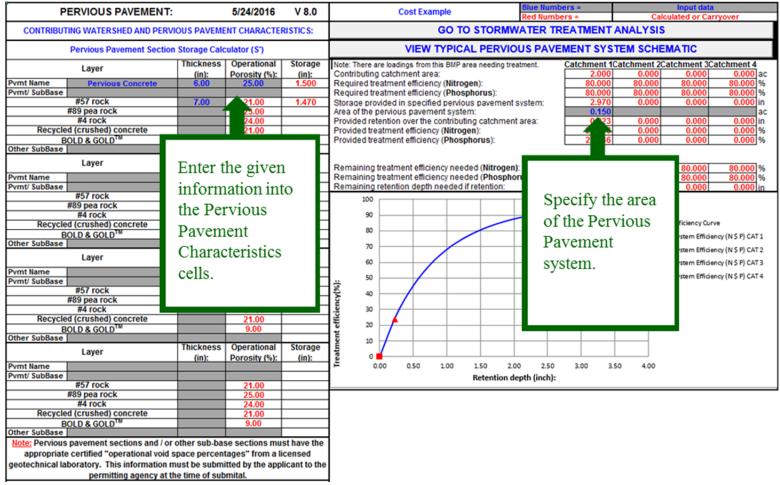
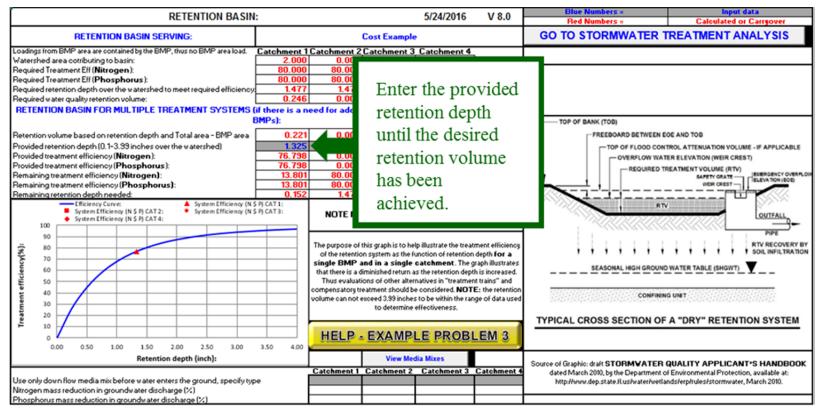


Figure 5-24 – Pervious Pavement BMP tab





#### Figure 5-25 - Retention Basin BMP tab

\*The problem stated that the provided retention volume for this scenario is 0.221 acre-ft. Use an iterative guess and check approach by entering in a *Provided retention depth* and seeing if the *Retention volume based on retention depth and Total area* – *BMP area* becomes the desired value (see Figure 5-25).



# 27. Return to the **Stormwater Treatment Analysis** worksheet and click **Catchment and Treatment Summary Results** (see Figure 5-26).

a. If the treatment objectives are not met, adjust the BMP inputs until it passes.

CATCHMENTS	ND TREATMEN	T SUMMARY RE	SULTS	V 8.0	Blue Nun Red Nun		Input data Calculated or Ca	
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lbb(r)	0.27	0.60						
Load Removed, N (kg/yr & lb/yr): Load Removed, P (kg/yr & lb/yr):		2.60						

Figure 5-26 - Catchments and Treatment Summary Results

#### Scenario 5, Costs

28. This Scenario requires additional land.

a. Based on Zillow, May 2016, 1 acre of land costs about \$525,000. For this scenario, the cost to purchase additional land would be \$63,000.

b. For the retention basin use the same *BMP Cost per acre-ft* used in Scenario 2, no further data entry is need for capital cost. Additionally, just as in Scenario 2, multiply the formula for *Estimated Annual BMP Maintenance Cost* is still 3% of the capital *BMP Cost*.

c. For pervious pavement, use the *BMP Cost* [\$/acre-ft] and *Estimated Annual BMP Maintenance Cost* determined in Scenario 1 for the current Scenario; both of these



are based on the area of impervious area being treated and as stated in Scenario 1 the entire paved and building covered area is being considered impervious for the purpose of cost estimate.

