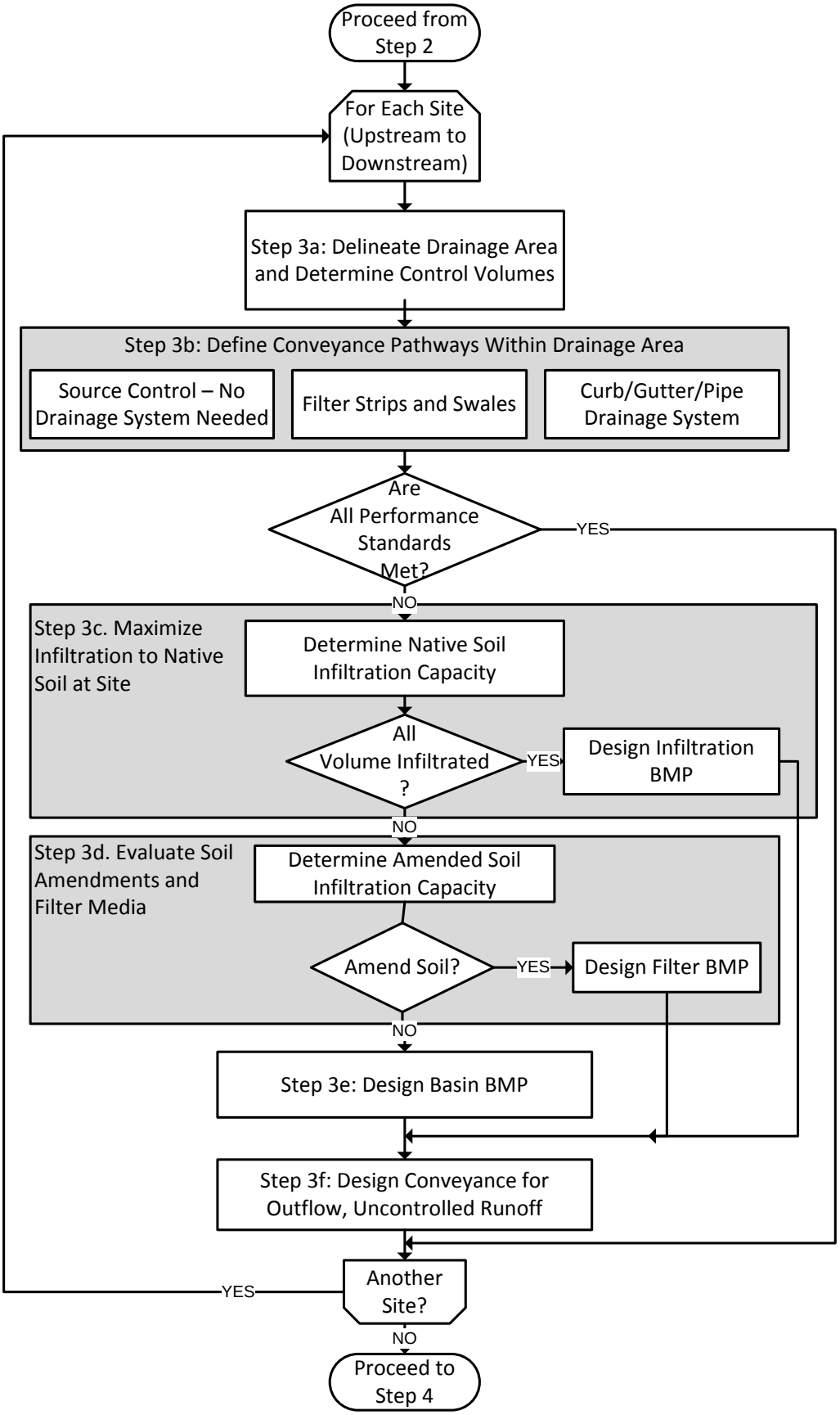
Section 6

Step 3: Siting and Sizing Stormwater Controls


Proceed from Step 2
For Each Site (Upstream to Downstream)
Step 3a: Delineate Drainage Area and Determine Control Volumes
Step 3b: Define Conveyance Pathways Within Drainage Area
Source Control – No Drainage System Needed
Filter Strips and Swales
Curb/Gutter/Pipe Drainage System
Are All Performance Standards Met?
YES
NO
Step 3c. Maximize Infiltration to Native Soil at Site
Determine Native Soil Infiltration Capacity
All Volume Infiltrated ?
YES
Design Infiltration BMP
NO
Step 3d. Evaluate Soil Amendments and Filter Media
Determine Amended Soil Infiltration Capacity
Amend Soil?
YES
Design Filter BMP
NO
Step 3e: Design Basin BMP
Step 3f: Design Conveyance for Outflow, Uncontrolled Runoff
Another Site?
YES
NO
Proceed to Step 4

Discussion Group Topic No. 4:

Siting and Sizing Storm Water Controls

Instructions

Objective: Identify and characterize potential locations for best management controls and assess inter/intra project drainage in siting best management control locations.

Group Discussion/Exercise (90 minutes):

This exercise is divided into three separate problem statements which provide the basic site parameters necessary to design BMPs suited to individual sub-basins within a project. Worksheets which systematically approach BMP design in a 5-step process will be used during this exercise. This 5-step process is divided into the following worksheets:

- Step 3a – Delineate Drainage areas and Determine Control Volumes
- Step 3b – Define conveyance Pathways within Drainage Area
- Steps 3 c-3e – Maximize Native Infiltration, Evaluate Soil Amendments and Design Basin BMP.

The problem statements for these steps are included in the following pages:

Problem Statement #1

Using Worksheet 3.a, determine the control volumes for design of a swale drainage system within Sub-area D. Once complete, use Worksheet 3.b to size the swale accordingly based on the following parameters:

Swale drainage area (A_R)	*2.3 acres*
Impervious fraction (i_T)	*0.4*
Time of Concentration(T_c)	*10 minutes*
Available swale length x width (including easement)	*687 feet x 30 feet*
Allowable surface ponding time (t)	*2 days*
Slope of Swale (S_S)	*0.04 ft/ft*
Peak 100-year flow (Q_{100})	*4.5 cfs*

Step 3a Worksheet

Delineate Drainage Areas and Determine Control Volumes

Name: _____

Site: _____

Date: _____

Use this worksheet to determine control volumes for best land use practice storm water BMPs. Complete one worksheet for the BMP site and each conveyance pathway (see Step 3b).

Step 3.a.1. Summarize BMP / conveyance pathway site characteristics.

Characteristic	Source
Catchment Area (A_R), acres = _____	*Project Site Plan (include area of BMP within catchment area)*
Available Surface Area (A_{BMP}), acres=_____	*Project Site Plan*
Tributary Area (A_T), acres=_____	$A_T = A_R - A_{BMP}$
Time of Concentration (T_c), minutes = _____	*Standard Hydrologic Calculation*

Characteristics of Soil at BMP / conveyance pathway Site (From Table 3.a.1)

Soil Characteristic	Native Soil Infiltration (NI)	Enhanced Soil Infiltration – Filter/Planting Media (EI)	Source
Soil Texture Class			Table 3.a.1 or field data
Saturated Hydraulic Conductivity (K_{sat}), in/hr	$K_{sat\text{-}NI}$ =___	$K_{sat\text{-}EI}$ =___	
Porosity (P), fraction	P_{NI} =___	P_{EI} =___	
Field Capacity (FC), fraction	FC_{NI} =___	FC_{EI} =___	
Wilting Point (WP), fraction	WP_{NI} =___	WP_{EI} =___	
Depth of Soil (D), feet	D_{GW} =___	D_M =___	• D_{GW} = depth to restrictive layer • D_M depth of amended filter / planting bed
Depth of Water in Soil at:			
- Porosity (V_P), feet	$V_{P\text{-}NI}$ =___	$V_{P\text{-}EI}$ =___	*P * D*
- Field Capacity (V_{FC}), feet	$V_{FC\text{-}NI}$ =___	V_{FC_EI} =___	*FC * D*
- Wilting Point (V_{WP}), feet	$V_{WP\text{-}NI}$ =___	$V_{WP\text{-}EI}$ =___	*WP * D*

STEP 3.a.2. Determine WQv for BMP and each conveyance pathway (depth and volume)

Characteristic	Source
Tributary Area Imperviousness (i_T), fraction = ____	*Post-construction land cover; i_T = a value between 0 and 1*
Tributary Area Water Quality Runoff Coefficient (C_T) = ____	$0.858*i_T^3 - 0.78*i_T^2 + 0.774*i_T + 0.04$
Catchment Water Quality Runoff Coefficient (C_{WQ}) = _____	$(A_{BMP} * 1 + A_T * C_T) / A_R$ *(Captures 100% of precipitation onto BMP, Swale, and Strip)*
Precipitation During Water Quality Event (P), feet = _____	*0.75 inches (0.0625 ft) per Ohio EPA General Construction Permit*
WQv as depth , feet = _____	$= C_{WQ}*P$
WQv as volume, acre-feet = _____	$= C_{WQ}*P*A_R$

STEP 3.a.3. Determine the Peak Flow Rate for the Water Quality Storm (Q_{WQ})

Characteristic	Source
Time of Concentration (T_C), minutes = _____	*Step 3.a.1*
Peak Intensity Rainfall, in/hr (I) = _____	*Interpolate from intensity-duration-frequency curves (see Figure 3.a.1 for Ohio Lake Erie region)*
Q_{WQ}, cfs = _____	$Q_{WQ} = C_{WQ}*I* A_R$

