A SunCam online continuing education course

Design of Infiltration & Extended Detention Basins

By

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Introduction:
This course presents an overview of the design features that go into both infiltration basins and extended detention basin. It includes design criteria for both of these stormwater management systems and describes limitations on the use of each of them.

When you complete this course you should be familiar with the functioning of both infiltration basins and extended detention basins. In addition, you should understand the process involved in retrofitting a standard detention basin to increase its ability to provide stormwater quality control. Several sources were used in preparing this course but the main reference is the New Jersey Department of Environmental Protection (NJDEP) "Stormwater Best Management Practices Manual."

Introduction:
The quality of stormwater runoff can affect public health, safety, and welfare in many ways. With increasing development it becomes ever more imperative that stormwater is properly treated before being allowed to run downstream into water bodies and potable water supplies. There are several ways to provide this quality control and this course will discuss two of the most common – infiltration basins and extended detention basins. In addition to providing stormwater runoff quality control both of these systems are used to attenuate peak flood flows and to reduce flooding downstream. In addition, infiltration basins provide another significant environmental benefit – they recharge water back into the ground. The United States Environmental Protection Agency (USEPA) recommends the use of infiltration basins as artificial aquifer recharge devices.

Overview of Infiltration Basins:
An infiltration basin is a special kind of detention facility that accepts stormwater runoff and infiltrates it back into the ground. Many infiltration basins are hybrid basins in that they infiltrate the runoff from smaller storms (e.g. the water quality storm) but route the runoff from larger storms downstream through a controlled outlet structure, functioning similarly to standard detention basins. The New York State Department of Conservation's "Stormwater Management Design Manual" lists the following five separate types of infiltration structures:

1. Infiltration basins.
2. Infiltration trenches.
3. Drywells.
4. Surface sand filters.

5. Underground sand filters.

This course will deal mainly with the design of infiltration basins. However, the design of infiltration trenches is obviously very similar except that the resulting facility will be relatively long and narrow. Drywells can be thought of as underground infiltration basins but they are generally used only for storing runoff from rooftop areas. A discussion of sand filters is beyond the scope of this course.

Infiltration basins are very useful at removing total Suspended Solids (TSS) and are also useful in removing additional pollutants such as phosphorous and nitrogen. The NJDEP assigns these features an 80% TSS removal rate, a 60% total phosphorous removal rate, and a 50% total nitrogen removal rate. These rates are among the highest that the NJDEP assigns to any type of stormwater management system. Of course, as an added benefit, an infiltration basin also provides very significant groundwater recharge. This is an environmental benefit in all areas, but especially in arid and drought-prone regions.

The photograph shown at the left, taken from the USEPA website, shows a typical infiltration basin. An overflow box is shown in the foreground.

Design of Infiltration Basins:

The main design parameters to consider with infiltration basins are the permeability rates of the underlying soil and the storage volume, depth, and duration of the stormwater within the basin. The main points to consider are the following:

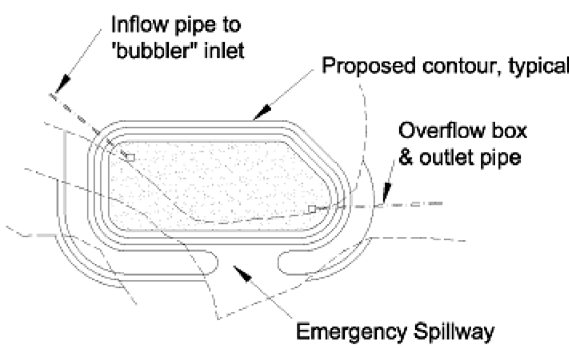
1. Infiltration basins are generally designed only to treat the runoff from smaller storms. They are designed to temporarily store the entire volume of a water quality storm but are not recommended (except in exceptional cases) to store the runoff from larger storms. Larger storms may either be bypassed over the basin through an overflow box or else controlled in the upper reaches of the basin through the use of a controlled outlet structure. The basins are generally designed to recharge the runoff from the water quality storm. The water quality storm is defined differently by different state reviewing agencies but it can be

thought of as a low-intensity, high frequency precipitation event. It is this run-of-the-mill type of storm which flushes the highest volume of pollutants downstream.

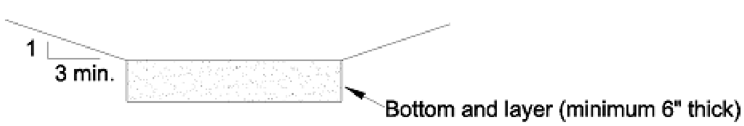
2. To avoid becoming a safety hazard, the maximum storage depth within the basin should be no more than 2 feet. If the depth is greater than 3 feet, then a safety ledge and/or a perimeter fence may need to be installed.
3. A bottom sand layer is essential in an infiltration basin. This layer should be between 6 and 12" deep. This layer has several purposes including (i) intercepting silt, sediment, and debris that could otherwise clog the top layer of the underlying soil and (ii) facilitating the removal of these materials during routine maintenance. The sand layer must have a permeability of K5 (i.e. >20 inches per hour). (The New York State Stormwater Management Design Manual indicates that this sand layer can be replaced in infiltration trenches by a Class "C" geotextile and stone aggregate).
4. In order to ensure that adequate percolation is provided, the bottom of the infiltration basin must be at least 2 feet above both the seasonal high water table and bedrock. This distance must be measured from the bottom of the sand layer.
5. The basin must be designed to drain completely within 72 hours after each rainfall.
6. The basin bottom must be as nearly level as possible to maximize the contact area and promote percolation.
7. When constructing the detention basin every effort must be made to avoid compacting the sand layer and the soils underlying it. Relatively light construction equipment should be used in the basin bottom when necessary and, if possible, construction equipment should work from the outside of the basin. If the soils are compacted it can cause the permeability to be significantly reduced and, consequently, cause the basin to cease functioning.
8. This course deals mainly with the design of above-ground infiltration basins. However, basins can be constructed underground in a variety of ways. Ordinarily, an underground infiltration basin consists of a stone pit which is deep enough to intercept a permeable soil layer but which will not intercept the groundwater. Depending on the situation, the stone pit can include perforated pipes, infiltrator chambers, or concrete seepage tanks. If the basin is placed under traffic areas, it is essential that these structures be able to withstand the traffic load.
9. It is essential that the flow into the infiltration basin be non-erosive. This can be accomplished in a variety of ways. Some of the most common are:

a. The basin can be equipped with a forebay which will break up the velocity of the inflow.
b. The inflow pipe can be directed into an underground "bubbler', which will allow the water to bubble up into the basin.
c. The inflow can be directed into conduit outlet protection equipped with baffles to reduce the velocity.

A typical plan and cross section of an infiltration basin is shown below. Note that in most respects an infiltration basin will look exactly like a standard detention basin. The only difference is that an infiltration basin will use percolation as its lowest outlet. In dry weather an inspection of the controlled outlet structure will show if a basin is a standard detention basin or an infiltration basin. If the lowest orifice in the controlled outlet is at the bottom of the basin, then it is a standard detention basin; otherwise it is an infiltration basin.



Typical Infiltration Basin Plan



Typical Infiltration Basin Section

The actual design of an infiltration basin is based on Darcy's Law:

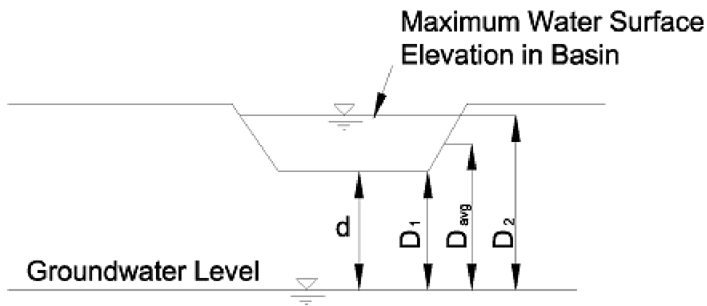
$Q = KIA$, where

Q is the rate of infiltration in cubic feet per second.
K is the hydraulic conductivity of the soil in feet per second.
I is the hydraulic gradient.
A is the area of infiltration in square feet.
In the design of an infiltration system it is recommended that a factor of safety of 2 be applied to the K value in order to account for potential siltation of the basin over time.
The term hydraulic conductivity is sometimes considered to be synonymous with permeability. However their meanings are related but not identical. The USDA website gives a good description of both of these terms and a comparison of them. Hydraulic conductivity is a property of both plants and soils and describes the ease with which a fluid (in this case, water) can move through a porous medium. Essentially, permeability (sometimes called "intrinsic permeability") is a quantitative property of porous media and is controlled solely by pore geometry. Unlike hydraulic conductivity it is independent of fluid viscosity and density. When the effects of the fluid's viscosity and density are removed, the intrinsic permeability becomes synonymous with the material's hydraulic conductivity.

