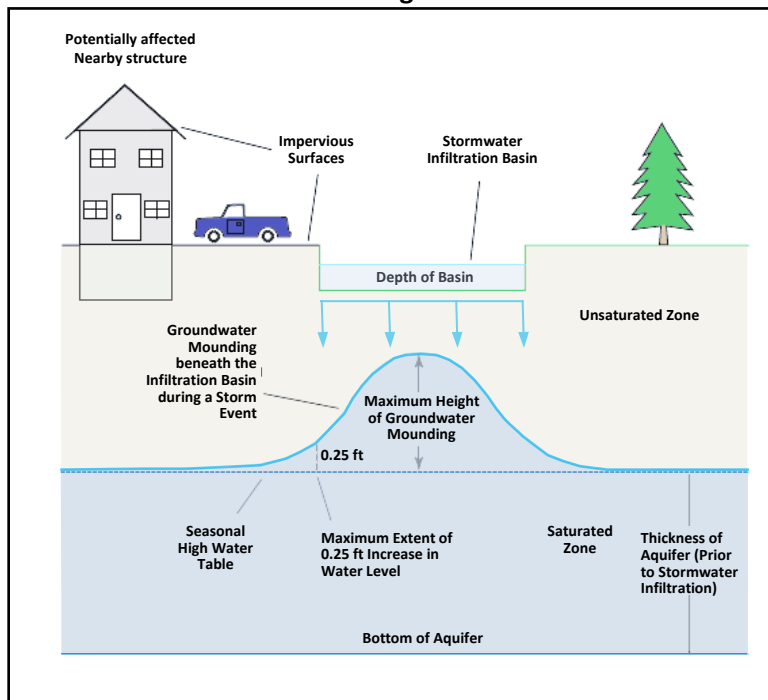


13: GROUNDWATER TABLE HYDRAULIC IMPACT ASSESSMENTS FOR INFILTRATION BMPs

The Stormwater Management rules at N.J.A.C. 7:8-5.2(h) require that *“Whenever the stormwater management design includes one or more BMPs that will infiltrate stormwater into subsoil, the design engineer shall assess the hydraulic impact on the groundwater table and design the site, so as to avoid adverse hydraulic impacts. Potential adverse hydraulic impacts include, but are not limited to, exacerbating a naturally or seasonally high water table, so as to cause surficial ponding, flooding of basements, or interference with the proper operation of subsurface sewage disposal systems or other subsurface structures within the zone of influence of the groundwater mound, or interference with the proper functioning of the stormwater management measure itself.”* Such an assessment is necessary because the simple drain time calculation assumes only a constant rate vertical movement of water and neglects the development of a temporary concentration of groundwater. This concentration takes the shape of a mound on top of the water table and forms in the unsaturated zone, i.e., the soil strata located below the root zone of the vegetation on site and above the groundwater table in the area directly below a stormwater recharge BMP, as shown in the image below.

Basics of Groundwater Mounding



Source: Carleton, Glen B. 2010. Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins, Scientific Investigations Report 2010-5102. U.S. Department of the Interior. U.S. Geological Survey. Reston, VA.

This mounding process is transient in that infiltrating runoff builds up in the unsaturated zone as stormwater infiltrates or recharges and then gradually spreads out to the surrounding area. The maximum height of the mounding is affected by the amount of infiltrated runoff, the ability of the soil

layers to transport water, the thickness of the saturated zone and the shape of the BMP. If the mounded groundwater reaches the bottom of the basin, the rate of infiltration out of the BMP is reduced and infiltration may stop.

Modelling Groundwater Mounding

In order to determine the height and range of groundwater mounding, U.S. Geological Survey (USGS), in cooperation with the Department, developed a report and a Microsoft Excel workbook of spreadsheets to simulate groundwater mounding beneath stormwater infiltration basins. The model developed by USGS, hereafter referred to as the *Hantush Spreadsheet*, calculates the maximum height of the transient mounding formed and assumes all groundwater flow is horizontal above an infinite aquifer. The maximum height of the mounding occurs when the entire volume of runoff has been infiltrated into the subsoil through the bottom of a BMP. It is assumed that if the calculated steady-state mounding reaches the bottom of the BMP, then infiltration will not occur as expected. The hydraulic impacts from the mounded groundwater table to adjacent underground structures can be assessed to check whether adjacent underground structures will be within the mounded groundwater area, which may cause temporary flooding in basement or excessive groundwater seepage into the structure.

The *Hantush Spreadsheet*, as modified by the Department, may be downloaded from the Department's website found at: https://njstormwater.org/bmp_manual2.htm. Once on the webpage, scroll down to *Chapter 13* and the link to the Excel spreadsheet is located immediately below the chapter title. Once downloaded and opened, the *Enable Macros* or *Enable Content* option must be selected before the spreadsheet can be used. The file should open on the *Results* tab. If not, select it and scroll to the top left of the spreadsheet.

Hantush Spreadsheet: An Overview

At first glance of the spreadsheet that is found on the *Results* tab of the workbook file, the user will see an *Input Values* section with cells filled in a gold or orange-yellow color, followed by two sets of output data represented by cells filled in red, a blue rectangular button labeled *Re-Calculate Now*, shown below,