29. Fill in the remaining fields (see Figure 5-27).

a. For What type of analysis would you like to perform select "Net Present Worth"

b. The most recent value published by the World Bank is for the year 2014 so we will use this value, which is 1.8%.

c. Problem statement gave life span as 20 years; assume the project duration is the same since not otherwise stated.

d. Leave *BMP Fixed Cost* blank since the source cost data had the *Fixed Data* and *BMP Cost* combined into a single value.

e. Leave *Estimated Future Cost of Replacement* blank since the Project Duration and Expected Lifespan are the same.

f. Leave *Cost Land needed for BMP* blank because according to the data for scenario3, no additional land is needed.

g. Enter the Scenario #

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				Life	e Cycle	Cost (	Γ	Sel		the	Ne	>t	eet							
	What type of analysis would yo	u like to perform?	Net Present V	forth Analysis	What Scenario is running? (max 25)	Scenario 5				nt W			NALYSIS	R	ESET BA	MP D/	ATA ONLY	GO TO GI	ENERAL SITE ATION PAGE	
	Interest Rate [%]	1.8%	Project Duration [yrs]	20	Cost of water [\$/1000gal]					sis a			WATER NALYSIS	G			ANALYSIS SHEET			-
	BMP	Treatment volume [ac-ft] <sup>ws</sup>	If User Defined BMP, Specify the unit that cost is based on [???] <sup>4</sup>	Cost of Land needed for BMP [\$]	Expected Life [yrs]	BMP Fixed Cost [\$]		app	ro	ỳ thơ priat natic	e		If User efined BMP Estimate Annual ference of pplemental Water quired and larvested water	Ann Re	timated ual Cost covery \$/yr]		otal Annual Lost [\$/yr]	Estimated Future Cost of Replacement [\$]	Present Value of Replacement [\$]	Present Worth [\$]
-	Retention Basin	0.2208		\$ 63,000.00	20		s	45,240.53	5	9,990.62	s	299.72	supplied [1000 nal/vr]	s		5	299.72		\$0.00	\$ 77,987.36
hment 1	Pervious Pavement	0.0371			20		-	200,561.29	\$	7,445.84	\$	2,017.28		\$		\$	2,017.28		\$0.00	\$ 41,076.85
Catchm														s		\$			\$0.00	
ont 2														\$	-	\$			\$0.00	
Ē							_							s	-	\$			\$0.00	
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Catchm										1	H			\$	-	\$			\$0.00	
_						the P	er	vious	S					\$	-	\$			\$0.00	
ent 4						Paver	m	ent a	ıd					\$	-	\$			\$0.00	-
Catchm						Reter					H			\$	-	\$			\$0.00	
	n roof, Vegetated Natural Buffer, o	or Vegetated Filter	Strip the Treatmen	t Area should be i	used in units of sou				as.		H			5		\$			\$0.00	\$ 119,064.22
* If green	n roof, Vegetated Natural Buffer, o twater harvesting or rainwater ha	or Vegetated Filter	Strip the cost sho	uld be in \$/sf of Bl	IIP area	syster	m	s.			F	COSTI	REFERENCE D	ATA			PERFO	ORM COST A	VALYSIS	
" If Storn	water harvesting or rainwater harvesting or rainwater harvesting or rainwater harvesting equivilent to the treatment volume	arvesting this term	should be in terms	of cost per ac-ft,	with the area based		ed o	in.												7.10 1.18