The US Department of Transportation gives the following general values for saturated hydraulic conductivity of various soils:

Soil Description	Hydraulic Conductivity (feet/sec)
Clean Gravel	$3X10^{-2}$ to 3
Sand-gravel mixtures	$3X10^{-4}$ to 0.3
Clean coarse sand	$3X10^{-4}$ to $3X10^{-2}$
Fine sand	$3X10^{-5}$ to $3X10^{-3}$
Silty sand	$3x10^{-5}$ to $3X10^{-4}$
Clayey sand	$3X10^{-6}$ to $3X10^{-4}$
Silt	$3X10^{-10}$ to $3\ X10^{-5}$
Clay	$3X10^{-12}$ to $3X10^{-8}$

The figure below graphically represents the hydraulic gradient. In this figure:
Maximum hydraulic gradient = D_2/d
Minimum hydraulic gradient = D_1/d
Average hydraulic gradient = D_{avg}/d



Darcy's Law Schematic

The hydraulic conductivity can be field measured or determined in a laboratory. A number of replicate tests should be done to ensure that the hydraulic conductivity of the underlying material is properly modeled in the design.

Example: An infiltration basin is proposed for a residential subdivision in New Jersey. The basin will have a bottom area of 6000 SF. Soils investigations have shown that the soil underlying the basin consists of coarse sand and that the groundwater will be 6 feet below the bottom of the basin. The maximum design depth in the basin will be 2 feet. Find the flow out of the basin bottom using a factor of safety of 2 for potential siltation over time. Then, assuming that the basin the total inflow into the basin during the design storm is 15,000 CF of runoff, find the time required to drain the basin.

Solution: Based on the description given in the statement of the problem we can determine the following:

- Hydraulic conductivity of clean, coarse sand ranges from $3X10^{-4}$ to $3x10^{-2}$. To be conservative we will use the lowest of these values ($3X10^{-4}$). Using a factor of safety of 2 divides this value in half. Therefore, the design hydraulic conductivity value is $1.5X10^{-4}$.
- The average hydraulic gradient is 7/6.
- The bottom area is 6000 SF

Therefore, we can insert these values into Darcy's Law to find:

$Q = (0.00015)(7/6)(6000) = 1.05 CFS$ This is the outflow from the basin due to percolation through the bottom.

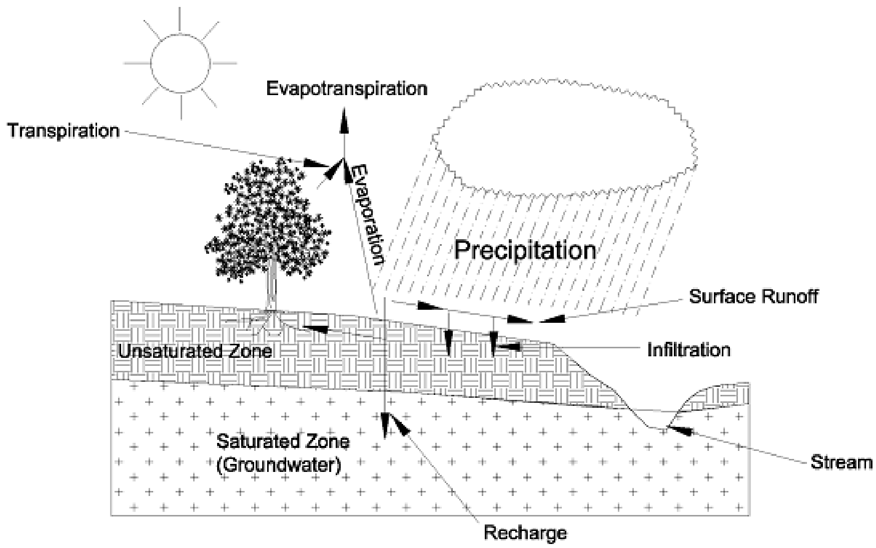
The time required to empty the basin through the bottom is the total runoff volume divided by the outflow rate:
$T = 15{,}000 / 1.05 = 14{,}285\,seconds / 3600 = 3.97\,hours$

Therefore, it takes slightly less than 4 hours to completely drain the basin.

Determination of Recharge Provided by Infiltration Basins:
The NJDEP requires that all major developments in New Jersey recharge stormwater into the ground and comply with either one of the following requirements:

1. 100% of the site's average annual pre-developed groundwater recharge volume be maintained after development, or
2. 100% of the difference between the site's pre-development and post-development 2 year runoff volumes be recharged.

Therefore, the engineer has the choice of complying with either of these criteria. Note that the modeling is different in each case. In the first scenario the engineer must calculate the entire annual groundwater runoff from the site, whereas in the second case the focus is on a single storm (i.e. the 2 year rainfall event). It should be noted that the NJDEP allows for a waiver of this requirement if on-site investigations show that recharge cannot be provided due to impervious soils or a high water table.
Groundwater recharge is defined as that portion of the precipitation that infiltrates into the soil and does not contribute to the runoff nor is it evapotranspirated. Instead, this water moves downward to a depth below the root zone. At this depth it is capable of joining either the regional groundwater, or (if there is an intervening layer of impermeable soil) joining a perched groundwater zone. Groundwater recharge is shown as part of the overall hydrologic cycle in the schematic below:

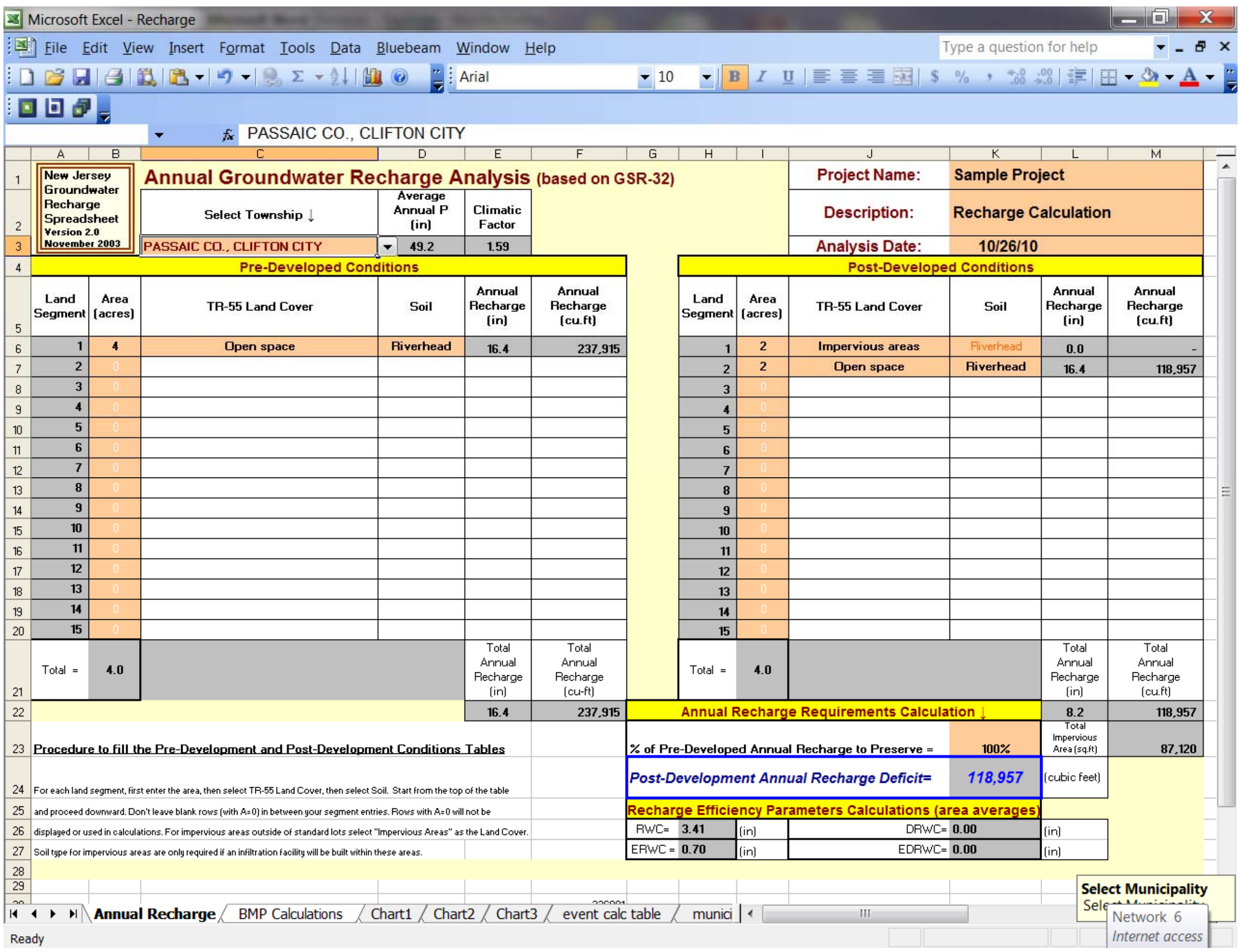


Schematic Showing Groundwater Recharge in the Hydrologic Cycle

Ordinarily, converting pervious areas to impervious surfaces will reduce the groundwater recharge taking place on the site. This is simply because more runoff (and, consequently, less infiltration) takes place over impervious areas than over areas that are at least partially pervious. The NJDEP has an Excel spreadsheet for computing the groundwater recharge deficit caused by a proposed development and the amount of recharge that can be provided by the use of an infiltration structure. Unfortunately, this spreadsheet represents something of a "black box" model because the methodology cannot be duplicated by conventional calculations. However, it is based on a significant amount of empirical data and is broken down by municipality and county for every region in the state.

A sample project will illustrate how the NJDEP spreadsheet calculates groundwater recharge. The sample project is a 4 acre site in the City of Clifton, Passaic County, NJ. The property is currently vacant and is underlain by Riverhead type soil. The proposal calls for the conversion of 50% of the site (2 acre) to rooftops, parking areas, and walkways. The remainder of the lot will remain as open space (lawn or landscaped areas).
This sample project is very simple and many projects will have more than one type of on-site soil and more than one type of existing on-site land use.

A screen shot for this sample problem is shown below. The city, county, soil types, land area, and existing and proposed land uses are input into the model as shown in the screen shot. In the lower right-hand corner the annual recharge deficit (118,947 CF) is shown.



In order to make up for this recharge deficit, an infiltration basin is proposed. The basin will have a bottom area of 10,000 SF and the excavation will be 2 feet deep. The maximum depth to be achieved within the basin during the water quality storm is also 2 feet. It is assumed that all 2 acres of impervious surfaces will drain into the infiltration basin.

The values to be input into the model are as follows:

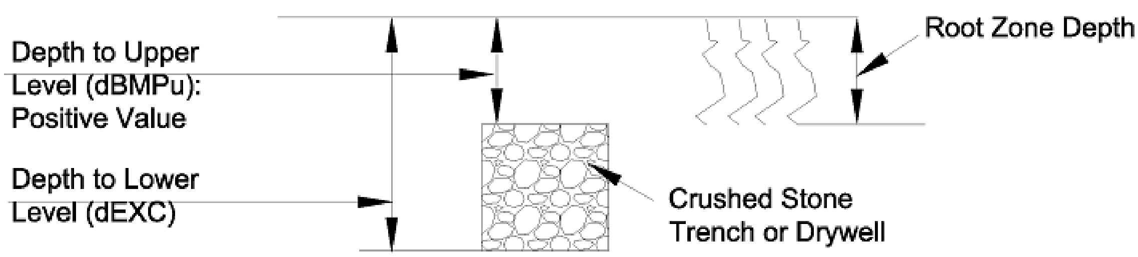
- ABMP is the area of the bottom of the infiltration basin in square feet.

- dBMP is the effective depth of the basin in inches.
- dBMPu is the upper level of the water surface within the basin in inches.
- dEXC is the lower level of the water surface in the basin in inches.
- Vdef is the post development deficit recharge deficit calculated above.
- Aimp is the post-development impervious area to be directed into the infiltration basin in square feet.

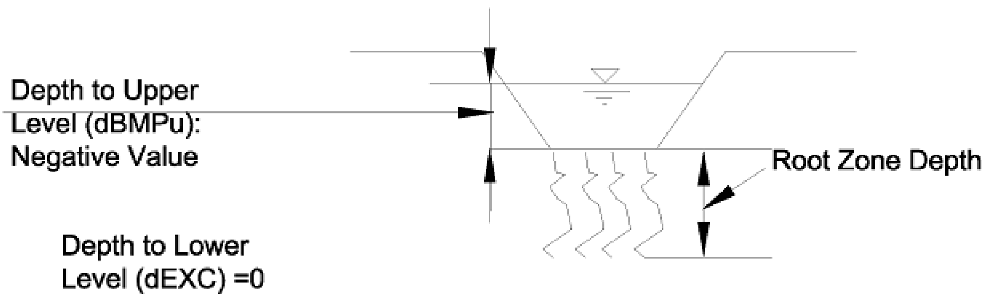
If the model shows that insufficient recharge is being provided, the engineer can adjust the design as follows:

1. Make the bottom area of the infiltration basin larger.
2. Make the basin deeper.
3. Direct more impervious surfaces into the basin.

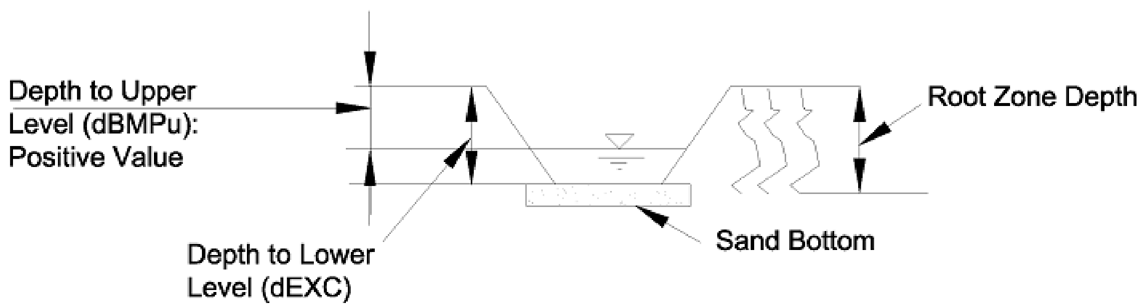
The values of the parameters are input differently based on whether the infiltration facility is an above-ground or a below ground facility. This is shown schematically in the figures below.