STEP 3.a.4. Determine Initial Soil Moisture Conditions

Characteristic	Source
Allowable period of surface ponding, days = _____	*Typically 2-3 days*
Antecedent Soil Moisture at Start of Water Quality Event (V_{AM}), feet = _____	$V_{FC\text{-}NI}$ or V_{FC_EI} *(see Step 3.a.1)*

Table 3.a.1 – Infiltration Properties of Typical Soil Types

Soil Texture Class	Saturated Hydraulic Conductivity (K_{sat}), in/hr	Suction Head (S), inch	Porosity (P), fraction	Field Capacity (FC), fraction	Wilting Point (WP), fraction
Sand	4.74	1.93	0.437	0.062	0.024
Loamy Sand	1.18	2.40	0.437	0.105	0.047
Sandy Loam	0.43	4.22	0.453	0.190	0.085
Loam	0.13	3.50	0.463	0.232	0.116
Silt Loam	0.26	6.69	0.501	0.284	0.135
Sandy Clay Loam	0.06	8.66	0.398	0.244	0.136
Clay Loam	0.04	8.27	0.464	0.310	0.187
Silty Clay Loam	0.04	10.63	0.471	0.342	0.210
Sandy Clay	0.02	9.45	0.430	0.321	0.221
Silty Clay	0.02	11.42	0.479	0.371	0.251
Clay	0.01	12.6	0.475	0.378	0.265

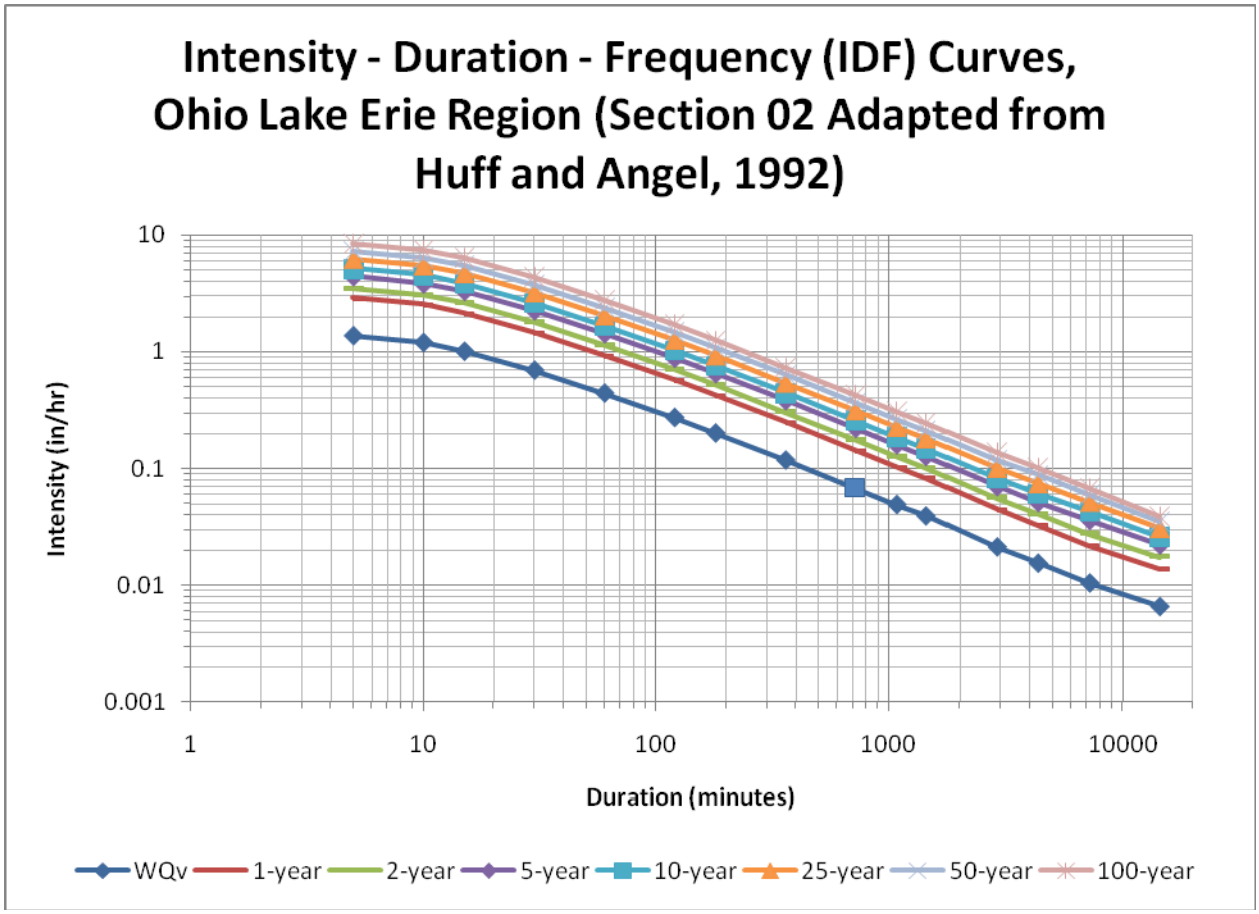


Figure 3.a.1 – Intensity-Duration-Frequency Curves for the Ohio Lake Erie Region – Adapted from Huff and Angel, 1992.

Step 3b Worksheet

Define Conveyance Pathways with Drainage Area

Name: _____

Site: _____

Date: _____

Complete this worksheet for each conveyance pathway draining to the BMP site to determine if a filter strip or swale BMP is a feasible conveyance option when developing a site layout plan using best land use practices.

Step 3.b.1. Summarize conveyance pathway characteristics.

Characteristic	Source
Area Tributary to conveyance pathway (A_T), acres=_____	*Step 3.a.1*
Tributary Area Imperviousness (i_T), fraction = _____	*Step 3.a.1*
Catchment slope (S_C) , ft/ft = _____	*Measure from proposed site topography*
Time of Concentration (T_c), minutes = _____	*Step 3.a.1*
Saturated hydraulic conductivity of native soil underlying conveyance pathway ($K_{sat\text{-}NI}$), in/hr = _____	*Step 3.a.1*
Porosity of native soil underlying conveyance pathway ($V_{P\text{-}NI}$), feet = _____	*Step 3.a.1*
Field capacity of native soil underlying conveyance pathway ($V_{FC\text{-}NI}$), feet = _____	*Step 3.a.1*
Slope of conveyance pathway (S_S), ft/ft = _____	*Measure from proposed site topography*
Available length of conveyance pathway (L_S), ft = _____	*Measure from proposed site plan*
Available width of conveyance pathway (TW), ft = _____	*Measure from proposed site plan*
Water Quality Volume entering conveyance pathway, as depth (WQv), feet = _____	*Step 3.a.2*
Peak Flow Rate of Water Quality Storm (Q_{WQ}), cfs = _____	*Step 3.a.3*

STEP 3.b.2: Evaluate Site Conditions to Determine if a Grass Filter Strip is a Feasible BMP Option.

Answer yes or no to each of the questions below.

_____ Will runoff enter the filter strip area as sheet flow?

_____ Is the slope of the filter strip area between 1 and 5 percent? (Calculated slope is ____ %)

_____ Do soil conditions allow for diffuse vegetative cover to become established?

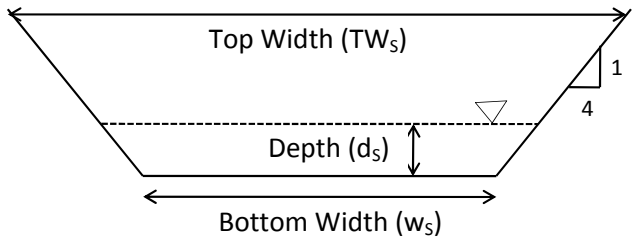
_____ Is the drainage area to the filter strip site less than 5 acres?

_____ Is a minimum filter strip length of 25 feet?

_____ Is the flow path through the filter strip area limited to 150 feet if completely vegetated or 75 feet if the area tributary to the filter strip area is impervious?

If you answered no to any of the questions above, a filter strip may not be feasible at the BMP site you are evaluating. Proceed to Step 3.b.3. to evaluate the feasibility of a vegetated swale conveyance system. If all questions were answered YES, then evaluate the infiltration with the filter strip area using Step 3.b.3 and a wide channel assumption for the swale bottom width.

STEP 3.b.3. Size swale to convey the Q_{WQ} from Step 3.a.3.



Use Manning's Equation (Q_{WQ} = [1.486* $A*R^{2/3}*S^{1/2}$] / n) and the following information to solve for $AR^{2/3}$. Use Table 3.b.1 to find the swale bottom width.

Characteristic	Source
Height of vegetation in swale, feet = _____	*Recommend mowing to height of 3 to 6 inches (0.25 to 0.5 ft)*
Mannings n (n_S) = _____	*Ranges between 0.2 and 0.3 if peak flow depth during Q_{WQ} is less than 50% of vegetation height within the swale*
Slope of swale (S_S), ft/ft = _____	*Range of 0.0005 to 0.05 ft/ft (0.5 to 5 percent) recommended*
$A*R^{2/3}$ = _____	*= [Q_{WQ} *n_S]/ [1.486*$S_S^{1/2}$]*
Maximum flow depth (d_{WQ}), ft = _____	*< 50% of mowed vegetation height*
Bottom width (w_S), ft = _____	*Use Table 3.b.1 , the calculated* $A*R^{2/3}$, and the maximum flow depth (d_{WQ}). Typically between *2 to 8 ft*
Length of swale (L_S), ft = _____	*Proposed site plan, minimum of 100 ft*
Side slope (H:1) = _____	*Usually milder than 3:1*

STEP 3.b.4. Calculate the swale cross-sectional area at peak Q_{WQ}.