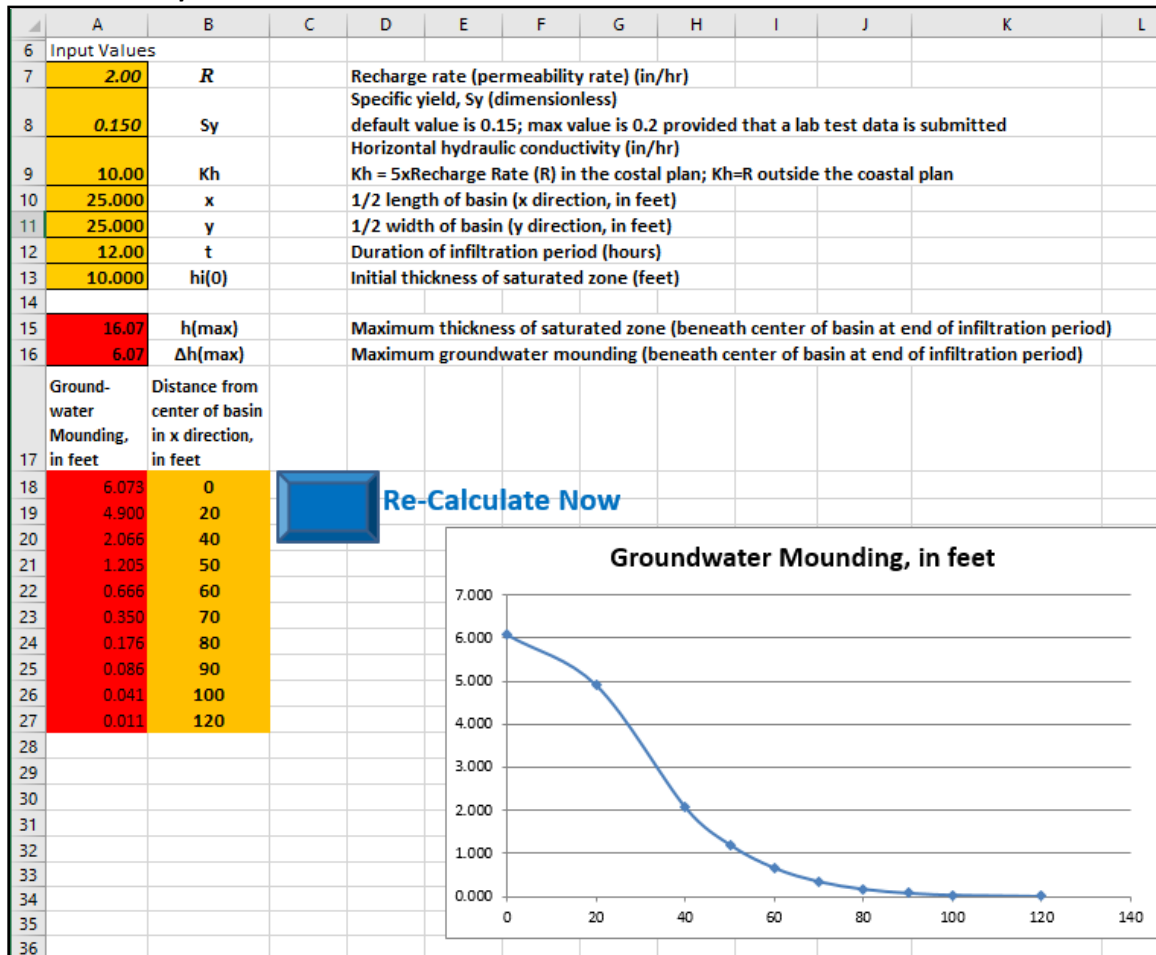


and a graph labeled *Groundwater Mounding, in feet*, as shown in the image on the following page. The user inputs will be discussed below and in detail in the Initial Model section which begins on Page 13.

Once the parameter values are input, the user will click on the blue button to enable the enabled macro to simultaneously solve the embedded equations. As for the graph depicted, the *Hantush Spreadsheet* sets the Seasonal High Water Table (SHWT) at elevation zero, with the coordinate origin (0,0,0) situated under the center of the BMP at the SHWT. The x-axis depicts a representative slice of the right-hand half of the groundwater mounding in the direction of the basin length being analyzed, showing the extent of the groundwater mounding in that direction only. The left half of the mounding is assumed to be symmetrical. It may be helpful to remember the vertical direction is the z-axis. The y-axis corresponds to the direction of the other basin dimension and extends into the page. To analyze the extent of the mounding in this direction, the user simply swaps the input value for the width with that of the length and runs the macro again.

The *Hantush Spreadsheet* accepts user-supplied values for horizontal hydraulic conductivity, initial saturated zone thickness, specific yield, basin length, basin width and duration and rate of recharge, which are discussed under the *Hantush Spreadsheet: User Inputs* header which begins on Page 4. The results of the *Hantush Spreadsheet* show the maximum mounding height under the infiltration BMP, at the end of infiltration, along with the mounding heights at locations measured away from the center of the BMP. Design engineers may use the results of the *Hantush Spreadsheet* to evaluate whether the maximum height of the groundwater mounding, $\Delta h(\max)$, which is found in cell A16, will reach the bottom of the infiltration BMP.

The Hantush Spreadsheet



Beginning on the following page is a description of the various input parameters in the *Hantush Spreadsheet* and default values and/or appropriate ranges for those parameters are provided. Some input parameters, such as the basin dimensions, are based solely on the proposed design and a range of values is not given. Since the spreadsheet can quickly calculate results, the most appropriate place to begin is with an *Initial Model* employing conservative values for each of the input parameters. The *Initial Model* is only the first step. Additional steps are required for a complete groundwater mounding analysis. These steps are listed in the second table found on Page 12. The *Initial Model* step discussion begins on Page 13. Examples illustrating the various steps are found beginning on Page 18.

Hantush Spreadsheet: User Inputs

Page 12 includes a table summarizing the range of acceptable input values for creating the initial model using the parameters discussed below in the *Hantush Spreadsheet*.

Recharge Rate

The recharge rate, R , is the vertical hydraulic conductivity, also called the permeability rate, of the most restrictive soil layer in the unsaturated zone below the infiltration BMP. The soil permeability rate must be tested in accordance with *Chapter 12: Soil Testing Criteria*. Since the actual permeability rate may vary from soil testing results and may decrease over time, a factor of safety of 2 must be applied to the slowest tested permeability rate to determine the design permeability rate. The mounding height is assessed initially with the recharge rate set using the design permeability rate as the vertical hydraulic conductivity, which is the expected infiltration rate of the runoff.

Acceptable Range for Input

- The highest recharge rate is 10 inches/hour.

If the groundwater mounding does not reach the bottom of the BMP using the recharge rate, it means that the design of the BMP may work as expected. If the groundwater mounding reaches the bottom of the BMP, the infiltration of runoff may become slower than expected, or the BMP may fail to infiltrate. Further analysis using an adjusted recharge rate would then be required. Adjustment of the recharge rate is discussed further beginning on Page 14.

Duration of Infiltration Period

The duration of the infiltration period, t , is equal to the time required for the BMP to drain the volume of stormwater runoff, at the specified recharge rate, and is calculated as follows:

$$\text{Duration of infiltration period, } t \text{ (hr)} = \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ in/ft}}{\text{Infiltration area (sf)} \times \text{Recharge rate (in/hr)}}$$

where the volume of runoff to be infiltrated may be either the runoff volume produced by the Water Quality Design Storm or the volume of runoff to be discharged through exfiltration, if exfiltration of runoff during basin routing is used.

When exfiltration is used, the duration of infiltration is calculated as stated below and continued on the following page:

- If the exfiltration volume and the exfiltration rate are known:

$$\text{Duration of infiltration period, } t \text{ (hr)} = \frac{\text{Discarded Volume via Exfiltration (cf)} \times 12 \text{ in/ft}}{\text{Infiltration area (sf)} \times \text{Exfiltration rate (in/hr)}}$$

- If only the exfiltration rate and the routing curve/table are known, the duration of infiltration period is the time between the start and the end of the exfiltration.
- If the routing curve does not distinguish the discharges through exfiltration and other outlets, then the duration of infiltration period is the timeframe from the start of the discharge to the time at which the discharge reaches zero.

- Under such circumstances, the time interval for calculation of and displaying the routing curve/table shall be set to the minimum interval allowed by the software program to provide better accuracy in estimating time from the routing curve/table.
- The recharge rate is the exfiltration rate used in the routing calculation.

Acceptable Range for Input

- The maximum duration of infiltration period that may be used in the *Hantush Spreadsheet* is 72 hours.

Specific Yield

Specific yield, S_y , is the volume of water that will drain from a soil specimen, due to gravity, divided by the total volume of the soil specimen. Coarse soil will likely have higher specific yield than fine-grained soil having the same porosity. Specific yield governs how much water the unsaturated zone can store when recharge reaches the water table. The more water that can be stored in the unsaturated zone, the lower the resulting mounding. Therefore, a soil having a higher specific yield may result in a lower mounding height than a soil having a lower specific yield, when other inputs remain the same.

For the purposes of this chapter, specific yield is not calculated by subtracting field capacity from porosity. Although other references use this concept for specific yield, it does not apply to the *Hantush Spreadsheet*. For more information, see *Chapter 12*.

Acceptable Range for Input

- There is no minimum specific yield that may be used in the *Hantush Spreadsheet*, but 0.15 is used as the default value.
- The use of specific yield values greater than 0.15 must be based upon soil testing of the soil samples from the substratum below the infiltration BMP and tested in accordance with *Chapter 12*, with a maximum value of 0.2 when the soil test results demonstrate a value higher than 0.2.