Subsurface Recharge Facility



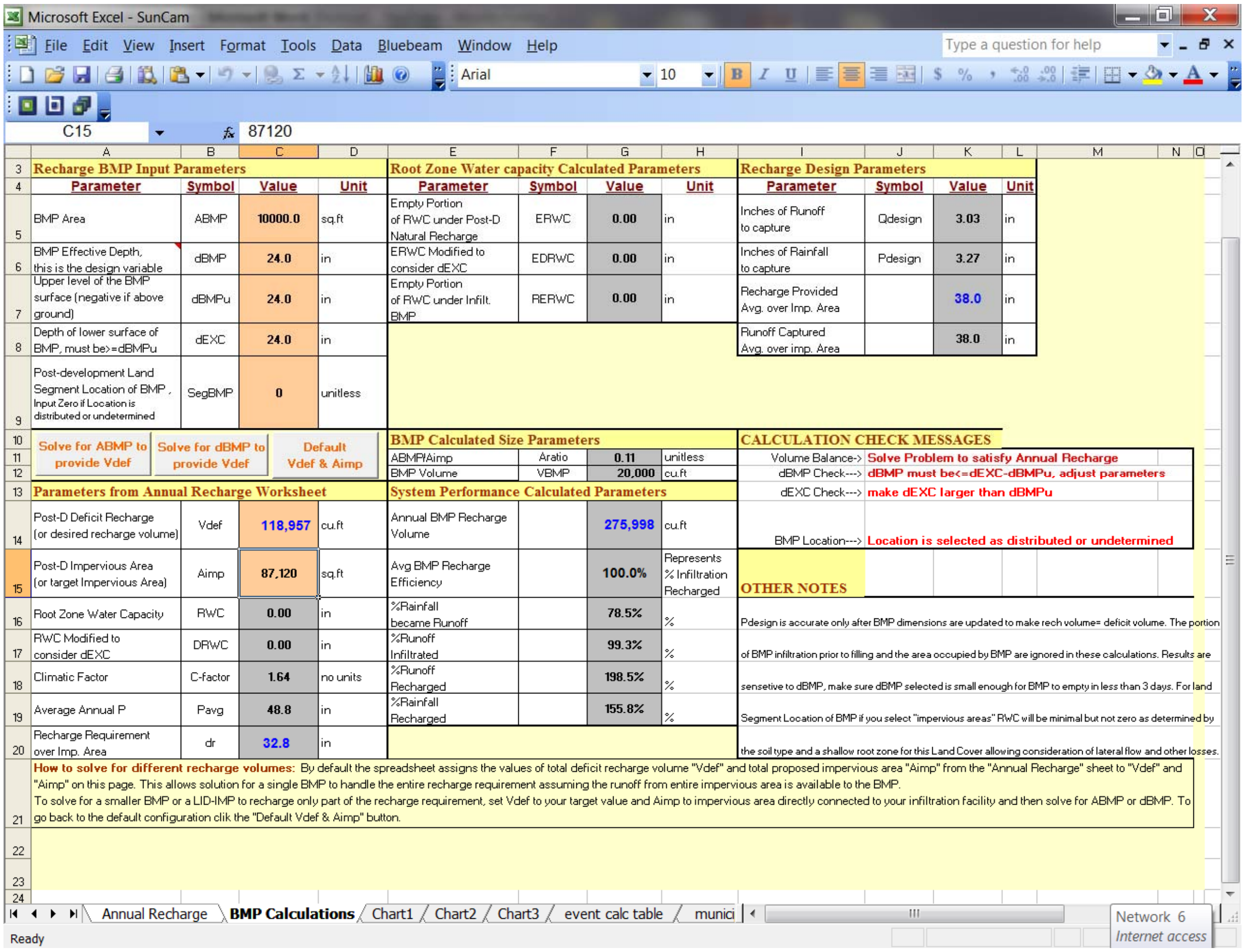
Vegetated Surface Recharge Facility



Unvegetated Surface Recharge Facility

The screen shot below shows the calculations. The input values shown in the screen shot are as follows:
-ABMP (the basin bottom area) is given in the problem as 10,000SF.
-dBMP (the effective depth) is 24 inches.
-dBMPu (the upper water surface level) is also 24"
-dEXC (the lower water surface level) is also 24".
-Vdef (the recharge deficit) was calculated above as 118,957 CF.
-Aimp (the impervious area draining into the basin) is given in the problem as 2 acres. This is input into the model in square feet. (2 acres = 87,120 SF).

Note that "Annual BMP Recharge Value" shown is 275,998 CF which is much greater than the 118,957 CF recharge deficit shown above. Therefore, the infiltration basin proposed is adequate for this site and will infiltrate more water into the ground, on an annual basis, then would be deprived of the groundwater by the development in the absence of the basin.



Recharge BMP Input Parameters

Parameter	Symbol	Value	Unit
BMP Area	ABMP	10000.0	sq.ft
BMP Effective Depth, this is the design variable	dBMP	24.0	in
Upper level of the BMP surface (negative if above ground)	dBMPu	24.0	in
Depth of lower surface of BMP, must be>=dBMPu	dEXC	24.0	in
Post-development Land Segment Location of BMP, Input Zero if Location is distributed or undetermined	SegBMP	0	unitless

Solve for ABMP to provide Vdef | Solve for dBMP to provide Vdef | Default Vdef & Aimp

Parameters from Annual Recharge Worksheet

Parameter	Symbol	Value	Unit
Post-D Deficit Recharge (or desired recharge volume)	Vdef	118,957	cu.ft
Post-D Impervious Area (or target Impervious Area)	Aimp	87,120	sq.ft
Root Zone Water Capacity	RWC	0.00	in
RWC Modified to consider dEXC	DRWC	0.00	in
Climatic Factor	C-factor	1.64	no units
Average Annual P	Pavg	48.8	in
Recharge Requirement over Imp. Area	dr	32.8	in

Root Zone Water capacity Calculated Parameters

Parameter	Symbol	Value	Unit
Empty Portion of RWC under Post-D Natural Recharge	ERWC	0.00	in
ERWC Modified to consider dEXC	EDRWC	0.00	in
Empty Portion of RWC under Infilt. BMP	RERWC	0.00	in

BMP Calculated Size Parameters

ABMP/Aimp	Aratio	0.11	unitless
BMP Volume	VBMP	20,000	cu.ft

System Performance Calculated Parameters

Annual BMP Recharge Volume		275,998	cu.ft
Avg BMP Recharge Efficiency		100.0%	Represents % Infiltration Recharged
%Rainfall became Runoff		78.5%	%
%Runoff Infiltrated		99.3%	%
%Runoff Recharged		198.5%	%
%Rainfall Recharged		155.8%	%

Recharge Design Parameters

Parameter	Symbol	Value	Unit
Inches of Runoff to capture	Qdesign	3.03	in
Inches of Rainfall to capture	Pdesign	3.27	in
Recharge Provided Avg. over Imp. Area		38.0	in
Runoff Captured Avg. over imp. Area		38.0	in

CALCULATION CHECK MESSAGES

Volume Balance->	Solve Problem to satisfy Annual Recharge
dBMP Check--->	dBMP must be<=dEXC-dBMPu, adjust parameters
dEXC Check--->	make dEXC larger than dBMPu
BMP Location--->	Location is selected as distributed or undetermined

OTHER NOTES

Pdesign is accurate only after BMP dimensions are updated to make rech volume= deficit volume. The portion of BMP infiltration prior to filling and the area occupied by BMP are ignored in these calculations. Results are sensetive to dBMP, make sure dBMP selected is small enough for BMP to empty in less than 3 days. For land Segment Location of BMP if you select "impervious areas" RWC will be minimal but not zero as determined by the soil type and a shallow root zone for this Land Cover allowing consideration of lateral flow and other losses.

How to solve for different recharge volumes: By default the spreadsheet assigns the values of total deficit recharge volume "Vdef" and total proposed impervious area "Aimp" from the "Annual Recharge" sheet to "Vdef" and "Aimp" on this page. This allows solution for a single BMP to handle the entire recharge requirement assuming the runoff from entire impervious area is available to the BMP.
To solve for a smaller BMP or a LID-IMP to recharge only part of the recharge requirement, set Vdef to your target value and Aimp to impervious area directly connected to your infiltration facility and then solve for ABMP or dBMP. To go back to the default configuration clik the "Default Vdef & Aimp" button.

Once again, the calculations cannot be duplicated except by using the spreadsheet (which can be downloaded in ether Excel 97 or Excel 2002 version by visiting the DEP's website at http://www.state.nj.us/dep/stormwater/bmp_manual2.htm). The model was developed using soils and climate data from each region of the state. The governing equations deal with the soil water capacity of the different regions.

Limitations on the Use of Infiltration Basins:

Despite the fact that infiltration basins can be very useful at providing stormwater quality control, peak flood attenuation, and groundwater recharge there are several limitation that prohibit their use in certain situations. The most obvious limitation is the permeability of the soil. If the soil is not highly permeable there is no opportunity to use an infiltration basin. No matter what is done at the surface of the basin the facility will not drain and will not provide any of the anticipated benefits. The NJDEP gives the following minimum values for permeability for infiltration basins. If on-site soils investigations indicate that this permeability is not present at the site an infiltration basin should not be used.