Characteristic	Source
Area (A_{WQ}), ft^2 = _____	$A_{WQ} = (w_S+4d_{WQ})*d_{WQ}$

STEP 3.b.5. Is the velocity for the Q_{WQ} less than 0.9 ft/sec?

Characteristic	Source
Velocity (v_{WQ}) , ft/sec = _____	*= Q_{WQ} / A_{WQ}; Maximum 0.9 ft/sec. If velocity is greater than 0.9 ft/sec, go back to site layout plan to flatten the longitudinal slope,, reduce tributary area to the swale, or use a conventional conveyance system.*

STEP 3.b.6. Calculate the travel time for the swale.

Characteristic	Source
Travel Time (T_t) , hr = _____	*= L_S / (v_{WQ} * 3600)*

STEP 3.b.7. Check for safe conveyance of peak 100-year flow.

Characteristic	Source
Peak 100-year flow (Q_{100}), cfs = _____	*Use standard hydrologic calculations*
Manning's n (n_{100}) = _____	*Ranges between 0.03 and 0.05 where peak flow depth during Q_{100} exceeds the height of vegetation.*
$A*R^{2/3}$ = _____	*= $[Q_{100} *n_{100}]/ [1.486*S_S^{1/2}]$*
Maximum flow depth (d_{100}), ft = _____	*Use Table 3.b.1, the calculated $A*R^{2/3}$, and the swale bottom width (w_S) determined in Step 3.b.3.*
TW_{100}, ft = _____	*= $w_S + 8*d_{100}$*
Check that TW_{100} is less than available top width of swale: YES NO	*If TW_{100} is greater than the width available for the BMP, go back to site layout plan to reduce tributary area to the swale, reduce impervious area, increase allowable area for the BMP or use a conventional conveyance system.*

STEP 3.b.8. Adjust WQv for Infiltration within Swale

Characteristic	Source
Travel time through swale (T_t), hours = _____	*From Step 3.b.6*
Infiltration during the WQ event (V_{NI}), feet = _____ (Note: use WQv as depth from Step 3.a.2)	*= Minimum of:* • $K_{sat\text{-}NI} * T_t$ • $WQv\ (ft) * A_R / (w_S * L_s)$
Runoff depth from Swale (WQv_{ADJ}), feet = _____	$WQv - V_{NI}$

- *If adjusted WQv (WQv_{ADJ})* = 0, swale / filter strip meets all storm water management objectives for the site. If not, set WQv = WQv_{ADJ} and proceed to Step 3c.
- *If multiple drainage paths exist within the catchment tributary to the BMP site, repeat Steps 3a and 3b for each path.*

Table 3.b.1. $AR^{2/3}$ for Trapezoidal Cross Section with 4:1 side slopes

width (w) in feet

depth (d) in feet

	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0
0.25	0.632	0.652	0.671	0.691	0.711	0.730	0.750	0.770	0.790	0.809	0.829
0.26	0.669	0.690	0.711	0.731	0.752	0.773	0.794	0.815	0.835	0.856	0.877
0.27	0.707	0.729	0.751	0.773	0.795	0.816	0.838	0.860	0.882	0.904	0.926
0.28	0.746	0.769	0.792	0.815	0.838	0.861	0.884	0.907	0.930	0.953	0.976
0.28	0.786	0.810	0.834	0.858	0.883	0.907	0.931	0.955	0.979	1.004	1.028
0.29	0.827	0.852	0.877	0.903	0.928	0.953	0.979	1.004	1.030	1.055	1.081
0.30	0.868	0.895	0.921	0.948	0.975	1.001	1.028	1.054	1.081	1.108	1.134
0.31	0.911	0.939	0.967	0.994	1.022	1.050	1.078	1.106	1.134	1.162	1.189
0.32	0.955	0.984	1.013	1.042	1.071	1.100	1.129	1.158	1.187	1.216	1.246
0.33	0.999	1.030	1.060	1.090	1.120	1.151	1.181	1.212	1.242	1.272	1.303
0.33	1.045	1.076	1.108	1.140	1.171	1.203	1.234	1.266	1.298	1.330	1.361
0.34	1.091	1.124	1.157	1.190	1.223	1.256	1.289	1.322	1.355	1.388	1.421
0.35	1.139	1.173	1.207	1.241	1.276	1.310	1.344	1.379	1.413	1.447	1.482
0.36	1.187	1.222	1.258	1.294	1.329	1.365	1.401	1.436	1.472	1.508	1.544
0.37	1.236	1.273	1.310	1.347	1.384	1.421	1.458	1.495	1.532	1.569	1.607
0.38	1.286	1.325	1.363	1.401	1.440	1.478	1.517	1.555	1.594	1.632	1.671
0.38	1.338	1.377	1.417	1.457	1.497	1.537	1.576	1.616	1.656	1.696	1.736
0.39	1.390	1.431	1.472	1.513	1.554	1.596	1.637	1.678	1.720	1.761	1.803
0.40	1.443	1.485	1.528	1.571	1.613	1.656	1.699	1.742	1.784	1.827	1.870
0.41	1.497	1.541	1.585	1.629	1.673	1.717	1.762	1.806	1.850	1.895	1.939
0.42	1.552	1.597	1.643	1.688	1.734	1.780	1.826	1.871	1.917	1.963	2.009
0.43	1.608	1.655	1.702	1.749	1.796	1.843	1.891	1.938	1.985	2.032	2.080
0.43	1.664	1.713	1.762	1.810	1.859	1.908	1.957	2.005	2.054	2.103	2.152
0.44	1.722	1.772	1.823	1.873	1.923	1.973	2.024	2.074	2.124	2.175	2.225
0.45	1.781	1.833	1.884	1.936	1.988	2.040	2.092	2.144	2.196	2.248	2.300
0.46	1.841	1.894	1.947	2.001	2.054	2.108	2.161	2.215	2.268	2.322	2.375

Problem Statement #2

Consider native soil properties within Sub-area D for ideal BMP locations. Using Worksheet 3.a, determine the control volumes for design of an infiltration/filter/basin BMP at locations ideal for this type of BMP. The swale designed in Problem Statement #1 should be included within this drainage area. Base your design upon the following parameters:

Catchment area (A_R)	*20.25 acres*
BMP surface area(A_{BMP})	*2.79 acres*
Impervious fraction (i_T)	*0.6*
Time of Concentration(T_c)	*20 minutes*

The next step will be to use Worksheets 3.c, 3.d, & 3.e to maximize native infiltration, evaluate soil amendments, and design a basin size for the control volumes calculated above and in Problem Statement #1. Worksheet 3.b is not used in this exercise because it is assumed that all drainage, other than that calculated in Problem Statement #1, is conveyed via conventional methods. Use the following parameters when completing the worksheets:

Allowable surface ponding time (t)	*24 hours*
Subsurface Dewatering Period (t_{DW})	*3 days*
Evapotranspiration rate (ET)	*0.11 in/day*
Time of Concentration(T_c)	*20 minutes*

Step 3a Worksheet

Delineate Drainage Areas and Determine Control Volumes

Name: _____

Site: _____

Date: _____

Use this worksheet to determine control volumes for best land use practice storm water BMPs. Complete one worksheet for the BMP site and each conveyance pathway (see Step 3b).

Step 3.a.1. Summarize BMP / conveyance pathway site characteristics.

Characteristic	Source
Catchment Area (A_R), acres = _____	*Project Site Plan (include area of BMP within catchment area)*
Available Surface Area (A_{BMP}), acres=_____	*Project Site Plan*
Tributary Area (A_T), acres=_____	$A_T = A_R - A_{BMP}$
Time of Concentration (T_c), minutes = _____	*Standard Hydrologic Calculation*

Characteristics of Soil at BMP / conveyance pathway Site (From Table 3.a.1)

Soil Characteristic	Native Soil Infiltration (NI)	Enhanced Soil Infiltration – Filter/Planting Media (EI)	Source
Soil Texture Class			Table 3.a.1 or field data
Saturated Hydraulic Conductivity (K_{sat}), in/hr	$K_{sat\text{-}NI}$ =___	$K_{sat\text{-}EI}$ =___	
Porosity (P), fraction	P_{NI} =___	P_{EI} =___	
Field Capacity (FC), fraction	FC_{NI} =___	FC_{EI} =___	
Wilting Point (WP), fraction	WP_{NI} =___	WP_{EI} =___	
Depth of Soil (D), feet	D_{GW} =___	D_M =___	• D_{GW} = depth to restrictive layer • D_M depth of amended filter / planting bed
Depth of Water in Soil at:			
- Porosity (V_P), feet	$V_{P\text{-}NI}$ =___	$V_{P\text{-}EI}$ =___	*P * D*
- Field Capacity (V_{FC}), feet	$V_{FC\text{-}NI}$ =___	V_{FC_EI} =___	*FC * D*
- Wilting Point (V_{WP}), feet	$V_{WP\text{-}NI}$ =___	$V_{WP\text{-}EI}$ =___	*WP * D*

STEP 3.a.2. Determine WQv for BMP and each conveyance pathway (depth and volume)