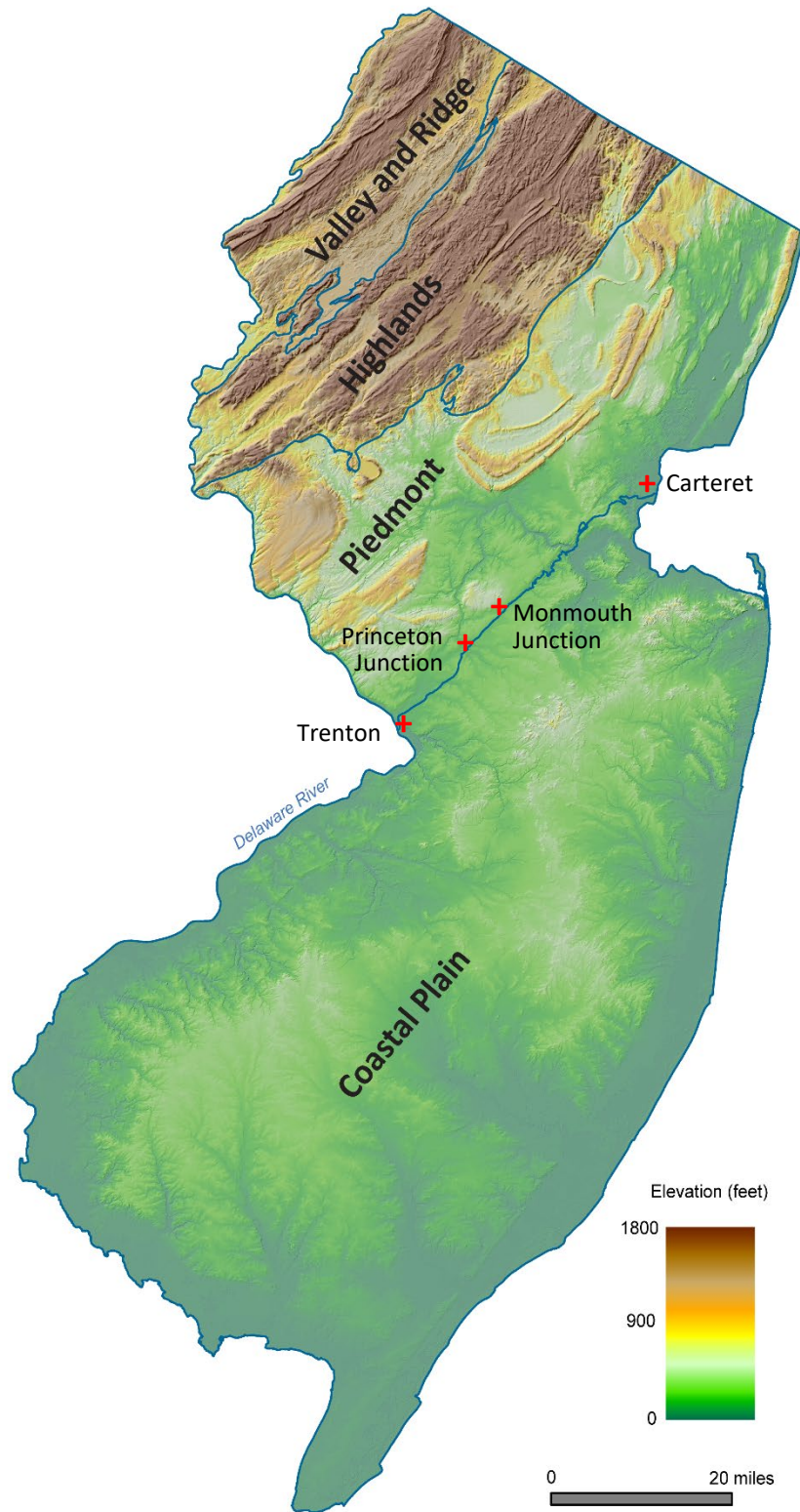
Horizontal Hydraulic Conductivity

The horizontal hydraulic conductivity, K_h , is, as the name suggests, the rate at which water can move in the horizontal direction. The default values depend upon the physiographic province in which the project is located. A map depicting these areas is provided on the following page. The default values, as listed below, must be used.

Default Range for Input

- For projects located within the coastal plain physiographic province of New Jersey:
 $K_h = 5R$, i.e., the horizontal hydraulic conductivity must be assumed to be 5 times the vertical hydraulic conductivity.
- For projects located outside the coastal plain physiographic province of New Jersey:
 $K_h = R$, i.e., the horizontal hydraulic conductivity must be assumed to be equal to the vertical hydraulic conductivity, as described above.

Physiographic Provinces of New Jersey.



Imagery modified from New Jersey Geological Survey Information Circular, "Physiographic Provinces of New Jersey," 2006 and used with permission

BMP Dimensions

When entering the basin dimensions into the *Hantush Spreadsheet*, one-half of the length and one-half of the width of the basin are entered as the values for x and y, respectively. Generally, a square basin, i.e., where $x = y$, will result in a higher mounding height than that produced by a rectangular basin of equal surface area.

Note that the results from the *Hantush Spreadsheet* provide only the mounding height along the x-direction. Therefore, for a rectangular basin, the inputs for x and y must be re-entered, i.e., with the length and width switched, to check the groundwater mounding in the other direction.

The size of an infiltration basin may affect the height of the groundwater mounding. Given that all other inputs are the same, a larger and shallower basin with a short duration of infiltration period will have a lower groundwater mounding height than a small and deep basin with a longer duration of infiltration period.

Input Values for Various BMP Footprint Shapes

- When the BMP footprint has a circular shape, use the radius of the circular basin as both x and y.
- When the BMP footprint is neither circular nor rectangular in shape, convert the shape to a rectangular shape that has same depth of stormwater runoff to be infiltrated and is best fitted to the original shape.
- The *Hantush Spreadsheet* assumes the sides of the BMP are vertical. If a BMP is designed with sloped sides, use the dimensions of the bottom footprint as the length and the width of the BMP and use the total volume of the runoff to be infiltrated divided by the area of the bottom footprint to calculate the duration of infiltration period.

For example, consider a rectangular basin having a 200 ft long by 100 ft wide bottom footprint, with 2 ft of runoff to be infiltrated and a side slope of 4:1, horizontal to vertical. Assume the recharge rate is 1 ft/day (0.5 in/hr). From the basin geometry, the volume to be infiltrated is 45,056 cf. The value entered in the *Hantush Spreadsheet* for x is 100 ft and y is similarly 50 ft. The period of infiltration is calculated as follows:

$$\begin{aligned}\text{Duration of infiltration period, } t &= \frac{\text{Volume of runoff to be infiltrated (cf)}}{\text{Infiltration area (sf)} \times \text{Recharge rate (ft/day)}} \\ &= \frac{45,056 \text{ cf}}{(200 \text{ ft} \times 100 \text{ ft}) \times 1 \text{ ft/day}} = 2.25 \text{ days (54.1 hr)}.\end{aligned}$$

Note that failing to include the volume of stormwater runoff occupying the sloped perimeter would result in an incorrect value for t, i.e., $(200 \text{ ft} \times 100 \text{ ft} \times 2 \text{ ft}) / (200 \text{ ft} \times 100 \text{ ft} \times 1 \text{ ft/day}) = 2 \text{ days (48 hr)}$.

For an irregular BMP with sloped sides, it will first be necessary to convert the irregular shape to a rectangular shape that best approximates the footprint area and has sloped sides, and then calculate the duration of infiltration period as shown above.

Initial Thickness of Saturated Zone

Unless proven by a field test showing the thickness of saturated zone beneath the proposed BMP, the default value is 10 ft. Note that the thickness of saturated zone used in the *Hantush spreadsheet* is not the thickness of a large regional aquifer. It is the distance from the Seasonal High Water Table (SHWT) to the first hydraulically restrictive layer.

Acceptable Range for Input

- Unless on-site testing has occurred, a value of 10 ft is used for the Initial Thickness of Saturated Zone, $hi(0)$.
- If a value greater than 10 ft is used, it must be accompanied by on-site testing results that demonstrates the value used is appropriate. The input value must never exceed 75 ft, which is based on the preliminary results of research conducted by the USGS. The exact maximum allowed value may be subject to revision based on the final results of the research. Any on-site boring used to justify a value greater than 10 ft must be a continuous sampling boring for the entire drilled depth, and it must be performed in accordance with the procedures outlined in *Chapter 12*.