Purpose of the Infiltration basin	**Basin Location**	**Minimum Design permeability (Inches/Hour)**
Groundwater Recharge	Subsurface	0.2
Groundwater Recharge	Surface	0.5
Stormwater Quality	Surface or Subsurface	0.5

The values given in the table above should be considered as absolute minimums. The design engineer should also analyze the basin to ensure that it will drain within 72 hours after each storm. When performing this analysis it is important to use actual field tests at the site of the proposed basin. Published soils data (contained in the National Resource Conservation Service's web soil survey) are good sources of information but are not adequate for designing an infiltration basin. The in-field test can be a perc test, a soil class rating analysis, or any other standard test for measuring soil permeability. Remember that in order to account for potential siltation of the basin bottom over time, the engineer should use a factor of safety of 2 in the design. That is, if a perc test shows that the soil has a permeability of 4 inches per hour, the design value used should one half of that, or 2 inches per hour.

Conversely, infiltration basins must not be used in highly permeable soils where there is a significant risk of basement flooding, seepage into septic systems, or other subsurface structures. The NJDEP also indicates that infiltration basins must not be used in the following areas:

1. Areas with high risk of spills of toxic materials such as gas stations and vehicle maintenance facilities. (These areas are referred to as "stormwater hotspots" by the USEPA.)
2. Industrial and commercial areas where solvents and/or petroleum products and/or pesticides are loaded, unloaded or stored.
3. Areas where industrial stormwater runoff is exposed to "source material". The NJDEP defines source material as any material or machinery, located at an industrial facility, that is directly or indirectly related to process, manufacturing, or other industrial activities, that could be a source of pollutants in any industrial

stormwater discharge to groundwater. Source materials include, but are not limited to raw materials, intermediate products, final products, waste materials, by-products, industrial machinery and fuels, and lubricants, solvents, and detergents that are related to process, manufacturing, or other industrial activities that are exposed to stormwater.

4. Karst Topography: Karst topography is a geologic formation underlain by layers of soluble bedrock, usually limestone. If karst topography is suspected, infiltration basins should not be used due to the potential for sinkhole formation (unless on-site investigations prove otherwise).

Additional Considerations Regarding Infiltration Basins:

1. Construction: During construction, every effort shall be made to prevent compacting the soil below the basin bottom. The most efficient way to do this is to prevent heavy equipment from driving on the basin bottom. If it is necessary to drive heavy equipment within the basin during construction, soil compaction can be mitigated against by incorporating soil additives consisting of 2" of compost mixed into 2" of topsoil. The soil mix should be incorporated into the existing soil using a chisel plow or rotary device reaching 12" below the surface. After construction, the basin bottom can be stabilized by seeding, applying sod, or by mulching.
2. Infiltration cells: In large infiltration basins it is sometimes desirable to divide the basin into individual "infiltration cells" using level spreaders to distribute the runoff through the cells. These cells promote even groundwater recharge around the entire basin and avoid the channelization of the runoff through the basin. (If the runoff is channeled through the basin there is the potential for erosion of the sand in the basin bottom. This could change the microtopography within the basin which will, in turn, reduce the effective bottom area of the basin.)
3. Pretreatment: Any stormwater quality control feature benefits by the use of a pretreatment device. However, because infiltration basins are so prone to become silted in, pretreatment is especially useful with these types of systems. Depending on the situation upstream of the infiltration basin any of the following pretreatment devices can be employed:

- Septic tank.
- Vegetated filter strip.
- Sand filter.
- Porous pavement.

4. Sensitivity of the Area: As indicated above, there are several areas that are not conducive to the employment of infiltration facilities. These include areas with insufficient permeability, areas where the permeability and proximity of other features mitigate against their use, and areas with a very high pollutant loading.
5. Slopes: Generally speaking infiltration basins will not function well in areas of steep slopes. However, if the permeability is sufficient, the design engineer may use infiltration swales in these areas. In steeply sloped areas, the earthwork involved in a standard infiltration basin is ordinarily too extensive to be practical. However, the same effect can often be obtained by using a series of long, narrow infiltration trenches placed more or less parallel to the existing contours. If trenches are used, care should be taken to ensure that flow into each trench is not erosive.

The photograph below shows an infiltration basin being constructed. A sand filter (under construction) is visible in the background. This sand filter will provide pre-treatment for the water entering the infiltration basin. The headwall to the right is the inflow to the basin. The overflow box is shown to the left. Note that retaining walls are used on this project because very little land was available for the detention facilities

The photograph below (taken from the University of Louisville website) shows an underground infiltration basin being constructed. This system consists of stone and concrete seepage tanks. Synthetic filter fabric can be seen in the photo as well. It is important in an underground system to wrap the stone in fabric to prevent fines from the surrounding soil from migrating into the stone and closing up the voids. This system will be covered with topsoil and planted with sod. It is part of a larger overall stormwater management project that incorporates a vegetated rooftop and other environmentally-beneficial elements.

Regional Design Variations:

Cold Climates:

Infiltration basins can be used in extremely cold climates but these climates (and especially those experiencing permafrost) can present the following challenges:

- The basin can become inoperable during the winter months when the surface is frozen.
- The quantity of snowmelt in the spring may be so great as to overwhelm the system. A method for estimating the volume of snow melt is presented below.
- The pollutant load in these areas often has a high concentration of salts and chlorides due to roadway maintenance activities.

The engineer has several options for dealing with these challenges. Some of these are discussed below:

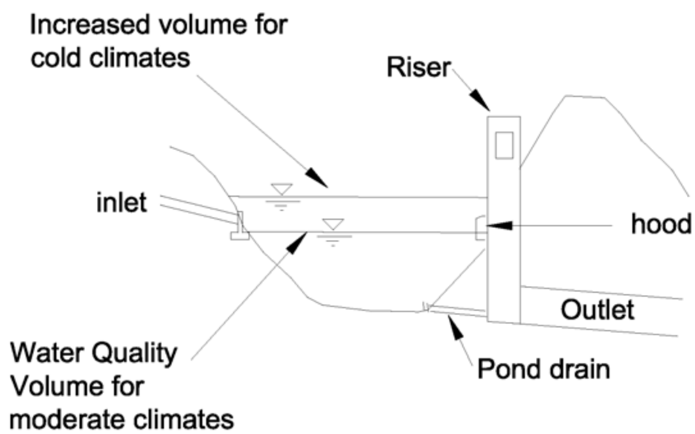
a. The basin could be made to be a seasonally operated facility. A seasonally operated basin combines several techniques to improve the performance of the facility in cold climates. The underdrain system and level control valves are especially useful in this regard. At the beginning of the winter, the level control valve is opened and the soil is drained. Then as the snow begins to melt in the winter, the underdrain and the level control valves are opened. The snowmelt will then be infiltrated until the moisture capacity of the soil is reached. At that point the system will again act as a detention basin and will provide temporary storage for solids to settle out of suspension. It is imperative to check with the reviewing agency, prior to design, to be sure that a seasonally-operated basin will be approved.

b. The basin could be taken off-line (by use of an upstream drainage structure) during the winter if the chloride load is expected to be high enough that it should not be recharged into the groundwater.
c. The bottom of the basin can be planted with salt-tolerant vegetation that will be able to withstand the yearly influx or road salts.
d. The storage volume within the basin can be made larger to deal with the expected spring snowmelt. In order to determine the amount of extra volume (if any) that must be provided to deal with snowmelt the engineer must first determine how much snowmelt is expected. A method for estimating this quantity is presented below.

The actual amount of snowmelt can be estimated in a variety of ways. In New York State the Capital District Regional Planning Commission (CDRPC) uses the Simple Method which is outlined as follows. The CDRPC requires that 90% of the annual pollutant load be treated in the infiltration basin. In order to accomplish this, the basin should generally be oversized if either of the following is anticipated:

- The average annual snowfall depth is greater than or equal to the annual precipitation depth.
- The area is in a coastal or Great Lakes region with more than 3 feet of annual snowfall. In these areas the basin may need to be oversized to address the effects of rain-on-snow events.

The increase in storage volume required in cold climates is shown schematically below:



Schematic: Increased Volume in Cold Climates

Ordinarily, in New York State, relatively small snow events occur throughout the winter. The resulting snowpack in the spring contains only a fraction of the moisture contained within the winter snows due to the effects of sublimation and management practices, such as hauling the snow to other locations. Therefore, the remaining moisture in the snowpack can be calculated by the following equation:

Equation S1: $M = (0.1)(S) - L_1 - L_2 - L_3$, where
M is the moisture remaining in the spring snowpack in inches.
S is the annual snowfall in inches.
L_1, L_2, and L_3 are the losses due to hauling, sublimation, and winter melt, respectively.