Characteristic	Source
Tributary Area Imperviousness (i_T), fraction = ____	*Post-construction land cover; i_T = a value between 0 and 1*
Tributary Area Water Quality Runoff Coefficient (C_T) = ____	$0.858*i_T^3 - 0.78*i_T^2 + 0.774*i_T + 0.04$
Catchment Water Quality Runoff Coefficient (C_{WQ}) = _____	$(A_{BMP} * 1 + A_T * C_T) / A_R$ *(Captures 100% of precipitation onto BMP, Swale, and Strip)*
Precipitation During Water Quality Event (P), feet = _____	*0.75 inches (0.0625 ft) per Ohio EPA General Construction Permit*
WQv as depth , feet = _____	$= C_{WQ}*P$
WQv as volume, acre-feet = _____	$= C_{WQ}*P*A_R$

STEP 3.a.3. Determine the Peak Flow Rate for the Water Quality Storm (Q_{WQ})

Characteristic	Source
Time of Concentration (T_C), minutes = _____	*Step 3.a.1*
Peak Intensity Rainfall, in/hr (I) = _____	*Interpolate from intensity-duration-frequency curves (see Figure 3.a.1 for Ohio Lake Erie region)*
Q_{WQ}, cfs = _____	$Q_{WQ} = C_{WQ}*I* A_R$

STEP 3.a.4. Determine Initial Soil Moisture Conditions

Characteristic	Source
Allowable period of surface ponding, days = _____	*Typically 2-3 days*
Antecedent Soil Moisture at Start of Water Quality Event (V_{AM}), feet = _____	$V_{FC\text{-}NI}$ or V_{FC_EI} *(see Step 3.a.1)*

Table 3.a.1 – Infiltration Properties of Typical Soil Types

Soil Texture Class	Saturated Hydraulic Conductivity (K_{sat}), in/hr	Suction Head (S), inch	Porosity (P), fraction	Field Capacity (FC), fraction	Wilting Point (WP), fraction
Sand	4.74	1.93	0.437	0.062	0.024
Loamy Sand	1.18	2.40	0.437	0.105	0.047
Sandy Loam	0.43	4.22	0.453	0.190	0.085
Loam	0.13	3.50	0.463	0.232	0.116
Silt Loam	0.26	6.69	0.501	0.284	0.135
Sandy Clay Loam	0.06	8.66	0.398	0.244	0.136
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Clay	0.01	12.6	0.475	0.378	0.265

Source: Rawls, W.J., et. al., (1983). J. Hyd. Engr., 109:1316

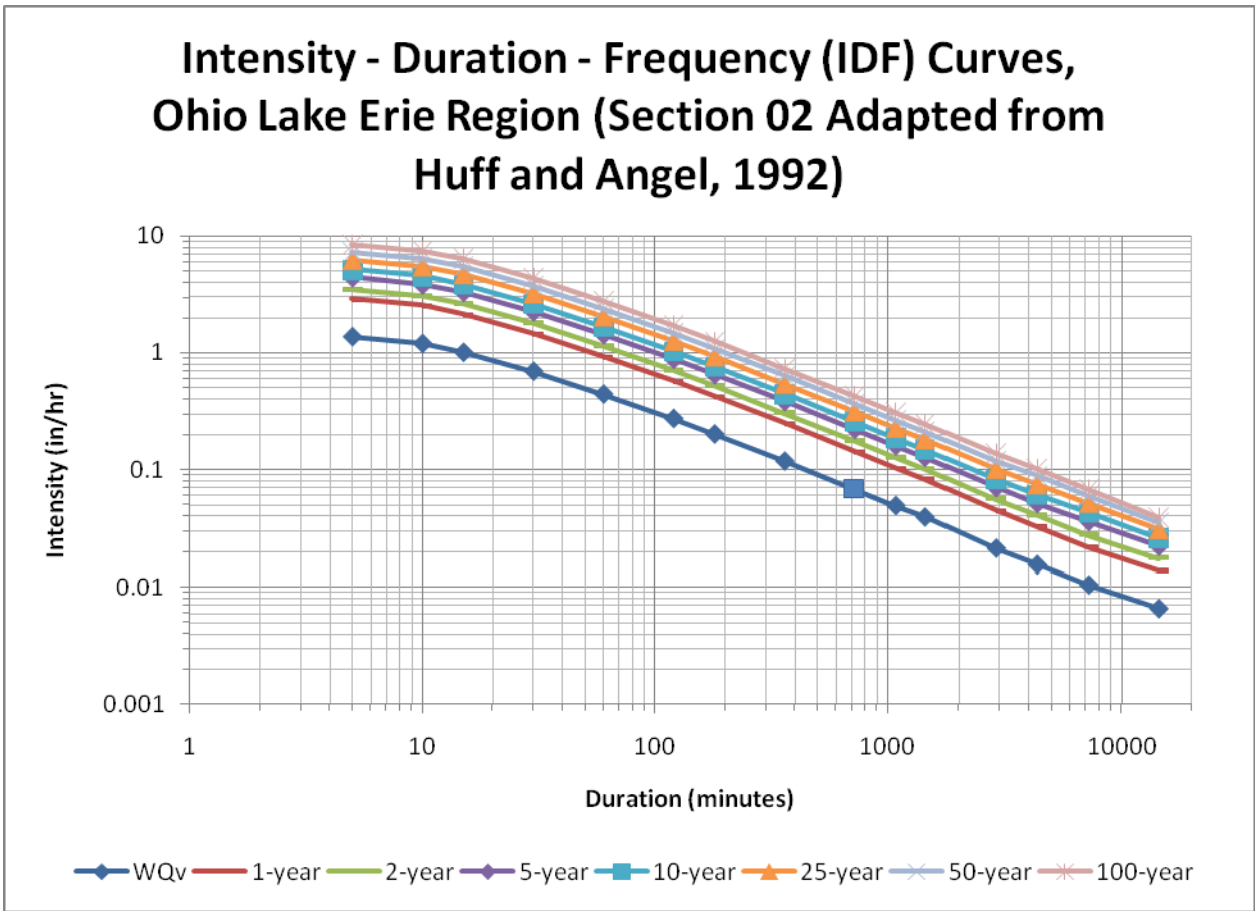

Figure 3.a.1 – Intensity-Duration-Frequency Curves for the Ohio Lake Erie Region – Adapted from Huff and Angel, 1992.

Steps 3c, 3d, and 3e Worksheet

Evaluate Native and Enhanced Soil Infiltration, and Determine Detention Requirements

Name: _____

Site: _____

Date: _____

This worksheet can be used to select BMPs to maximize infiltration and subsurface storage through the use of soil amendments and underdrain systems. First, maximize infiltration of the native soil, then investigate the use of soil amendments and finally determine if additional detention and underdrain is required.

Step 3.c.1. Summarize BMP site characteristics.

Characteristic	Source
Catchment Area (A_R), acres = _____	*Step 3.a.1*
Surface Area of BMP (A_{BMP}), acres=_____	*Step 3.a.1*
Area Tributary to BMP (A_T), acres=_____	*Step 3.a.1*

Step 3.c.2 Determine Total Water Quality Volume Entering BMP Site

Conveyance Pathway ID	Runoff Area (A_R), acres	Water Quality Volume (WQv or WQv_{ADJ}),	
		Depth (feet), from Step 3.a.2	Volume (ac-ft) = A_R * WQv (ft)
BMP surface*			
Total	**Σ A_R = ____**	**N/A**	**Σ WQv (by volume) = _____**
***WQv in BMP (D_{BMP}), by depth (ft)* = Σ WQv (by volume) / Σ A_{BMP} = _____**			

* Unless already included in the WQv calculation in Step 3.a.2

STEP 3.c.3 Native Soil in BMP (Pass 1)

Characteristic	Source
Allowable surface ponding time (t), hours = _____	*Typically 24 to 48 hours*
Infiltration into Native Soil (V_{NI}), feet = _____	*Minimum of :* • $K_{sat\text{-}NI} * t$ • D_{BMP} *(from 3.c.2)*
Surface condition: Ponded Infiltrated	*If* $D_{BMP} > V_{NI}$, *surface ponding occurs* *If* $V_{NI} \geq D_{BMP}$ *then the water is infiltrated into the native soil.*
Surface detention volume (V_{SD}), feet = _____	$D_{BMP} - V_{NI}$

If the surface condition is infiltrated then infiltration into the native soil appears to be a feasible option for this BMP site. Site measured infiltration rates should be used during design and a monthly water budget should be performed to determine soil moisture conditions for plant survivability during wet and dry months. If surface condition is ponded, then a soil amendment (Step 3.d) can be considered or proceed directly to basin BMP design (Step 3.e.).

STEP 3.d.1 Amended Soil in BMP (Pass 2)

Characteristic	Source
Infiltration into Surface of BMP (V_{EI}), feet = _____	*Minimum of :* • $K_{sat\text{-}EI} * t$ • D_{BMP}
Surface condition: Ponded Infiltrated	*If* $D_{BMP} > V_{EI}$, *surface ponding occurs* *If* $V_{EI} \geq D_{BMP}$ *then the water is infiltrated into the amended soil.*
Surface detention volume (V_{SD}), feet = _____	$D_{BMP} - V_{EI}$

If the surface condition is infiltrated then infiltration into the amended soil appears to be a feasible option for this BMP site. Continue with Step 3.d.2 to determine if an underdrain is needed. If surface condition is ponded, then proceed directly to basin BMP design (Step 3e).