Notes on Using the Design Permeability Rate or Tested Permeability Rate as the Recharge Rate in the *Hantush Spreadsheet*

As required in *Chapter 12* and the chapters for various infiltration BMPs, the design permeability rate is the tested permeability rate applied with a factor of safety of 2. An infiltration BMP must use the design permeability in sizing the BMP and calculating the drain time. For example, a permeability rate of 2 in/hr obtained from a Percolation Test or Tube Permeameter Test must to be divided by 2, resulting in the design permeability rate of 1 in/hr. If a bioretention basin with a 50 ft x 50 ft footprint is designed to infiltrate 5,000 cf of runoff volume, the time it will take to infiltrate the runoff will be calculated as follows:

$$\begin{aligned}\text{Duration of infiltration period, } t &= \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ in/ft}}{\text{Infiltration area (sf)} \times \text{Recharge rate (in/hr)}} \\ &= \frac{5,000 \text{ (cf)} \times 12 \text{ in/ft}}{2,500 \text{ (sf)} \times 1 \text{ (in/hr)}} = 24 \text{ hours}\end{aligned}$$

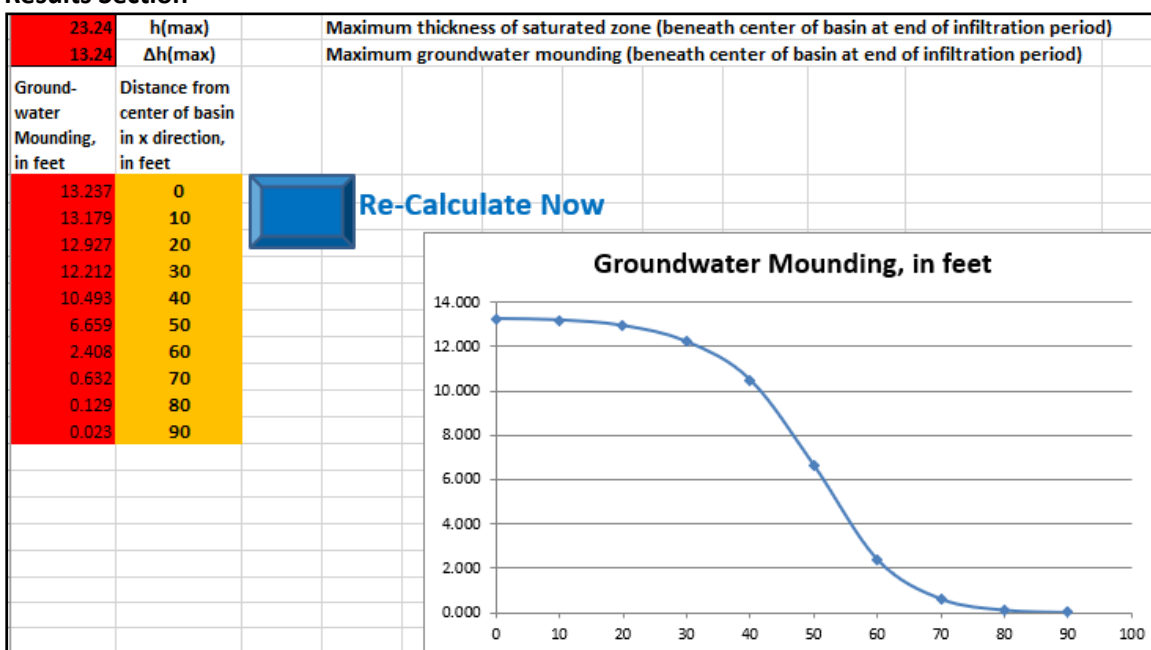
Since 1 in/hr is used as the infiltration rate in the design of the BMP, the 1 in/hr is also used as the recharge rate in the *Hantush Spreadsheet*. Furthermore, assuming the basin is not in the coastal plain, the horizontal hydraulic conductivity rate also uses the value of recharge rate as 1 in/hr by default. The inputs for the *Hantush Spreadsheet* are thus based on the above information and are shown below:

Input Section

Input Values											
1.000	R			Recharge rate (permeability rate) (in/hr)							
0.150	Sy			Specific yield, Sy (dimensionless)							
				default value is 0.15; max value is 0.2 provided that a lab test data is submitted							
1.00	Kh			Horizontal hydraulic conductivity (in/hr)							
				Kh = 5xRecharge Rate (R) in the coastal plain; Kh=R outside the coastal plain							
50.000	x			1/2 length of basin (x direction, in feet)							
50.000	y			1/2 width of basin (y direction, in feet)							
24.00	t			Duration of infiltration period (hours)							
10.000	hi(0)			Initial thickness of saturated zone (feet)							

The results section is depicted below.

Results Section



The mounding height is 13.24 feet based on a recharge rate, i.e. the design permeability rate, of 1 in/hr.

If, instead of the design permeability rate, the tested permeability rate of 2 in/hr is used in the *Hantush Spreadsheet*, what mounding height will result? If the tested permeability rate, 2 in/hr, is used, the duration of infiltration will be recalculated as:

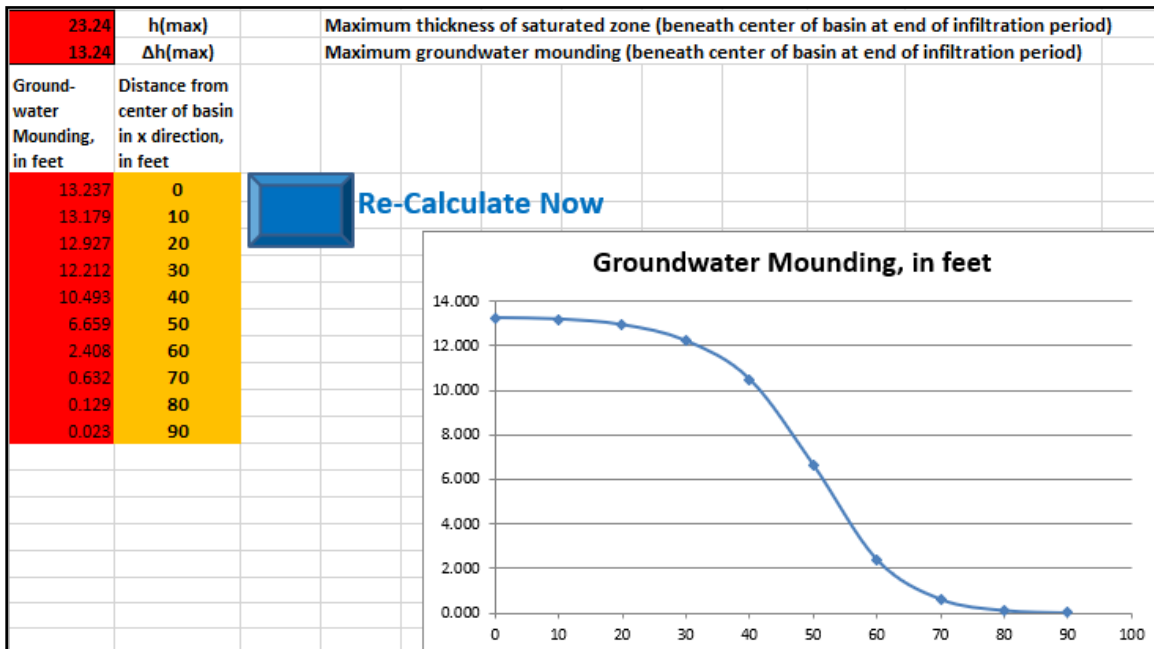
$$\text{Duration of infiltration period, } t \text{ (hr)} = \frac{5,000 \text{ (cf)} \times 12 \text{ in/ft}}{2,500 \text{ (sf)} \times 2 \text{ (in/hr)}} = 12 \text{ hours}$$