The Simple Method uses a "rule of thumb" approach to estimate the winter snowmelt and relates the amount of snowmelt to the average maximum daily temperature in January. After adjusting for snow plowing and sublimation, it is assumed that one half of the snow melts during the winter in very cold regions and that two thirds of the snow melts during the winter in moderately cold regions. Very cold regions are considered to be those areas where the average January maximum daily temperature is less than 25^0 F and moderately cold regions are those areas where the average January daily temperature is between 25^0 F and 35^0 F. The table below shows the amount of snowmelt expected in different regions:

Table of Winter Snowmelt*

Adjusted Snowfall Moisture Equivalent	**Winter Snowmelt in Very Cold Regions**	**Winter Snowmelt in Moderately Cold Regions**
2"	1.0"	1.3"
4"	2.0"	2.7"
6"	3.0"	4.0"
8"	4.0"	5.3"
10"	5.0"	6.7"
12"	6.0"	8.0"

* This table deals only with snowmelt occurring before the spring snowmelt event and is based on the moisture content in the annual snowfall. The value in the first column is adjusted for losses due to sublimation and plowing of the snow off-site.

It should be noted that snowmelt is actually a very complicated process and is subject to very wide annual fluctuations. These include not only variations in snowfall and winter temperature from year to year but also changes in snow management practices. In some areas the resulting snowpack is actually enhanced and not reduced by snow management practices. The method described is generally not applicable to these snow-storage areas. If local experience or data show that this method is not adequately modeling the situation then more sophisticated models should be employed.

Snowmelt is converted to runoff only when the rate of snowmelt exceeds the infiltration capacity of the soil. Therefore, the two most important factors in determining the snowmelt becoming runoff are the water content in the snow and the soil moisture content of the soil. If the soil is relatively dry, it could have a significant permeability. However, if the soil is saturated it will generally become frozen and the ice will form an impermeable layer causing virtually all of the snowmelt to become runoff.

The CDRPC requires that no more than 5% of the annual runoff volume bypass the treatment facility (i.e. the infiltration basin). In order to treat 90% of the annual runoff volume, generally some of the spring snowmelt, in an average year, will go untreated. In addition, much of the runoff from large storm events during the summer months will go untreated. Limiting the volume that bypasses treatment during the spring snowmelt will allow the 90% treatment goal to be reached while allowing these large storms to bypass the basin. The resulting equation describing the volume of runoff treated is shown below:

Equation S2: $T = (R_S - 0.05xR)A/12$, where:

T= Volume of runoff treated in acre-feet
R_S = Snowmelt runoff (see below)
R= Annual Runoff Volume in inches (see below)

Snowmelt ordinarily occurs over an extended period of time (in contrast to storm events which generally create runoff over a fairly short time period). Therefore, the basin does not have to treat all of the snowmelt runoff volume over a 24 hour period, but may have a week or even more for treatment.. Therefore, the required water quality treatment volume is less than the treatment volume. Many experts assume that the required volume of the basin (WQ) is ½ of the computed treatment volume, T. Expressed mathematically, this is Equation S3: $WQ_V = 1/2T$

The base criteria, which was developed for moderate climates, is a widely-used water quality basin sizing rule. In some areas the runoff from a 1" precipitation event is used as the base criteria. Using a one inch rainfall allows for treatment of approximately 90% of the storms (at least in New York and surrounding areas). The base criteria storm will vary significantly given the wide range of climate variation across the country. However, the modifications required to treat snowmelt can be used in any cold climate.

Runoff from rain events can be calculated based on the Simple Method using the following equation:
Equation S4: $r = p(0.05 + 0.9xI)$, where:

r = Event Rainfall runoff in inches
p =Event Precipitation in inches
I = Impervious Area Fraction

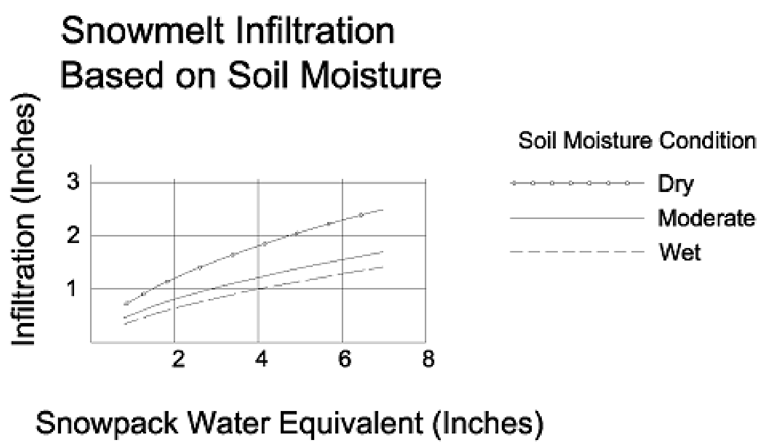
Therefore, the water quality volume for the base criteria can be determined by the following:
Equation S5: $WQ_V = (0.05 + 0.9xI)(A/12)$, where:

WQ_V = Water Quality Volume, in acre-feet
I = Impervious Fraction
A = Contributing Drainage Area, in acres

Finally, the Simple Method can be used to determine the annual runoff volume. To accomplish this, another factor, P_J, is added to account for the fact that not all rainfall events produce runoff. A value of 0.9 is generally assumed for P_J, which yields the following equation:
Equation S6: $R = 0.9P(0.05 + 0.9xI)$, where:

R = Annual runoff, in inches
P = Annual Rainfall, in inches

In order to complete the sizing of the basin in cold climates it is necessary to calculate the snowmelt runoff. As stated above, the soil moisture content has a lot to do with the amount of snowmelt that actually becomes runoff. The chart below shows the relation between the soil moisture and the resulting runoff. As can be seen by the chart, the more saturated the soil, the more runoff is produced by the snowmelt. Impervious areas are generally considered to convert 100% of the rainfall into runoff. In fact, snow falling on roadways, parking lots, sidewalks, and other impervious surfaces may be significantly less than 100% due to the effects of snow removal and sublimation. However, stockpiled snow piles adjacent to these impervious surfaces often exhibit increased runoff rates due to the high moisture content in the stockpiled snow. This offsets the reduced runoff from roads and other impervious areas.



The resulting equation to calculate snowmelt runoff volume (based on all of these assumptions) is expressed as Equation S7, below. This equation can be thought of as expressing the snowmelt runoff as the sum of the runoff generated from pervious area and the runoff generated from impervious areas.

Equation S7: $R_S = ((1-I)(M - Inf)) + (IxM))$, where:

R_S = Snowmelt Runoff
I = Impervious Fraction
M = Snowmelt, in inches
Inf = Infiltration, in inches

In the photograph below, the snow has not yet reached a point where it is affecting the outlet structure of this basin. This photograph was taken early in the winter and, with additional snowfall, this basin could need to be oversized to address the volume of the snowmelt.

The following example shows the process for determining snowmelt and its effect on the design of an infiltration system:

Statement of the problem:
Contributing drainage area = 20 acres.
Amount of impervious surface = 40%.
Average annual snowfall = 72”.
Average annual precipitation = 36”.
Average daily maximum January temperature = 22^0.
Amount of snowfall hauled away = 25%.
Sublimation is negligible and can be ignored.
Pre-winter soil conditions: moderate moisture

Solution:
Step 1: Determine if is necessary to oversize the basin. In this case, the average annual precipitation is only one half of the annual snowfall, so it will be necessary to oversize the basin.

Step 2: Determine the annual loss of snow due to snow plowing and sublimation. According to the problem statement, the sublimation is negligible. Therefore $L_2 = 0$. Based on the 25% snow removal L_1 is calculated as follows:

$L_1 = (0.25)(0.1)S$, where

L_1 is the water equivalent lost to plowing (in inches)

S = annual snowfall (in inches)

0.1 is the factor to convert snowfall to water equivalent

Therefore, the snow plowed off site is calculated as:

$L_1 = (0.25)(0.10(72") = 1.8 inches$

Step 3: Determine the annual water equivalent lost due to winter snowmelt events. Using the information in step 2, find that the moisture equivalent remaining in the snowpack after plowing is: $72" x 0.1 - 1.8" = 5.4 inches$

Interpolating from the Winter Snowmelt Table above, it can be seen that the volume lost to winter melt (L_3) = 2.7 inches.