#### Figure 5-27 – Life Cycle Cost Comparison Worksheet

30. Perform Cost Analysis (see Figure 5-28).

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]		ST ANALYSIS (SHEET					Life Cycle Cost Analysis Summary Capital Cost [\$]
	Life Cyc	le Cost Anal	sis Summar	у		\$140,000.00	
	Net Present Worth [\$]	Cost of N Removed [\$/kg yr]	Cost of P - Removed [\$/kg yr]	TN - Removed [kg/yr]	TP Removed [kg/yr]	\$120,000.00 \$100,000.00	
Scenario 1	\$ 83,269.93		\$ 71,453.90	7.00	1.17	\$80,000.00	
Scenario 2	\$ 77,444.86			6.99	1.16	\$60,000.00	
Scenario 3	\$ 71,721.59	\$ 10,252.00	\$ 61,621.09	7.00	1.16	\$60,000.00	
Scenario 4	\$ 99,852.33			7.06	1.18	\$40,000.00	
Scenario 5	\$ 119,064.22	\$ 16,772.15	\$ 100,811.30	7.10	1.18	\$20,000.00	
Scenario 6							
Scenario 7						Ş-	
Scenario 8							Scenario 1 Scenario 2 Scenario 2 Scenario 4 Scenario 5 Scenario 7 Scenario 2 Scenario 10 Scenario 20 Scenario 20 Scenario 22 Scenario 23 Scenario 23 S
Scenario 9							Scenario Sce
Scenario 10							, , , , , , , , , , , , , , , , , , ,
Scenario 11							
Scenario 12							Life Cycle Cost of N and P Removed [\$/kg-yr]
Scenario 13							
Scenario 14							Cost of N Removed [\$/kg-yr] Cost of P Removed [\$/kg-yr]
Scenario 15						\$120,000.00	
Scenario 16							
Scenario 17						\$100,000.00	
Scenario 18						\$80,000.00	
Scenario 19							1. 11
Scenario 20						\$60,000.00	
Scenario 21						\$40,000.00	
Scenario 22						\$40,000.00	
Scenario 23						\$20,000.00	┤╂╏┨┨┛
Scenario 24							
Scenario 25						Ş-	22 22 22 22 22 22 22 22 22 22 22 22 22
							Scenario 1 Scenario 2 Scenario 3 Scenario 5 Scenario 5 Scenario 6 Scenario 1 Scenario 10 Scenario 20 Scenario 23 Scenario 23 Scenario 23 Scenario 23 Scenario 23 Scenario 23 Scenario 22 Scenario 23 Scenario 23 S

#### Figure 5-28 – Life Cycle Cost Analysis Summary

31. Return to **Stormwater Treatment Analysis** worksheet.



#### Scenario 6

The pervious concrete area, retention basin volume, and additional land required for Scenario 6 is presented in Table 5-11.

#### Table 5-11 – Scenario 6

BMP Characteristics											
Scenario	Pervious Concrete	<b>Retention Basin Volume</b>	Additional Land								
	Area [ac]	[ac-ft]	Required [ac]								
6	0	0.271	0.171								

32. Select the BMP from the list and enter the information into the tab as you did in Step 3; however, this time you will also have to enter information for the retention basin.



a. The information you previously entered for Pervious Pavement should still be in the cells and you will need to change the value for *Area of the pervious pavement system* to **0.0** (see Figure 5-29).