Step 3.d.2. Determine Infiltration, Evapotranspiration, and Soil Moisture Within BMP

Characteristic	Source
Subsurface Dewatering Period (t_{DW}), days = _____	*Up to 3 days of subsurface dewatering typically will not affect plants within BMP*
Evapotranspiration rate (ET), in/day = _____	*Local Climate Data, check seasonal differences (see Table 3.c.1).*
Evapotranspiration in BMP (V_{ET}), feet = ____	$V_{ET} = ET * t_{DW} / 12$
Antecedent Soil Moisture at Start of Water Quality Event (V_{AM}), feet = _____	*Step 3.a.4*
Area available for infiltration into native soil surrounding planting bed (A_{NI}), ft^2 = _____	$A_{BMP} + 4 * D_M * A_{BMP}^{1/2}$
Infiltration from BMP into underlying native soil (V_{NI}), feet = _____	• *If* $FC_{EI} \geq V_{AM} + V_{EI} - V_{ET}$, *then* $V_{NI} = 0$. • *If* $FC_{EI} < V_{AM} + V_{EI} - V_{ET}$, *then* V_{NI} = *minimum of:* -- $V_{AM} + V_{EI} - V_{ET}$ -- $A_{NI} / A_{BMP} * [K_{sat\text{-}NI} * t_{DW} * 24 / 12]$
Soil Moisture at End of Dewatering Period (no Underdrain) (V_{END}), feet = _____	$V_{END} = V_{AM} + V_{EI} - V_{ET} - V_{NI}$
Determine Soil Moisture Condition: Ponded Saturated Normal Wilted (Note: Results may differ seasonally)	**Ponded**: $V_{END} > V_{P\text{-}EI}$ *(Surface Ponding expected without underdrain)* **Saturated**: $V_{FC\text{-}EI} < V_{END} < V_{P\text{-}EI}$ *(soil may go anoxic)* **Normal**: $V_{WP\text{-}EI} > V_{END} > V_{FC\text{-}EI}$ *(normal for plant growth)* **Wilted**: $V_{END} < V_{WP\text{-}EI}$ *(Soil moisture less than wilting point - plants will die)*
Underground detention volume (V_{UD}), ft = ___	Maximum of $V_{END} - V_{FC\text{-}EI}$, 0

STEP 3.e. Design Basin BMP (if soil moisture condition is Saturated or Ponded after Step 3.c.3 and/or 3.d.2)

Characteristic	Source
Extended Detention Volume (V_{ED}), feet = ___	$V_{SD} + V_{UD}$, *Steps 3.c.3 and 3.d.2*
Soil Moisture at End of Dewatering Period (with Underdrain), feet = _____	$V_{END} = V_{AM} + V_{EI} - V_{ET} - V_{NI} - V_{UD}$
Determine Soil Moisture Condition: Ponded Saturated Normal Wilted	**Ponded**: $V_{END} > V_{P\text{-}EI}$ *(Surface Ponding expected without underdrain)* **Saturated**: $V_{FC\text{-}EI} < V_{END} < V_{P\text{-}EI}$ *(soil may go anoxic)* **Normal**: $V_{WP\text{-}EI} > V_{END} > V_{FC\text{-}EI}$ *(normal for plant growth)* **Wilted**: $V_{END} < V_{WP\text{-}EI}$ *(Soil moisture less than wilting point - plants will die)*

Table 3.c.1. Monthly Climatic Data

Month	Evapotranspiration (ET)		Average Monthly Precipitation, inches	
	inches/day	Inches/month	Cleveland	Toledo
January	0.01	0.31	2.53	1.88
February	0.04	1.12	2.19	1.82
March	0.05	1.55	2.83	2.39
April	0.05	1.50	3.36	2.97
May	0.10	3.10	3.37	3.14
June	0.24	7.20	3.38	3.49
July	0.25	7.75	3.40	3.22
August	0.24	7.44	3.45	3.21
September	0.16	4.80	3.34	2.72
October	0.11	3.41	2.67	2.23
November	0.03	0.90	3.22	2.69
December	0.01	0.31	2.85	2.60
Average	0.11	39.39	36.59	32.36

Problem Statement #3

Sub-area A provides opportunity to infiltrate stormwater through a possible bio-retention cell. Locate and evaluate functionality of a bioretention facility within this sub-area by using worksheets 3.a-3.e to determine control volumes (3.a), maximize native infiltration (3.c), evaluate amended soil infiltration (3.d), and design a basin BMP (3.e) if necessary. Assume that all drainage from this sub-area is conveyed via conventional methods directly to the bioretention facility. Base design off the following parameters:

Catchment area (A_R)	*36 acres*
BMP surface area(A_{BMP})	*3 acres*
Impervious fraction (i_T)	*0.6*
Time of Concentration(T_c)	*30 minutes*
Allowable surface ponding time (t)	*24 hours*
Subsurface Dewatering Period (t_{DW})	*1 days*
Evapotranspiration rate (ET)	*0.11 in/day*
Amended soil type	*Loamy Sand*
Depth of amended soil	*5 feet*

Step 3a Worksheet

Delineate Drainage Areas and Determine Control Volumes

Name: _____

Site: _____

Date: _____

Use this worksheet to determine control volumes for best land use practice storm water BMPs. Complete one worksheet for the BMP site and each conveyance pathway (see Step 3b).

Step 3.a.1. Summarize BMP / conveyance pathway site characteristics.

Characteristic	Source
Catchment Area (A_R), acres = _____	*Project Site Plan (include area of BMP within catchment area)*
Available Surface Area (A_{BMP}), acres=_____	*Project Site Plan*
Tributary Area (A_T), acres=_____	$A_T = A_R - A_{BMP}$
Time of Concentration (T_c), minutes = _____	*Standard Hydrologic Calculation*

Characteristics of Soil at BMP / conveyance pathway Site (From Table 3.a.1)

Soil Characteristic	Native Soil Infiltration (NI)	Enhanced Soil Infiltration – Filter/Planting Media (EI)	Source
Soil Texture Class			Table 3.a.1 or field data
Saturated Hydraulic Conductivity (K_{sat}), in/hr	$K_{sat\text{-}NI}$ =___	$K_{sat\text{-}EI}$ =___	
Porosity (P), fraction	P_{NI} =___	P_{EI} =___	
Field Capacity (FC), fraction	FC_{NI} =___	FC_{EI} =___	
Wilting Point (WP), fraction	WP_{NI} =___	WP_{EI} =___	
Depth of Soil (D), feet	D_{GW} =___	D_M =___	• D_{GW} = depth to restrictive layer • D_M depth of amended filter / planting bed
Depth of Water in Soil at:			
- Porosity (V_P), feet	$V_{P\text{-}NI}$ =___	$V_{P\text{-}EI}$ =___	*P * D*
- Field Capacity (V_{FC}), feet	$V_{FC\text{-}NI}$ =___	V_{FC_EI} =___	*FC * D*
- Wilting Point (V_{WP}), feet	$V_{WP\text{-}NI}$ =___	$V_{WP\text{-}EI}$ =___	*WP * D*

STEP 3.a.2. Determine WQv for BMP and each conveyance pathway (depth and volume)

Characteristic	Source
Tributary Area Imperviousness (i_T), fraction = ____	*Post-construction land cover; i_T = a value between 0 and 1*
Tributary Area Water Quality Runoff Coefficient (C_T) = ____	$0.858*i_T^3 - 0.78*i_T^2 + 0.774*i_T + 0.04$
Catchment Water Quality Runoff Coefficient (C_{WQ}) = _____	$(A_{BMP} * 1 + A_T * C_T) / A_R$ *(Captures 100% of precipitation onto BMP, Swale, and Strip)*
Precipitation During Water Quality Event (P), feet = _____	*0.75 inches (0.0625 ft) per Ohio EPA General Construction Permit*
WQv as depth , feet = _____	$= C_{WQ}*P$
WQv as volume, acre-feet = _____	$= C_{WQ}*P*A_R$

STEP 3.a.3. Determine the Peak Flow Rate for the Water Quality Storm (Q_{WQ})

Characteristic	Source
Time of Concentration (T_C), minutes = _____	*Step 3.a.1*
Peak Intensity Rainfall, in/hr (I) = _____	*Interpolate from intensity-duration-frequency curves (see Figure 3.a.1 for Ohio Lake Erie region)*
Q_{WQ}, cfs = _____	$Q_{WQ} = C_{WQ}*I* A_R$

STEP 3.a.4. Determine Initial Soil Moisture Conditions

Characteristic	Source
Allowable period of surface ponding, days = _____	*Typically 2-3 days*
Antecedent Soil Moisture at Start of Water Quality Event (V_{AM}), feet = _____	$V_{FC\text{-}NI}$ or V_{FC_EI} *(see Step 3.a.1)*

Table 3.a.1 – Infiltration Properties of Typical Soil Types

Soil Texture Class	Saturated Hydraulic Conductivity (K_{sat}), in/hr	Suction Head (S), inch	Porosity (P), fraction	Field Capacity (FC), fraction	Wilting Point (WP), fraction
Sand	4.74	1.93	0.437	0.062	0.024
Loamy Sand	1.18	2.40	0.437	0.105	0.047
Sandy Loam	0.43	4.22	0.453	0.190	0.085
Loam	0.13	3.50	0.463	0.232	0.116
Silt Loam	0.26	6.69	0.501	0.284	0.135
Sandy Clay Loam	0.06	8.66	0.398	0.244	0.136
Clay Loam	0.04	8.27	0.464	0.310	0.187
Silty Clay Loam	0.04	10.63	0.471	0.342	0.210
Sandy Clay	0.02	9.45	0.430	0.321	0.221
Silty Clay	0.02	11.42	0.479	0.371	0.251
Clay	0.01	12.6	0.475	0.378	0.265