Step 4: Calculate the final snowpack, in inches, using Equation S1, as follows:

$M = 0.1S - L_1 - L_2 - L_3$

$M = 0.1(72") - 1.8" - 0" - 2.7" = 2.7"$

Step 5: Calculate the snowmelt runoff volume, R_S, using the following equation:

$Rs = (1 - I)(M - Inf) + IxM$, where:

M=2.7"

I=0.4

Inf=0.8" (Using the Snowmelt Infiltration Graph on page 22 and assuming average moisture

$Rs = (1 - 0.4)(2.7" - 0.8") + 0.4x2.7" = 2.2"$

Step 6: Determine the annual runoff volume, R, using the Simple Method to calculate runoff:

$R = 0.9(0.05 + 0.9xI)P$, where

I=0.4

P=36"

$r = 0.9(0.05 + 0.9X0.4)36 = 13.3"$

Step 7: Determine the runoff to be treated, T, using equation S2:

$$T = (Rs - 0.05xR)A/12$$

R_S=2.2"

R=13.3"

A=20 acres

$$T = (2.2 - 0.05x13.3)20/12 = 2.56ac - ft$$

Step 8: Size the basin. The volume treated by the base criteria, from equation S5, would be:

$WQV = (0.05 + 0.9xI)(1/12)(A)$, or:

$$WQV = (0.05 + 0.9x0.4)(1/12)(20acres) = 0.68ac - ft$$

However, for cold climates, equation S3 is used:

$$WQV = (1/2)(T) = 1/2x2.56ac - ft = 1.28ac - ft$$

The cold-climate sizing criteria is larger and governs in this situation.

The CDRPC Stormwater manual also has a methodology for determining the runoff from rain-on-snow events. This involves developing a rain-on-snow data set made up of all precipitation events during a typical winter. However, a complete discussion of this methodology is beyond the scope of this course.

The photograph below shows an infiltration basin in winter in New Jersey. The inflow pipe is to the left and the overflow box is located in the foreground. Note that puddles of water have frozen in the bottom of the basin.

Arid Climates:
In arid regions, such as the southwest of the United States, infiltration basins are highly recommended because they promote badly needed groundwater recharge. In the southwest, pretreatment is to be emphasized because stormwater runoff in this area often carries a high sediment loading. A sediment forebay or other pretreatment device is necessary, therefore, to prevent the basin bottom from clogging. Also to help prevent clogging, the basin bottom can be planted with drought tolerant species that can also tolerate short periods of inundation. As an alternative the bottom of the basin is sometimes covered with a coarse sand or gravel. Underground infiltration basins are also recommended in arid areas.

Gravel can be seen at the bottom of the basin in the photograph shown below.

The photograph at the left shows an infiltration basin in an arid climate. This photograph was taken from the Nevada Division of Environmental Protection website.

Maintenance of Infiltration Basins:
If not properly maintained, infiltration basins can fail to provide the design benefits in a fairly short amount of time. In fact, infiltration basins have the highest failure rate of any commonly-employed stormwater best management practice. For this reason it is absolutely essential that regular maintenance be performed. The following general maintenance schedule for infiltration basins are modified from guidelines promulgated by the USEPA.

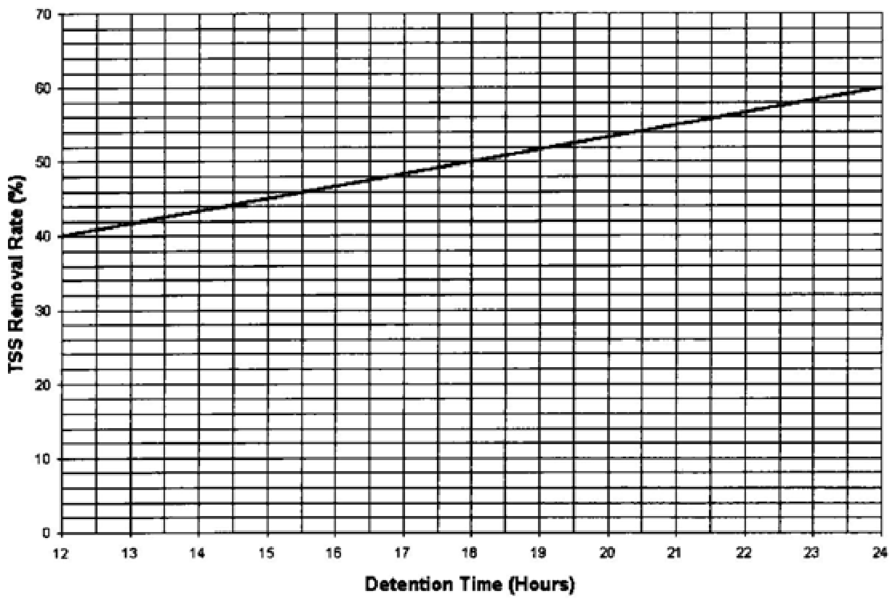
Maintenance Activity	Schedule
Inspect facility for signs of wetness or damage to structures and note any eroded areas. If dead or dying grass is noted in the basin bottom, check to make sure that the basin is draining within 2 to 3 days after a rainfall event.	Semi-annual inspection
Note signs of petroleum hydrocarbon contamination and remediate same.	Semi-annual inspection
Mow grass and remove litter and debris.	Monthly during the growing season.
Stabilize eroded banks and repair undercut or eroded areas at inflow and outflow structures.	As needed.
Disc or otherwise aerate the bottom and de-thatch the basin bottom.	Annually (unless inspections indicate that this must be done more often).
Scrape the bottom and remove sediment. Restore original cross section and infiltration rate.	Every 5 years (unless inspections indicate that it is needed more often).
Seed or sod to restore ground cover.	Every 5 years (unless inspections indicate that it is needed more often).

In addition to the above, the controlled outlet (or overflow box) must also be maintained in hybrid infiltration basins. This structure should be checked several times a year and after all large storm events to ensure that it has not become clogged.

The photograph below shows a well maintained overflow box.

Overview of Extended Detention Basins:
A detention basin is simply a facility designed to catch and temporarily store stormwater runoff. An extended detention basin is a detention basin with built in features that are designed to increase the time that stormwater stays in the basin. Theoretically, the longer the water stays in the basin, the more solids will settle out of the stormwater. This relationship is shown in the graph below, which is taken from Chapter 9.4 of the NJDEP's Stormwater Best Management Practices Manual. From this graph it can be seen that the NJDEP assigns a value of 40% to 60% TSS removal for these basins depending on the residence time within the basin. In order to achieve the 60% TSS removal rate, the basin must retain at least 10% of the total runoff from a water quality storm for 24 hours.

Figure 9.4-2: TSS Removal Rate vs. Detention Time



This TSS removal rate is not as high as many other stormwater control practices, such as infiltration basins, sand filters, constructed wetlands, bioretention systems, and others. Therefore, it is often necessary to provide some form of pretreatment upstream of the extended detention basin in order to achieve the desired TSS removal rate.

Example 3: The total inflow volume into a detention basin during a water quality storm event is 8500 CF. Routing procedures through the basin have shown that 850 CF remain in the basin after 12 hours. What would be the NJDEP-adopted TSS removal rate for this basin?

Solution: 850 CF (10% of the total inflow of 8500 CF) remains in the basin after 12 hours. Based on the chart above, the TSS removal rate for this basin would be only 40%.

Design of Extended Detention Basins:

An extended detention basin is designed and functions very much like a standard detention basin. The only difference is that the standard detention basin is designed only to attenuate the peak flow rate during the design storm(s) whereas an extended detention basin is also designed to retain the runoff from smaller storms (which generally flush the majority of the pollutants downstream) for a longer period of time to provide water quality benefits. As with any detention basin the main design criteria for an extended detention basin are its stage-storage-discharge relationships. These relationships determine the characteristics of the storm routings through the basin and are used to determine the amount of peak flow attenuation accomplished. In addition, however, an extended detention basin uses some or all of the following to increase the storage time within the basin. Note that all of these will, in some way, affect the stage-storage discharge relationships described above.