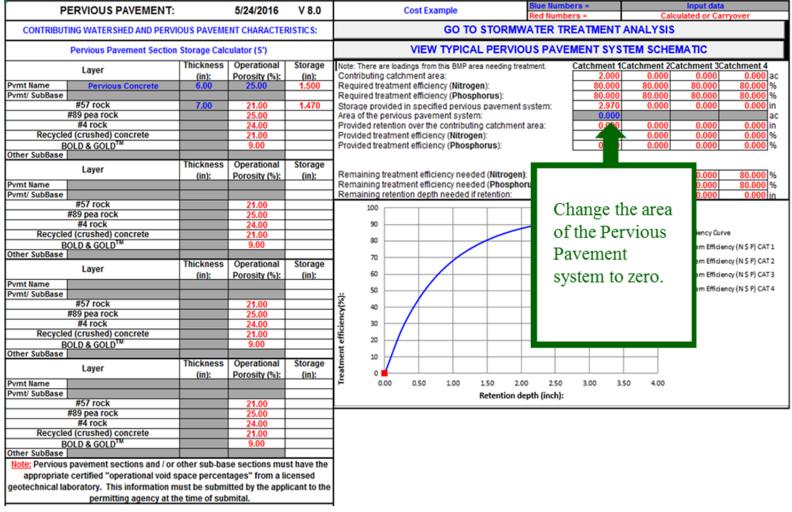


Figure 5-29 - Pervious Pavement BMP tab

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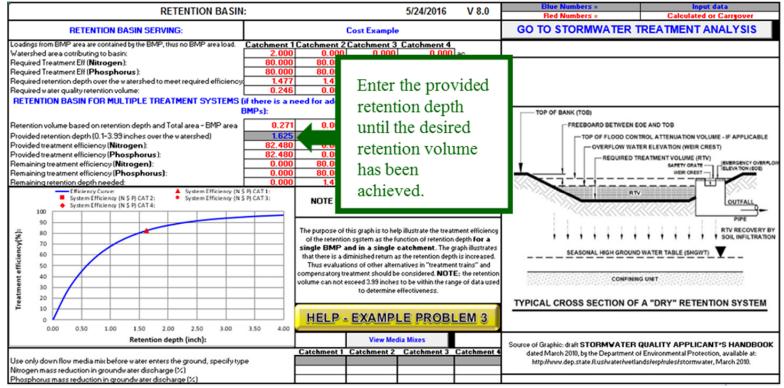


Figure 5-30 - Retention Basin BMP tab

\*The problem stated that the provided retention volume for this scenario is 0.271 acre-ft. Use an iterative guess and check approach by entering in a *Provided retention depth* and seeing if the *Retention volume based on retention depth and Total area* – *BMP area* becomes the desired value (see Figure 5-30).



# 33. Return to the **Stormwater Treatment Analysis** worksheet and click **Catchment and Treatment Summary Results** (see Figure 5-31).

#### a. If the treatment objectives are not met, adjust the BMP inputs until it passes.

CATCHMENTS	AND TREATMEN		Blue Numbers =         Input data           Red Numbers =         Calculated or Carryover								
CALCULATION METHODS: 1. The effectiveness of each BMP 2. Certain BMP treatment train co	-	GO TO STORMWATER TREATMENT ANALYSIS									
an example is a greenroof foll 3. Wet detention is last when use		GO TO WATERSHED CHARACTERISTICS									
PROJECT TITLE Cos	t Example Catchment 1	Optional Identification Catchment 2	Catchment 4	AINS model.							
BMP Name BMP Name BMP Name	Retention Basin				NOTE ar purpe m	Proc	eed to the	catchment ulation series use n be a			
S	ummary Perform	maxi		Analysis	tchment.						
Candon Con Ni				2016 NS MODEL	GO 1	worl	csheet.	ON PAGE			
Pho Ni Pho objective of 8		Treatment Objectives						5			
Tar Tar Targe TP has been t		or Target	$\frown$		HE	ELP - 3 C TCHMENTS					
Targe Provie Provie				))/		GO TO COST ANALYSIS WORKSHEET					
Discharged Load, it (kgyr & Discharged Load, it (kgyr & Ibar): Load Removed, N (kg/yr & Ib/yr): Load Removed, P (kg/yr & Ib/yr):	1.53 0.25 7.21 1.20	3.37 0.56 15.87 2.64		(((							

**Figure 5-31 – Catchments and Treatment Summary Results** 

#### Scenario 6, Costs

34. This Scenario requires additional land.

a. Based on Zillow, May 2016, 1 acre of land costs about \$525,000. For this scenario, the cost to purchase additional land would be \$89,775.

b. For the retention basin use the same *BMP Cost per acre-ft* used in Scenario 2, no further data entry is need for capital cost. Additionally, just as in Scenario 2, multiply the formula for *Estimated Annual BMP Maintenance Cost* is still 3% of the capital *BMP Cost*.

c. In Scenario 6 there is no pervious pavement present.

35. Fill in the remaining fields (see Figure 5-32).



a. For What type of analysis would you like to perform select "Net Present Worth"

b. The most recent value published by the World Bank is for the year 2014 so we will use this value, which is 1.8%.

c. Problem statement gave life span as 20 years; assume the project duration is the same since not otherwise stated.

d. Leave *BMP Fixed Cost* blank since the source cost data had the *Fixed Data* and *BMP Cost* combined into a single value.

e. Leave *Estimated Future Cost of Replacement* blank since the Project Duration and Expected Lifespan are the same.

f. Leave *Cost Land needed for BMP* blank because according to the data for scenario 3, no additional land is needed.