The recharge rate now uses the tested permeability rate, 2 in/hr. The horizontal hydraulic conductivity in the Hantush Spreadsheet uses the recharge rate as 2 in/hr. The inputs, shown below, and the results, shown on the following page, based on the tested permeability rate are now recalculated as:

Input Section

Input Values		
2.000	R	Recharge rate (permeability rate) (in/hr)
0.150	Sy	Specific yield, Sy (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted
2.00	Kh	Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan
50.000	x	1/2 length of basin (x direction, in feet)
50.000	y	1/2 width of basin (y direction, in feet)
12.00	t	Duration of infiltration period (hours)
10.000	hi(0)	Initial thickness of saturated zone (feet)

Results Section



The mounding height is still 13.24 ft and **the mounding curve is exactly the same as the curve based on the design permeability rate.**

If the bioretention basin is now located in the coastal plain, the horizontal hydraulic conductivity rate will be 5 times that of the recharge rate used in the *Hantush Spreadsheet*. Screenshots of the *Hantush Spreadsheet* based on design permeability rate of 1 in/hr (recharge rate 1 in/hr and horizontal hydraulic conductivity rate 5 in/hr) and the tested permeability rate of 2 in/hr (recharge rate 2 in/hr and horizontal hydraulic conductivity rate 10 in/hr) are shown below or on the next page:

Calculation Based on the Design Permeability Rate

Input Values		
1.000	R	Recharge rate (permeability rate) (in/hr)
0.150	Sy	Specific yield, Sy (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted
5.00	Kh	Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan
50.000	x	1/2 length of basin (x direction, in feet)
50.000	y	1/2 width of basin (y direction, in feet)
24.00	t	Duration of infiltration period (hours)
10.000	hi(0)	Initial thickness of saturated zone (feet)
20.48	h(max)	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)
10.48	Δh(max)	Maximum groundwater mounding (beneath center of basin at end of infiltration period)

Calculation Based on the Tested Permeability Rate

Input Values		
2.000	R	Recharge rate (permeability rate) (in/hr)
		Specific yield, Sy (dimensionless)
0.150	Sy	default value is 0.15; max value is 0.2 provided that a lab test data is submitted
		Horizontal hydraulic conductivity (in/hr)
10.00	Kh	Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the costal plan
50.000	x	1/2 length of basin (x direction, in feet)
50.000	y	1/2 width of basin (y direction, in feet)
12.00	t	Duration of infiltration period (hours)
10.000	hi(0)	Initial thickness of saturated zone (feet)
20.48	h(max)	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)
10.48	Δh(max)	Maximum groundwater mounding (beneath center of basin at end of infiltration period)

Once more, the mounding analysis using the *Hantush Spreadsheet* for a specific basin will be the same whether based on the design permeability rate or the tested permeability rate.

This same relationship will be maintained even if the horizontal hydraulic conductivity entered does not equal the default value. For example, if the tested permeability rate for the vertical direction is 2 in/hr and the tested horizontal hydraulic conductivity rate is 8 in/hr, the design rates computed, after the application of the factor of safety = 2, will yield 1 in/hr for the vertical direction design permeability and 4 in/hr for the design horizontal hydraulic conductivity. The corresponding screenshots of the *Hantush Spreadsheet* for each of the above rates are shown below and discussed on the next page:

Calculation for R = 2 in/hr Tested Vertical Permeability Rate and Kh = 8 in/hr Tested Horizontal Hydraulic Conductivity Rate

Input Values		
2.000	R	Recharge rate (permeability rate) (in/hr)
		Specific yield, Sy (dimensionless)
0.150	Sy	default value is 0.15; max value is 0.2 provided that a lab test data is submitted
		Horizontal hydraulic conductivity (in/hr)
8.00	Kh	Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the costal plan
50.000	x	1/2 length of basin (x direction, in feet)
50.000	y	1/2 width of basin (y direction, in feet)
12.00	t	Duration of infiltration period (hours)
10.000	hi(0)	Initial thickness of saturated zone (feet)
21.12	h(max)	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)
11.12	Δh(max)	Maximum groundwater mounding (beneath center of basin at end of infiltration period)

Calculation for R = 1 in/hr Design Vertical Permeability Rate and Kh = 4 in/hr Design Horizontal Hydraulic Conductivity Rate

Input Values		
1.000	R	Recharge rate (permeability rate) (in/hr)
		Specific yield, Sy (dimensionless)
0.150	Sy	default value is 0.15; max value is 0.2 provided that a lab test data is submitted
		Horizontal hydraulic conductivity (in/hr)
4.00	Kh	Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the costal plan
50.000	x	1/2 length of basin (x direction, in feet)
50.000	y	1/2 width of basin (y direction, in feet)
24.00	t	Duration of infiltration period (hours)
10.000	hi(0)	Initial thickness of saturated zone (feet)
21.12	h(max)	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)
11.12	Δh(max)	Maximum groundwater mounding (beneath center of basin at end of infiltration period)

The results are the same again. The above demonstration dispels the misconception that using the design permeability rate in the *Hantush Spreadsheet* will produce a different outcome from the tested permeability rate. To maintain consistency, always use the design permeability rate in both sizing the BMP and in performing a Groundwater Mounding Analysis.

Summary of Model Input Parameters	
Input Parameter	Value for Initial Model Run
Recharge Rate, R	½ the lowest tested permeability rate, determined in accordance with <i>Chapter 12: Soil Testing Criteria</i> , of the most hydraulically restrictive layer located between the basin bottom and the SHWT. Values are between 0.5 in/hr to 10 in/hr.
Specific Yield, S_y	Default value 0.15 and up to a maximum value 0.2, with supporting soil test results
Horizontal Hydraulic Conductivity, K_h	In the coastal plain: 5 x recharge rate Outside the coastal plain: 1 x recharge rate
Basin length, x	½ the proposed basin length
Basin width, y	½ the proposed basin width
Duration of Infiltration Period, t	Time for infiltrating the runoff volume through the BMP using the recharge rate above. Maximum value is 72 hr.
Initial Thickness of Saturated Zone, $h_i(0)$	Default value 10 ft and up to a maximum value of 75 ft* with supporting continuous boring test results.

*The maximum is based on the preliminary results of research conducted by the USGS. The exact value may be subject to revision based on the final results of the research.

The table below is an index of important steps to be addressed in a groundwater mounding analysis

Groundwater Mounding Analysis Steps	Page No.
Creation of the Initial Model	13
Adjustment of the Recharge Rate and the Duration of Infiltration Period	14
Adjustment of the Basin Size and Depth of Stormwater Runoff to be Infiltrated	17
Evaluate Impacts to Nearby Underground Structures	17
Calculate the Height of Groundwater Mounding for Two or More Nearby Basins	17

Initial Model

The first part of this step is calculating the duration of the infiltration period. Next, use the values shown in the table below as inputs into the *Hantush Spreadsheet* in the gold shaded cells in rows 7 through 13 of column A of the *Hantush Spreadsheet*:

Initial Model Input Parameters	
Input Parameter	Value for Initial Model Run
Recharge Rate, R	½ the lowest tested permeability rate, determined in accordance with <i>Chapter 12</i> , of the most hydraulically restrictive layer located between the basin bottom and the SHWT.
Specific Yield, S_y	0.15
Horizontal Hydraulic Conductivity, K_h	In the coastal plain: 5 x recharge rate Outside the coastal plain: 1 x recharge rate
Basin length, x	½ the proposed basin length
Basin width, y	½ the proposed basin width
Duration of Infiltration Period, t	Time for infiltrating the runoff volume through the BMP using the recharge rate above
Initial Thickness of Saturated Zone, $h_i(0)$	10 ft