Source: Rawls, W.J., et. al., (1983). J. Hyd. Engr., 109:1316

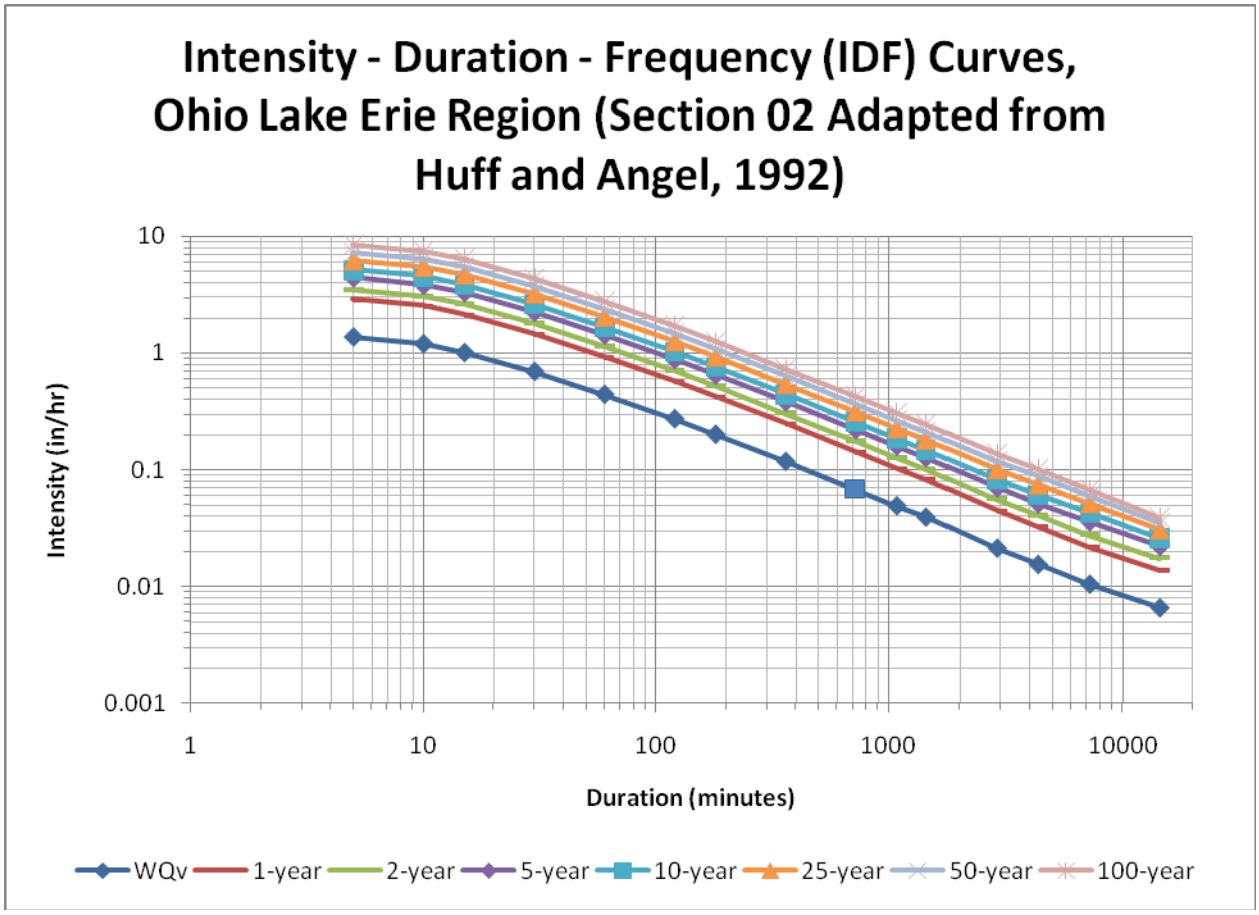

Figure 3.a.1 – Intensity-Duration-Frequency Curves for the Ohio Lake Erie Region – Adapted from Huff and Angel, 1992.

Steps 3c, 3d, and 3e Worksheet
Evaluate Native and Enhanced Soil Infiltration, and Determine Detention Requirements

Name: _____

Site: _____

Date: _____

This worksheet can be used to select BMPs to maximize infiltration and subsurface storage through the use of soil amendments and underdrain systems. First, maximize infiltration of the native soil, then investigate the use of soil amendments and finally determine if additional detention and underdrain is required.

Step 3.c.1. Summarize BMP site characteristics.

Characteristic	Source
Catchment Area (A_R), acres = _____	*Step 3.a.1*
Surface Area of BMP (A_{BMP}), acres=_____	*Step 3.a.1*
Area Tributary to BMP (A_T), acres=_____	*Step 3.a.1*

Step 3.c.2 Determine Total Water Quality Volume Entering BMP Site

Conveyance Pathway ID	Runoff Area (A_R), acres	Water Quality Volume (WQv or WQv_{ADJ}),	
		Depth (feet), from Step 3.a.2	Volume (ac-ft) = A_R * WQv (ft)
BMP surface*			
Total	**Σ A_R = ____**	**N/A**	**Σ WQv (by volume) = _____**
***WQv in BMP (D_{BMP}), by depth (ft)* = Σ WQv (by volume) / Σ A_{BMP} = _____**			

* Unless already included in the WQv calculation in Step 3.a.2

STEP 3.c.3 Native Soil in BMP (Pass 1)

Characteristic	Source
Allowable surface ponding time (t), hours = _____	*Typically 24 to 48 hours*
Infiltration into Native Soil (V_{NI}), feet = _____	*Minimum of :* • $K_{sat\text{-}NI} * t$ • D_{BMP} *(from 3.c.2)*
Surface condition: Ponded Infiltrated	*If* $D_{BMP} > V_{NI}$, *surface ponding occurs* *If* $V_{NI} \geq D_{BMP}$ *then the water is infiltrated into the native soil.*
Surface detention volume (V_{SD}), feet = _____	$D_{BMP} - V_{NI}$

If the surface condition is infiltrated then infiltration into the native soil appears to be a feasible option for this BMP site. Site measured infiltration rates should be used during design and a monthly water budget should be performed to determine soil moisture conditions for plant survivability during wet and dry months. If surface condition is ponded, then a soil amendment (Step 3.d) can be considered or proceed directly to basin BMP design (Step 3.e.).

STEP 3.d.1 Amended Soil in BMP (Pass 2)

Characteristic	Source
Infiltration into Surface of BMP (V_{EI}), feet = _____	*Minimum of :* • $K_{sat\text{-}EI} * t$ • D_{BMP}
Surface condition: Ponded Infiltrated	*If* $D_{BMP} > V_{EI}$, *surface ponding occurs* *If* $V_{EI} \geq D_{BMP}$ *then the water is infiltrated into the amended soil.*
Surface detention volume (V_{SD}), feet = _____	$D_{BMP} - V_{EI}$

If the surface condition is infiltrated then infiltration into the amended soil appears to be a feasible option for this BMP site. Continue with Step 3.d.2 to determine if an underdrain is needed. If surface condition is ponded, then proceed directly to basin BMP design (Step 3e).

Step 3.d.2. Determine Infiltration, Evapotranspiration, and Soil Moisture Within BMP

Characteristic	Source
Subsurface Dewatering Period (t_{DW}), days = _____	*Up to 3 days of subsurface dewatering typically will not affect plants within BMP*
Evapotranspiration rate (ET), in/day = _____	*Local Climate Data, check seasonal differences (see Table 3.c.1).*
Evapotranspiration in BMP (V_{ET}), feet = ____	$V_{ET} = ET * t_{DW} / 12$
Antecedent Soil Moisture at Start of Water Quality Event (V_{AM}), feet = _____	*Step 3.a.4*
Area available for infiltration into native soil surrounding planting bed (A_{NI}), ft^2 = _____	$A_{BMP} + 4 * D_M * A_{BMP}^{1/2}$
Infiltration from BMP into underlying native soil (V_{NI}), feet = _____	• *If* $FC_{EI} \geq V_{AM} + V_{EI} - V_{ET}$, *then* $V_{NI} = 0$. • *If* $FC_{EI} < V_{AM} + V_{EI} - V_{ET}$, *then* V_{NI} = *minimum of:* -- $V_{AM} + V_{EI} - V_{ET}$ -- $A_{NI} / A_{BMP} * [K_{sat\text{-}NI} * t_{DW} * 24 / 12]$
Soil Moisture at End of Dewatering Period (no Underdrain) (V_{END}), feet = _____	$V_{END} = V_{AM} + V_{EI} - V_{ET} - V_{NI}$
Determine Soil Moisture Condition: Ponded Saturated Normal Wilted (Note: Results may differ seasonally)	**Ponded**: $V_{END} > V_{P\text{-}EI}$ *(Surface Ponding expected without underdrain)* **Saturated**: $V_{FC\text{-}EI} < V_{END} < V_{P\text{-}EI}$ *(soil may go anoxic)* **Normal**: $V_{WP\text{-}EI} > V_{END} > V_{FC\text{-}EI}$ *(normal for plant growth)* **Wilted**: $V_{END} < V_{WP\text{-}EI}$ *(Soil moisture less than wilting point - plants will die)*
Underground detention volume (V_{UD}), ft = ___	Maximum of $V_{END} - V_{FC\text{-}EI}$, 0