Practice	**Affect on Stage-Storage-Discharge Relationship**
Forebay	Will affect the time spent within the basin, reducing effective volume.
Low flow channel	Will affect the time spent within the basin, reducing effective volume.
Reducing the size of the lowest orifice in the controlled outlet	Will reduce the discharge at lower stages and require more storage within the basin.

The extended detention basin shown in the photograph below has a large forebay (shown on the left). The berm shown is an intermediate berm between the forebay and the main body of the basin on the right. The outlet from the forebay into the main basin is located at the far end of the photograph with the structures being hidden by shrubs.

Additional Considerations:

1. Pretreatment: Pretreatment is always recommended because it can prolong the effective lifespan of any water quality feature. However, it is not as necessary in an extended detention basin as it is with an infiltration system because these features tend to be more robust and do not clog as easily. On the other hand, pretreatment might be more important in this case because the overall TSS removal rate for extended detention basins is fairly low and it can be enhanced by a pretreatment unit. As with an infiltration basin, a pretreatment unit here can take many forms including:

- Septic tank.
- Vegetated filter.
- Sand filter.
- Porous pavement.

In fact infiltration basins or swales are sometimes used as pretreatment units in front of extended detention basin.

2. Sediment Accumulation: If sediment accumulates (particularly in the forebay or around the outlet structure) it can negatively impact the functioning of the basin. As explained below, regular removal of excess sediment is essential for the long-term functioning of the basin.
3. Flow Paths Through the Basin: In order to provide the maximum filtering benefit to the stormwater, flow paths through the extended detention basin should be as long and as sinuous as possible. Every effort should be made to avoid short-circuiting the runoff. Conventional detention basins sometimes make use of a combined inlet/outlet structure but this arrangement is not appropriate in an extended detention basin.
4. Creation of Artificial Wetlands: Extended detention basins are sometimes planted with native wetlands herbaceous and woody species. These greatly enhance the filtering capabilities of the system. However, a discussion of the design of artificial stormwater wetlands is beyond the scope of this course.
5. Water Depth: As with infiltration basins the maximum water depth achieved within an extended detention basin can become a matter of concern. Even though the maximum water depth usually only persists for a matter of several hours after a rainfall event, precautions should be taken to ensure public safety. If the maximum water depth is expected to be greater than 3 feet, a safety bench

and/or a fence may be required. This is especially true in residential areas or other areas where children may be present.

6. Detention basins can be used in a wider variety of situations than infiltration basins because they do not depend on permeable soils. However, there are a few limitations on their use. Generally, extended detention basins should be used with caution in areas where mosquito breeding can become a problem. However, even in these areas extended detention basins can be used but they may require modifications. One possible way to combat mosquitoes is to install a permanent pool at the bottom of the basin and stock the pool with fish that will prey on the mosquitoes and their larvae.

Retrofitting Existing Detention Basins:

Existing detention basins can often be retrofitted to become extended detention basins and provide the water quality benefits inherent in these systems. Retrofitting in this way can be fairly simple and can consist in some or all of the following:

1. Adding a sediment forebay to trap sediments as they enter the basin. The forebay berm can be constructed of a semi-permeable material which will allow the runoff to percolate into the main body of the basin while leaving the solids behind. If there is more than one inlet pipe into the basin a forebay should be provided at each inlet. If this is not practical, it may be easier to re-route the inflow pipes so that they all enter the basin at a common point.
2. If the detention basin includes a fairly straight low flow channel, this can be removed and replaced with a more sinuous one which will increase both the time of concentration within the basin and the contact area.
3. If the low flow channel is made of concrete or other impermeable substance it can be replaced by gravel or sod (depending on the anticipated velocity of the runoff).
4. The outlet structure can be re-configured. Generally, the smaller the lowest orifice, the more settling will take place within the basin. However, many experts recommend using at least a 3" diameter orifice to prevent clogging. If the outlet structure is to be re-configured, the design engineer must re-evaluate all of the storm routings through the basin to ensure the following:
    - The peak runoff from the design storm or storms are still being kept at or below the original design values.
    - The basin will not overtop during a large (e.g. 100 year, 24 hour) storm.
5. Planting water tolerant vegetation (including woody vegetation) can increase the filtering potential of the retro-fitted basin.

6. Re-routing the inflow pipes is sometimes beneficial to increase the time of concentration and to allow all of the inflow to receive pre-treatment in the forebay.

When considering a retro-fit of an existing detention basin, the design engineer should look at the above options and see which, if any, can be used in the particular situation at hand. It is usually not feasible to use all of these methods in a single basin, but most basins will allow at least some of these methods to be employed.

The photograph below shows a relatively straight, concrete low flow channel. This could be replaced with a more sinuous, grass or gravel channel to increase the filtering properties of the basin.

The photograph below shows a conventional detention basin. It has two low flow channels heading to the controlled outlet structure. Providing two forebays (one at each inlet) would be a simple, inexpensive way to enable this basin to provide some water quality benefits.

Maintenance of Extended Detention Basins:
Generally speaking, the maintenance of an extended detention basin is no different that what is required for a standard detention basin. A typical maintenance schedule for an extended detention basin is shown below:

Maintenance Activity	**Schedule**
Conduct annual vegetation management during the summer, removing weeds and harvesting vegetation.	Annually.
Trim vegetation at beginning and end of wet season to prevent establishment of woody vegetation, and for aesthetics and mosquito control.	Each spring & fall.
Evaluate health of vegetation and remove or replace any dead or dying plants.	Twice a year.
Mow turf grass (if applicable). Avoid causing ruts when mowing.	Monthly during the growing season.
Remove sediment from forebay when sediment approaches 50% of forebay volume.	When inspection indicates that it is necessary.
Remove sediment from the body of the basin.	When sediment build-up appears to be in danger of affecting the functioning of the basin. Generally, sediment should be removed at least once every 10 years.*
Remove accumulated trash and debris from forebay and the main bottom of the basin.	Twice a year.
Irrigate vegetation.	As needed during dry weather.
Miscellaneous inspection of basin components including forebay, inlet and outlet structures, berm, emergency spillway, and vegetation.	At least four times a year and after all major rainfall events.

* Removal of sediment should be done when the basin bottom is dry.
In addition, when performing vegetation maintenance the use of pesticides is discouraged.

Conclusion:
Both infiltration basins and extended detention basins are of benefit in providing stormwater quality and quantity control. However, there are several differences between the two. The table below shows many of the differences between these two types of systems:

Description	**Infiltration Basin**	**Extended Detention Basin**
TSS Removal Rate*	80%	40% to 60% Depending on the residence time in the basin**
Phosphorous Removal Rate*	60%	20%
Total Nitrogen Removal Rate*	50%	20%
Groundwater Recharge Provided	Yes	No
Peak Flood Attenuation Provided	Yes, but generally above the maximum elevation of the infiltration basin.	Yes
Maintenance Required	Yes.	Yes, but not as critical as in Infiltration Basins
Limitations	Cannot be used if there is insufficient permeability, in areas with shallow groundwater, if there is the potential for interaction with other features, or in stormwater hotspots.	Can be used in almost all situations.

* The removal rates shown hereon are the ones adopted by the NJDEP Best Management Practices Manual for these features.
** See the graph on page 30 for the exact relationship between residence time in the basin and the NJDEP-adopted TSS removal rate.

From the table above, it can be seen that infiltration basins are more efficient at pollutant removal than are extended detention basins. According to the NJDEP, they are significantly more efficient at removing total suspended solids and between 2 and 3 times as efficient at removing phosphorous and nitrogen. Of course, they also provide an additional environmental benefit in that they provide groundwater recharge. Therefore, the design engineer should give consideration to these types of systems when choosing an overall stormwater management strategy for a site.

Conversely, extended detention basins can be used in a wider variety of situations and are more robust, in that they generally do not need the same level of maintenance. If aesthetics are a factor (e.g. in public areas or in residential neighborhoods), extended detention basins ordinarily can be planted with a greater variety of vegetation than infiltration basins. All of these considerations must be taken into account when determining the proper system for a specific project.