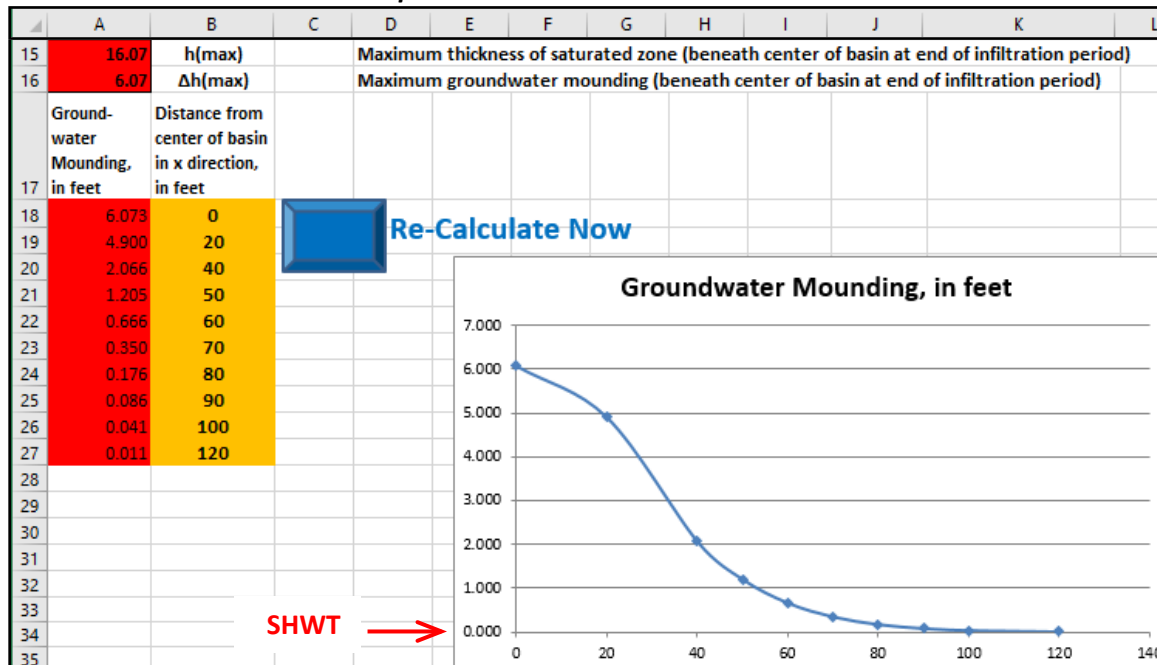
The Input Section of the *Hantush Spreadsheet* is shown below for a different BMP.

Input Section of the *Hantush Spreadsheet*

	A	B	C	D	E	F	G	H	I	J	K
6	Input Values										
7	2.00	R		Recharge rate (permeability rate) (in/hr)							
8	0.150	S_y		Specific yield, S_y (dimensionless)							
9	10.00	K_h		default value is 0.15; max value is 0.2 provided that a lab test data is submitted							
10	25.000	x		Horizontal hydraulic conductivity (in/hr)							
11	25.000	y		$K_h = 5 \times \text{Recharge Rate (R)}$ in the costal plan; $K_h=R$ outside the coastal plan							
12	12.00	t		1/2 length of basin (x direction, in feet)							
13	10.000	$h_i(0)$		1/2 width of basin (y direction, in feet)							
				Duration of infiltration period (hours)							
				Initial thickness of saturated zone (feet)							

On the following page, the corresponding Results Section of the *Hantush Spreadsheet* is depicted. The values in column B, from row 18 to row 27, are the distances from the center of the infiltration BMP to depict the mounding height. The values can be adjusted to show a larger or smaller distance between stations shown in the result, but it is recommended that the stations all be the same distance apart when modifying the default station locations. However, unless the basin is so large that the distances shown in rows 18 through 27, in column B do not extend beyond the basin limits, the default values do not require any changes. Be aware that a change of the values in the gold-shaded cells in rows 18 through 27 may result in a distorted or cut-off display of the groundwater mounding curve.

Results Section of the *Hantush Spreadsheet*



The user then clicks on the blue button adjacent to the words “Recalculate Now.” The spreadsheet will recalculate the height of the mound, measured upward from the SHWT, which is at elevation 0.00. The calculated mounding height corresponding to a certain distance from the center of the basin in the x direction will appear in the red cells under the label “Groundwater Mounding, in feet,” i.e., the cells within the range A18:A27. If the model shows that the groundwater mounding height will not reach the bottom of the proposed BMP, then the infiltration in the proposed BMP will have no adverse impacts on the performance of the BMP. However, the evaluation of the hydraulic impact to the water table may be required if the nearby underground structures are fully or partially within the extent of the mounding curve. The discussion of the hydraulic impact to nearby underground structures is addressed on Page 17 and Examples 5 through 8 of this chapter.

Adjustment of the Recharge Rate and the Duration of Infiltration Period

In the event the height of the groundwater mounding reaches or exceeds the elevation of the bottom of the BMP, the design must be adjusted and a new model created. This is because the elevated groundwater table below the BMP will reduce the vertical hydraulic gradient, meaning the recharge rate will be less than the design value. Adjustment of the recharge rate to a lower value allows slower infiltration of runoff and more time for the infiltrated runoff to dissipate into the saturated zone. A reduced recharge rate will have a smaller mounding height but result in a longer duration of infiltration period. Several trials of different reduced recharge rates may be needed to find which recharge rate works. The duration of infiltration period based on the reduced recharge rate may not exceed 72 hours. If the adjustment of the recharge rate still does not allow the proposed BMP to be drained within 72 hours using the designed dimensions of the BMP with the intended runoff infiltration volume, adjustment of the BMP size or an alternative design using another type of BMP may be required to avoid groundwater mounding issues.

In the event that the recharge rate needs to be reduced, the duration of infiltration period must be increased proportionally, without exceeding the 72 hours maximum allowable timeframe.

Consider a groundwater mounding analysis with the initial model shown as below.

Initial Model

2.00	R	Recharge rate (permeability rate) (in/hr)					
0.150	Sy	Specific yield, Sy (dimensionless, default value is 0.15; max value is 0.2 only if proved with lab test data of 0.2 or higher)					
2.00	Kh	Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan					
75.000	x	1/2 length of basin (x direction, in feet)					
50.000	y	1/2 width of basin (y direction, in feet)					
12.00	t	Duration of infiltration period (hours)					
10.000	hi(0)	Initial thickness of saturated zone (feet)					
23.284	h(max)	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)					
13.284	Δh(max)	Maximum groundwater mounding (beneath center of basin at end of infiltration period)					

In the initial model, if the stormwater runoff volume calculated to take 12 hours to infiltrate for a recharge rate of 2 in/hr results in a groundwater mounding height that would project above the bottom of the BMP, the model could be adjusted with a recharge rate reduced by 50% to 1 in/hr and a duration of infiltration period increased by 200% from 12 hours to 24 hours to maintain the proportionality. No changes would be made to any other inputs at this time.

Adjusted Model

Input Values							
1.00	R	Recharge rate (permeability rate) (in/hr)					
0.150	Sy	Specific yield, Sy (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted					
2.00	Kh	Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan					
75.000	x	1/2 length of basin (x direction, in feet)					
50.000	y	1/2 width of basin (y direction, in feet)					
24.00	t	Duration of infiltration period (hours)					
10.000	hi(0)	Initial thickness of saturated zone (feet)					
22.934	h(max)	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)					
12.934	Δh(max)	Maximum groundwater mounding (beneath center of basin at end of infiltration period)					

Note that the horizontal hydraulic conductivity remains constant and is not affected by an elevated groundwater table because it is less affected by changes in the vertical hydraulic gradient. Therefore, input values for the horizontal hydraulic conductivity must not be altered, even in instances in which the input value for the recharge rate is adjusted to evaluate the possibility of reducing the height of groundwater mounding. **At this point in the analysis, the user may wish to create a table to record the input values of the required parameters along with the results and any notes.** Example 2, which begins on Page 20, includes a sample recordkeeping table or spreadsheet, depicted on Page 23. Screen captures may prove useful for inclusion in the groundwater mounding analysis report.