STEP 3.e. Design Basin BMP (if soil moisture condition is Saturated or Ponded after Step 3.c.3 and/or 3.d.2)

Characteristic	Source
Extended Detention Volume (V_{ED}), feet = ___	$V_{SD} + V_{UD}$, *Steps 3.c.3 and 3.d.2*
Soil Moisture at End of Dewatering Period (with Underdrain), feet = _____	$V_{END} = V_{AM} + V_{EI} - V_{ET} - V_{NI} - V_{UD}$
Determine Soil Moisture Condition: Ponded Saturated Normal Wilted	**Ponded**: $V_{END} > V_{P\text{-}EI}$ *(Surface Ponding expected without underdrain)* **Saturated**: $V_{FC\text{-}EI} < V_{END} < V_{P\text{-}EI}$ *(soil may go anoxic)* **Normal**: $V_{WP\text{-}EI} > V_{END} > V_{FC\text{-}EI}$ *(normal for plant growth)* **Wilted**: $V_{END} < V_{WP\text{-}EI}$ *(Soil moisture less than wilting point - plants will die)*

Table 3.c.1. Monthly Climatic Data

Month	Evapotranspiration (ET)		Average Monthly Precipitation, inches	
	inches/day	Inches/month	Cleveland	Toledo
January	0.01	0.31	2.53	1.88
February	0.04	1.12	2.19	1.82
March	0.05	1.55	2.83	2.39
April	0.05	1.50	3.36	2.97
May	0.10	3.10	3.37	3.14
June	0.24	7.20	3.38	3.49
July	0.25	7.75	3.40	3.22
August	0.24	7.44	3.45	3.21
September	0.16	4.80	3.34	2.72
October	0.11	3.41	2.67	2.23
November	0.03	0.90	3.22	2.69
December	0.01	0.31	2.85	2.60
Average	0.11	39.39	36.59	32.36

Problem Statement #4

A commercial development is proposed east of the residential development. The development will include one building, a parking lot, and lawn areas. Using worksheets 3.a- 3.e to determine control volumes (3.a), maximize native infiltration (3.c), evaluate amended soil infiltration (3.d), and design a basin BMP (3.e) if necessary; attempt to incorporate pervious pavement within a sub-area of the commercial development according to the following parameters:

Catchment area (A_R)	*4 acres*
BMP surface area(A_{BMP})	*1.5 acres*
Impervious fraction (i_T)	*0.6*
Time of Concentration(T_c)	*3 minutes*
Allowable surface ponding time (t)	*1 hour*
Subsurface Dewatering Period (t_{DW})	*1 day*
Amended soil type	*Sand*
Depth of amended soil	*2.5 feet*

Step 3a Worksheet

Delineate Drainage Areas and Determine Control Volumes

Name: _____

Site: _____

Date: _____

Use this worksheet to determine control volumes for best land use practice storm water BMPs. Complete one worksheet for the BMP site and each conveyance pathway (see Step 3b).

Step 3.a.1. Summarize BMP / conveyance pathway site characteristics.

Characteristic	Source
Catchment Area (A_R), acres = _____	*Project Site Plan (include area of BMP within catchment area)*
Available Surface Area (A_{BMP}), acres=_____	*Project Site Plan*
Tributary Area (A_T), acres=_____	$A_T = A_R - A_{BMP}$
Time of Concentration (T_c), minutes = _____	*Standard Hydrologic Calculation*

Characteristics of Soil at BMP / conveyance pathway Site (From Table 3.a.1)

Soil Characteristic	Native Soil Infiltration (NI)	Enhanced Soil Infiltration – Filter/Planting Media (EI)	Source
Soil Texture Class			Table 3.a.1 or field data
Saturated Hydraulic Conductivity (K_{sat}), in/hr	$K_{sat\text{-}NI}$ =___	$K_{sat\text{-}EI}$ =___	
Porosity (P), fraction	P_{NI} =___	P_{EI} =___	
Field Capacity (FC), fraction	FC_{NI} =___	FC_{EI} =___	
Wilting Point (WP), fraction	WP_{NI} =___	WP_{EI} =___	
Depth of Soil (D), feet	D_{GW} =___	D_M =___	• D_{GW} = depth to restrictive layer • D_M depth of amended filter / planting bed
Depth of Water in Soil at:			
- Porosity (V_P), feet	$V_{P\text{-}NI}$ =___	$V_{P\text{-}EI}$ =___	*P * D*
- Field Capacity (V_{FC}), feet	$V_{FC\text{-}NI}$ =___	V_{FC_EI} =___	*FC * D*
- Wilting Point (V_{WP}), feet	$V_{WP\text{-}NI}$ =___	$V_{WP\text{-}EI}$ =___	*WP * D*

STEP 3.a.2. Determine WQv for BMP and each conveyance pathway (depth and volume)

Characteristic	Source
Tributary Area Imperviousness (i_T), fraction = ____	*Post-construction land cover; i_T = a value between 0 and 1*
Tributary Area Water Quality Runoff Coefficient (C_T) = ____	$0.858*i_T^3 - 0.78*i_T^2 + 0.774*i_T + 0.04$
Catchment Water Quality Runoff Coefficient (C_{WQ}) = _____	$(A_{BMP} * 1 + A_T * C_T) / A_R$ *(Captures 100% of precipitation onto BMP, Swale, and Strip)*
Precipitation During Water Quality Event (P), feet = _____	*0.75 inches (0.0625 ft) per Ohio EPA General Construction Permit*
WQv as depth , feet = _____	$= C_{WQ}*P$
WQv as volume, acre-feet = _____	$= C_{WQ}*P*A_R$

STEP 3.a.3. Determine the Peak Flow Rate for the Water Quality Storm (Q_{WQ})

Characteristic	Source
Time of Concentration (T_C), minutes = _____	*Step 3.a.1*
Peak Intensity Rainfall, in/hr (I) = _____	*Interpolate from intensity-duration-frequency curves (see Figure 3.a.1 for Ohio Lake Erie region)*
Q_{WQ}, cfs = _____	$Q_{WQ} = C_{WQ}*I* A_R$

STEP 3.a.4. Determine Initial Soil Moisture Conditions

Characteristic	Source
Allowable period of surface ponding, days = _____	*Typically 2-3 days*
Antecedent Soil Moisture at Start of Water Quality Event (V_{AM}), feet = _____	$V_{FC\text{-}NI}$ or V_{FC_EI} *(see Step 3.a.1)*

Table 3.a.1 – Infiltration Properties of Typical Soil Types

Soil Texture Class	Saturated Hydraulic Conductivity (K_{sat}), in/hr	Suction Head (S), inch	Porosity (P), fraction	Field Capacity (FC), fraction	Wilting Point (WP), fraction
Sand	4.74	1.93	0.437	0.062	0.024
Loamy Sand	1.18	2.40	0.437	0.105	0.047
Sandy Loam	0.43	4.22	0.453	0.190	0.085
Loam	0.13	3.50	0.463	0.232	0.116
Silt Loam	0.26	6.69	0.501	0.284	0.135
Sandy Clay Loam	0.06	8.66	0.398	0.244	0.136
Clay Loam	0.04	8.27	0.464	0.310	0.187
Silty Clay Loam	0.04	10.63	0.471	0.342	0.210
Sandy Clay	0.02	9.45	0.430	0.321	0.221
Silty Clay	0.02	11.42	0.479	0.371	0.251
Clay	0.01	12.6	0.475	0.378	0.265