g. Enter the Scenario #

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What type of analysis would you like to perform?     Net Present Worth Analysis     What Scenario is running? (max 25)     Scenario 6     ref     Select the Net     Stis     RESET BMP DATA ONLY     GO TO GENERAL SITE INFORMATION PAGE														1						
	Interest Rate [%]	Project Duration [yrs]	20	Cost of water [\$/1000ga]		rer		Analysis and								NALYSIS SHEET	1			
	BMP	Treatment volume [ac-ft] <sup>#5</sup>	If User Defined BMP, Specify the unit that cost is based on [???]*	Cost of Land needed for BMP [\$]	Expected Life [yrs]	BMP Fixed Cost [\$]	вм	ar	opro	ify t opri rmat		ate			ated I Cost very /r]		ial Annual ost [\$/yr]	Estimated Future Cost of Replacement [\$]	Present Value of Replacement [5]	Present Worth [\$]
ent 1	Retention Basin	0.2708		\$ 89,775.00	20		\$	45,240.53	<b>\$</b> 12	2,252.64	\$ 367.58			\$	-	\$	367.58		\$0.00	\$ 108,155.73
Catchment												<u> </u>	_	s s	-	\$			\$0.00 \$0.00	
2											-		-	s s		s 5			\$0.00	
Catchment						Enter	r t	he co	ne cost					\$	-	\$			\$0.00	
Cat														\$	-	\$	-		\$0.00	
ort 3						information for							\$		\$			\$0.00		
Catchment						the Retention Basin systems.								\$	•	\$			\$0.00	
_													_	\$	•	\$			\$0.00	
hert 4											-		-	\$	-	\$	-		\$0.00	
Catchment														\$		S -			\$0.00	
* If green	roof, Vegetated Natural Buffer, o		S - S - COST REFERENCE DATA PERFORM COST ANAL							\$0.00	\$ 108,155.73									
f If storm	If green roof, Vegetated Natural Buffer, or Vegetated Filter Strip the cost should be in S/sf of BMP area  If stormwater harvesting or rainwater harvesting this treatment volume in terms of cost per ac-ft, with the area based on the EIA  If Stormwater harvesting or rainwater harvesting this term should be in terms of cost per ac-ft, with the area based on the EIA  This is equivalent to the treatment volume specified in column C and could be hours, square food, ac-ft, or whatever the BMP cost is based on.													7.21 1.20						

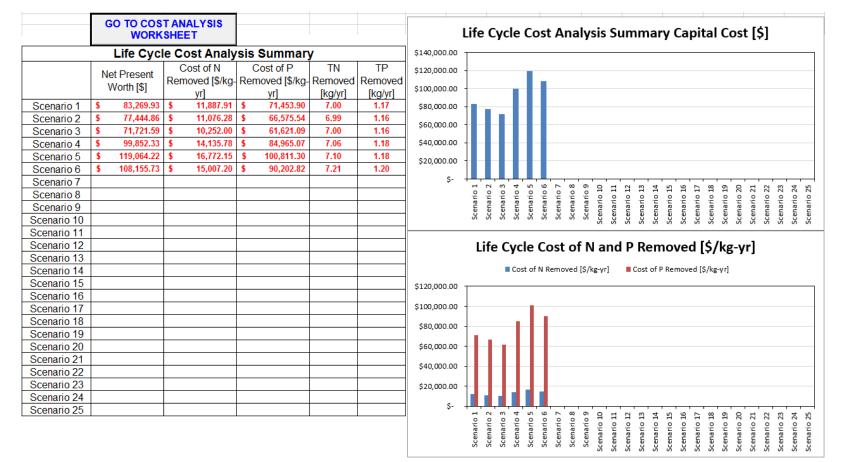
#### Figure 5-32 – Life Cycle Cost Comparison Worksheet

36. Perform Cost Analysis (see Figure 5-33).

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#### Figure 5-33 – Life Cycle Cost Analysis Summary

37. As seen in the Life Cycle Cost Analysis Summary, Scenario 3 is the most cost effective treatment method of the six scenarios. Scenario 3 utilizes 0.65 acres of pervious concrete and a retention basin with a volume of 0.0833 acre-feet. In Scenario 3, purchasing additional land is not required.



#### 6. Conclusions

The previous BMPTRAINS model was a useful tool for comparing various BMP options for performance. The cost updates will enhance the BMPTRAINS model and assist engineers in choosing the most economical BMP option that achieves the required performance level. As shown in this memo, cost inputs for the model can be found in journal articles, government reports, and other similar documents.



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