- If the adjusted model shows that the groundwater mounding height will not reach the bottom of the proposed BMP, then groundwater mounding will have no adverse impacts on the BMP.
- Alternatively, the duration of infiltration can be further extended, or *stretched*, up to the 72 hr maximum, measured from the end of the precipitation event, provided the recharge rate is

proportionally reduced. Stretching the time frame requires the recharge rate be proportionally reduced, assuming no change to any other parameters.

For the example shown on the previous page, the initial model begins with a recharge rate of 2 in/hr by using the design permeability rate obtained from soil testing and a duration of infiltration period of 12 hr. The calculated mounding height is 13.284 ft. The time frame may be extended, with the corresponding recharge rate pro-rated, as follows:

For a desired t value, $R_{t_new} = R_{design} \times [t_{initial} (hr) / t_{desired} (hr)]$, such that for

- $t = 32$ hours, $R_{32} = 2 \text{ in/hr} \times (12 \text{ hr} / 32 \text{ hr}) = 0.75 \text{ in/hr}$

Initial Model with Adjusted $t = 32$ hr

0.75	R	Recharge rate (permeability rate) (in/hr)			
0.150	S_y	Specific yield, S_y (dimensionless, default value is 0.15; max value is 0.2 only if proved with lab test data of 0.2 or higher)			
		Horizontal hydraulic conductivity (in/hr)			
2.00	K_h	$K_h = 5 \times \text{Recharge Rate } (R) \text{ in the costal plan; } K_h=R \text{ outside the coastal plan}$			
75.000	x	1/2 length of basin (x direction, in feet)			
50.000	y	1/2 width of basin (y direction, in feet)			
32.00	t	Duration of infiltration period (hours)			
10.000	$h_i(0)$	Initial thickness of saturated zone (feet)			
22.599	$h(\text{max})$	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)			
12.599	$\Delta h(\text{max})$	Maximum groundwater mounding (beneath center of basin at end of infiltration period)			

- $t = 48$ hours, $R_{48} = 2 \text{ in/hr} \times (12 \text{ hr} / 48 \text{ hr}) = 0.5 \text{ in/hr}$.

Initial Model with Adjusted $t = 48$ hr

0.50	R	Recharge rate (permeability rate) (in/hr)			
0.150	S_y	Specific yield, S_y (dimensionless, default value is 0.15; max value is 0.2 only if proved with lab test data of 0.2 or higher)			
		Horizontal hydraulic conductivity (in/hr)			
2.00	K_h	$K_h = 5 \times \text{Recharge Rate } (R) \text{ in the costal plan; } K_h=R \text{ outside the coastal plan}$			
75.000	x	1/2 length of basin (x direction, in feet)			
50.000	y	1/2 width of basin (y direction, in feet)			
48.00	t	Duration of infiltration period (hours)			
10.000	$h_i(0)$	Initial thickness of saturated zone (feet)			
21.883	$h(\text{max})$	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)			
11.883	$\Delta h(\text{max})$	Maximum groundwater mounding (beneath center of basin at end of infiltration period)			

As shown in the lower red shaded cells of the above two images, the calculated mounding heights are lower than that of the initial model; e.g., for a reduced recharge rate of 0.75 in/hr with a proportionally increased duration of infiltration period of 32 hr, the calculated height of groundwater mounding is 12.599 ft. Likewise, for a reduced recharge rate of 0.5 in/hr and a duration of infiltration period of 48 hr, the calculated height of groundwater mounding is 11.883 ft. As previously stated, the duration of infiltration period may be stretched only if the recharge rate is proportionally reduced and other inputs are not changed.

Adjustment of the Basin Size and Depth of Stormwater Runoff to be Infiltrated

If the adjustments to the recharge rate and duration of infiltration period still result in adverse impacts, changes to the basin geometry must then be evaluated to reduce the concentration of stormwater at this location. In other words, the BMP bottom area may be too small or the depth of ponding is too great, or both, resulting in an excessive concentration of stormwater runoff to be infiltrated. The user must enlarge the BMP bottom area and/or reduce the depth of stormwater runoff to be infiltrated accordingly to contain the same volume of stormwater runoff. Care should be taken to ensure the distances used by the spreadsheet for graphing, e.g., cells B18 through B27, are appropriate for the new size of the BMP and any nearby structures.

Recalculating the height of groundwater mounding may show the mounding has been reduced below the BMP at the end of the duration of infiltration period. If the model shows that the groundwater mounding height will not reach the bottom of the proposed BMP, then the BMP will successfully infiltrate the required volume of stormwater in the established timeframe. Additionally, nearby underground structures may experience flooding by this temporary elevation of the groundwater table if the enlarged BMP now is closer to nearby underground structures. Further analysis is required to evaluate the impacts to any nearby structures or if there is more than one BMP present, as discussed in the limitations section below.

Evaluate Impacts to Nearby Underground Structures

The *Hantush Spreadsheet* calculates the maximum height of groundwater mounding below the center of the BMP at the moment all of the runoff has infiltrated through the BMP bottom and underlying soils and encounters the groundwater table. The graph produced by the *Hantush Spreadsheet* is also a curve providing the height of groundwater mounding extending radially from the center of the BMP at the end of the duration of infiltration period. However, the curve does not predict the decay and spread of the mounding from the maximum height after this period. The actual groundwater mounding may expand farther in the horizontal direction after the duration of infiltration period ends. Therefore, if a nearby underground structure will be partially or fully within the range of the curve, it will be impacted by the rise of the groundwater mounding caused by the BMP. Moreover, if the underground structure within the proximity of the expanding transient mounding – but outside the limits of the curve, it may be also be impacted. This is related to the fact that the curve only shows the mounding at the moment when infiltration stops. If either situation occurs, redesign of the BMP sizing and location may be needed. Alternatively, a redesign or relocation of the underground structure or reinforcement of groundwater-proof measures may be needed.

Calculating Groundwater Mounding for Two or More Nearby Basins

The groundwater mounding resulting from two or more infiltration BMPs can be conservatively estimated by simulating each separately and adding the mounding height at a given location for each BMP. There is a known error in using this method because of the non-linearity of the governing equations. However, provided the height of the two individual moundings are small in comparison to the thickness of the saturated zone, the estimate will be conservative and the error will be small.

Examples

The following examples illustrate how to use the groundwater mounding analysis spreadsheet (USGS's *Hantush Spreadsheet*) to evaluate the hydraulic impact to groundwater from infiltration practices.

Example No.	Scenario Description	Page No.
1	No adverse hydraulic impact to groundwater	18
2	Adverse hydraulic impact to groundwater and adjustment of infiltration period	20
3	Adverse hydraulic impact to groundwater and adjustment of basin size	24
4	Rectangular or round infiltration BMP	29
5	Underground perforated pipe	31
6	Drywell	34
7	Replacement of soil below an infiltration BMP	35
8	Small-scale Infiltration Basin (Green Infrastructure BMP) in 'B' Soils	39

Example 1: No adverse hydraulic impact to groundwater scenario

A development located in the coastal plain proposes an infiltration basin, whose bottom footprint measures 50 ft by 50 ft, to infiltrate 5,000 cf of runoff generated by the Water Quality Design Storm (WQDS). The maximum depth of stormwater runoff to be infiltrated is designed to be 2 feet. Soil testing was performed in accordance with *Chapter 12*. The soil testing report shows that the Seasonal High Water Table (SHWT) is 7.5 ft below the 6 in thick bottom sand layer of the basin. The tested soil permeability rate of the most restrictive soil horizon below the basin is 4 in/hr. No nearby underground structure is present in this scenario.