Source: Rawls, W.J., et. al., (1983). J. Hyd. Engr., 109:1316

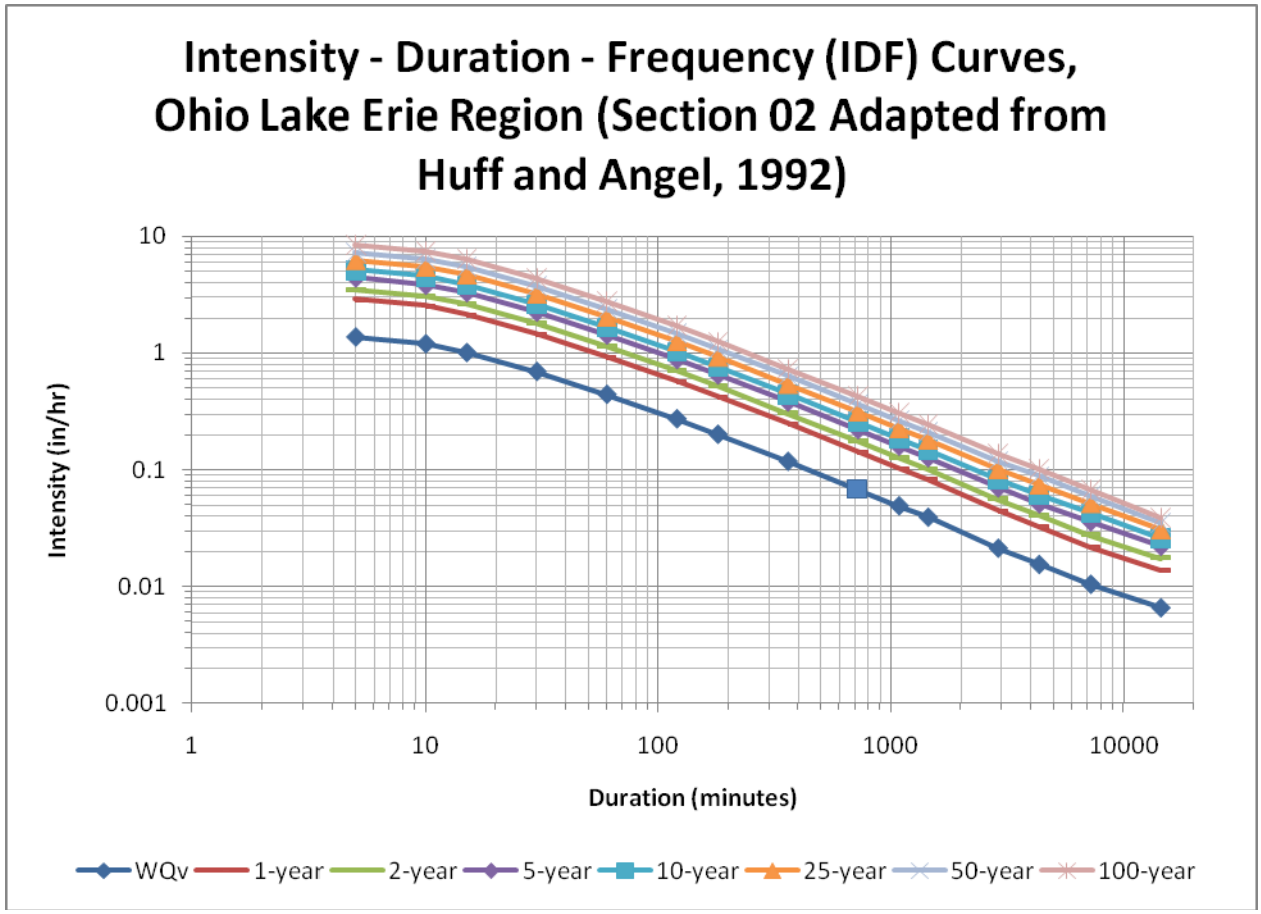

Figure 3.a.1 – Intensity-Duration-Frequency Curves for the Ohio Lake Erie Region – Adapted from Huff and Angel, 1992.

Steps 3c, 3d, and 3e Worksheet
Evaluate Native and Enhanced Soil Infiltration, and Determine Detention Requirements

Name: _____

Site: _____

Date: _____

This worksheet can be used to select BMPs to maximize infiltration and subsurface storage through the use of soil amendments and underdrain systems. First, maximize infiltration of the native soil, then investigate the use of soil amendments and finally determine if additional detention and underdrain is required.

Step 3.c.1. Summarize BMP site characteristics.

Characteristic	Source
Catchment Area (A_R), acres = _____	*Step 3.a.1*
Surface Area of BMP (A_{BMP}), acres=_____	*Step 3.a.1*
Area Tributary to BMP (A_T), acres=_____	*Step 3.a.1*

Step 3.c.2 Determine Total Water Quality Volume Entering BMP Site

Conveyance Pathway ID	Runoff Area (A_R), acres	Water Quality Volume (WQv or WQv_{ADJ}),	
		Depth (feet), from Step 3.a.2	Volume (ac-ft) = A_R * WQv (ft)
BMP surface*			
Total	**Σ A_R = ____**	**N/A**	**Σ WQv (by volume) = _____**
***WQv in BMP (D_{BMP}), by depth (ft)* = Σ WQv (by volume) / Σ A_{BMP} = _____**			

* Unless already included in the WQv calculation in Step 3.a.2

STEP 3.c.3 Native Soil in BMP (Pass 1)

Characteristic	Source
Allowable surface ponding time (t), hours = _____	*Typically 24 to 48 hours*
Infiltration into Native Soil (V_{NI}), feet = _____	*Minimum of :* • $K_{sat\text{-}NI} * t$ • D_{BMP} *(from 3.c.2)*
Surface condition: Ponded Infiltrated	*If* $D_{BMP} > V_{NI}$, *surface ponding occurs* *If* $V_{NI} \geq D_{BMP}$ *then the water is infiltrated into the native soil.*
Surface detention volume (V_{SD}), feet = _____	$D_{BMP} - V_{NI}$

If the surface condition is infiltrated then infiltration into the native soil appears to be a feasible option for this BMP site. Site measured infiltration rates should be used during design and a monthly water budget should be performed to determine soil moisture conditions for plant survivability during wet and dry months. If surface condition is ponded, then a soil amendment (Step 3.d) can be considered or proceed directly to basin BMP design (Step 3.e.).

STEP 3.d.1 Amended Soil in BMP (Pass 2)

Characteristic	Source
Infiltration into Surface of BMP (V_{EI}), feet = _____	*Minimum of :* • $K_{sat\text{-}EI} * t$ • D_{BMP}
Surface condition: Ponded Infiltrated	*If* $D_{BMP} > V_{EI}$, *surface ponding occurs* *If* $V_{EI} \geq D_{BMP}$ *then the water is infiltrated into the amended soil.*
Surface detention volume (V_{SD}), feet = _____	$D_{BMP} - V_{EI}$

If the surface condition is infiltrated then infiltration into the amended soil appears to be a feasible option for this BMP site. Continue with Step 3.d.2 to determine if an underdrain is needed. If surface condition is ponded, then proceed directly to basin BMP design (Step 3e).

Step 3.d.2. Determine Infiltration, Evapotranspiration, and Soil Moisture Within BMP

Characteristic	Source
Subsurface Dewatering Period (t_{DW}), days = _____	*Up to 3 days of subsurface dewatering typically will not affect plants within BMP*
Evapotranspiration rate (ET), in/day = _____	*Local Climate Data, check seasonal differences (see Table 3.c.1).*
Evapotranspiration in BMP (V_{ET}), feet = ____	$V_{ET} = ET * t_{DW} / 12$
Antecedent Soil Moisture at Start of Water Quality Event (V_{AM}), feet = _____	*Step 3.a.4*
Area available for infiltration into native soil surrounding planting bed (A_{NI}), ft^2 = _____	$A_{BMP} + 4 * D_M * A_{BMP}^{1/2}$
Infiltration from BMP into underlying native soil (V_{NI}), feet = _____	• *If* $FC_{EI} \geq V_{AM} + V_{EI} - V_{ET}$, *then* $V_{NI} = 0$. • *If* $FC_{EI} < V_{AM} + V_{EI} - V_{ET}$, *then* V_{NI} = *minimum of:* -- $V_{AM} + V_{EI} - V_{ET}$ -- $A_{NI} / A_{BMP} * [K_{sat\text{-}NI} * t_{DW} * 24 / 12]$
Soil Moisture at End of Dewatering Period (no Underdrain) (V_{END}), feet = _____	$V_{END} = V_{AM} + V_{EI} - V_{ET} - V_{NI}$
Determine Soil Moisture Condition: Ponded Saturated Normal Wilted (Note: Results may differ seasonally)	**Ponded**: $V_{END} > V_{P\text{-}EI}$ *(Surface Ponding expected without underdrain)* **Saturated**: $V_{FC\text{-}EI} < V_{END} < V_{P\text{-}EI}$ *(soil may go anoxic)* **Normal**: $V_{WP\text{-}EI} > V_{END} > V_{FC\text{-}EI}$ *(normal for plant growth)* **Wilted**: $V_{END} < V_{WP\text{-}EI}$ *(Soil moisture less than wilting point - plants will die)*
Underground detention volume (V_{UD}), ft = ___	Maximum of $V_{END} - V_{FC\text{-}EI}$, 0

STEP 3.e. Design Basin BMP (if soil moisture condition is Saturated or Ponded after Step 3.c.3 and/or 3.d.2)

Characteristic	Source
Extended Detention Volume (V_{ED}), feet = ___	$V_{SD} + V_{UD}$, *Steps 3.c.3 and 3.d.2*
Soil Moisture at End of Dewatering Period (with Underdrain), feet = _____	$V_{END} = V_{AM} + V_{EI} - V_{ET} - V_{NI} - V_{UD}$
Determine Soil Moisture Condition: Ponded Saturated Normal Wilted	**Ponded**: $V_{END} > V_{P\text{-}EI}$ *(Surface Ponding expected without underdrain)* **Saturated**: $V_{FC\text{-}EI} < V_{END} < V_{P\text{-}EI}$ *(soil may go anoxic)* **Normal**: $V_{WP\text{-}EI} > V_{END} > V_{FC\text{-}EI}$ *(normal for plant growth)* **Wilted**: $V_{END} < V_{WP\text{-}EI}$ *(Soil moisture less than wilting point - plants will die)*

Table 3.c.1. Monthly Climatic Data

Month	Evapotranspiration (ET)		Average Monthly Precipitation, inches	
	inches/day	Inches/month	Cleveland	Toledo
January	0.01	0.31	2.53	1.88
February	0.04	1.12	2.19	1.82
March	0.05	1.55	2.83	2.39
April	0.05	1.50	3.36	2.97
May	0.10	3.10	3.37	3.14
June	0.24	7.20	3.38	3.49
July	0.25	7.75	3.40	3.22
August	0.24	7.44	3.45	3.21
September	0.16	4.80	3.34	2.72
October	0.11	3.41	2.67	2.23
November	0.03	0.90	3.22	2.69
December	0.01	0.31	2.85	2.60
Average	0.11	39.39	36.59	32.36