Step 1: Calculate the duration of infiltration period

$$\begin{aligned}
 \text{Duration of infiltration period, } t \text{ (hours)} &= \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ in/ft}}{\text{Infiltration area (sf)} \times \text{Recharge rate (in/hr)}} \\
 \text{Infiltration area} &= 50 \text{ ft} \times 50 \text{ ft} = 2,500 \text{ sf} \\
 \text{Recharge rate} &= \frac{1}{2} \text{ tested permeability rate} = \frac{1}{2} \times 4 \text{ in/hr} = 2 \text{ in/hr} \\
 t &= \frac{5,000 \text{ cf} \times 12 \text{ in/ft}}{2,500 \text{ sf} \times 2 \text{ in/hr}} = 12 \text{ hr}
 \end{aligned}$$

Step 2: Prepare the inputs for the spreadsheet

The design permeability rate, 2 in/hr, is used for the recharge rate in the spreadsheet. The specific yield is the default value, 0.15. The horizontal hydraulic conductivity is 5 times the vertical hydraulic conductivity since the infiltration basin is located in the coastal plain. The duration of infiltration period is obtained from Step 1. The initial thickness of saturated zone uses the default value, 10 feet.

Recharge rate (R) = 2 in/hr
 Specific yield (S_y) = 0.15
 Horizontal hydraulic conductivity (K_h) = 10 in/hr
 ½ length of basin (x direction) = 25 ft
 ½ length of basin (y direction) = 25 ft
 Duration of infiltration period (t) = 12 hr
 Initial thickness of saturated zone ($h_i(0)$) = 10 ft

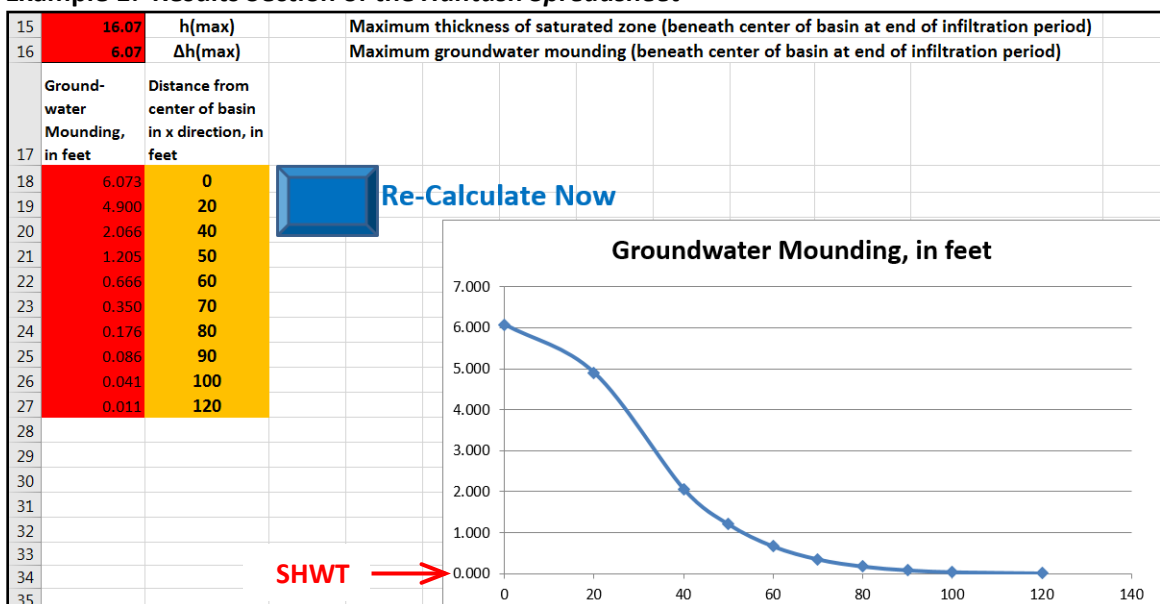
The graphic below depicts the input section of the *Hantush Spreadsheet* with the parameter values shown above entered.

Example 1: Input Section of the *Hantush Spreadsheet*

	A	B	C	D	E	F	G	H	I	J	K
6	Input Values										
7	2.00	R		Recharge rate (permeability rate) (in/hr)							
8	0.150	S_y		Specific yield, S_y (dimensionless)							
				default value is 0.15; max value is 0.2 provided that a lab test data is submitted							
9	10.00	K_h		Horizontal hydraulic conductivity (in/hr)							
				$K_h = 5 \times \text{Recharge Rate (R)}$ in the costal plan; $K_h = R$ outside the coastal plan							
10	25.000	x		1/2 length of basin (x direction, in feet)							
11	25.000	y		1/2 width of basin (y direction, in feet)							
12	12.00	t		Duration of infiltration period (hours)							
13	10.000	$h_i(0)$		Initial thickness of saturated zone (feet)							

The results, depicted below, show the maximum height of groundwater mounding, 6.07 ft, that will occur at the end of the duration of infiltration period. Since the SHWT is 7.5 ft below the bottom of the sand layer, the temporarily elevated groundwater table, located at 6.07 ft above the SHWT elevation, will not reach the bottom of the BMP. Therefore, the assessment shows no adverse hydraulic impact to the groundwater table from the proposed infiltration BMP.

Example 1: Results Section of the *Hantush Spreadsheet*



Example 2: Adverse hydraulic impact to groundwater and adjustment of infiltration period scenario

A major development located in the coastal plain proposes an infiltration basin, whose bottom footprint measures 88 ft by 88 ft, to infiltrate 15,000 cf of runoff generated by the 2-year design storm. The maximum depth of stormwater runoff to be infiltrated is designed to be approximately 2 ft. Soil testing was performed in accordance with *Chapter 12*. The soil testing report shows that the SHWT is 7.5 ft below the 6 in thick bottom sand layer of the basin. The tested soil permeability rate of the most restrictive soil horizon below the basin is 4 in/hr.

Step 1: Calculate the duration of infiltration period

$$\begin{aligned} \text{Duration of infiltration period, } t \text{ (hours)} &= \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ ft/in}}{\text{Infiltration area (sf)} \times \text{Recharge rate rate (in/hr)}} \\ \text{Infiltration area} &= 88 \text{ ft} \times 88 \text{ ft} = 7,744 \text{ sf} \\ \text{Design permeability rate} &= \frac{1}{2} \text{ tested permeability rate} = \frac{1}{2} \times 4 \text{ in/hr} = 2 \text{ in/hr} \\ t &= \frac{15,000 \text{ cf} \times 12 \text{ in/ft}}{7,744 \text{ sf} \times 2 \text{ in/hr}} = 11.62 \text{ hr} \end{aligned}$$

Step 2: Prepare the inputs for the spreadsheet

The design permeability rate, 2 in/hr, is used for the recharge rate in the spreadsheet. The specific yield is the default value, 0.15. The horizontal hydraulic conductivity is 5 times the vertical hydraulic conductivity since the infiltration basin is located in the coastal plain. The duration of infiltration period is obtained from Step 1. The initial thickness of saturated zone uses the default value, 10 feet.

$$\begin{aligned} \text{Recharge rate (R)} &= 2 \text{ in/hr} \\ \text{Specific yield (S}_y\text{)} &= 0.15 \\ \text{Horizontal hydraulic conductivity (K}_h\text{)} &= 10 \text{ in/hr} \\ \frac{1}{2} \text{ length of basin (x direction)} &= 44 \text{ ft} \\ \frac{1}{2} \text{ length of basin (y direction)} &= 44 \text{ ft} \\ \text{Duration of infiltration period (t)} &= 11.62 \text{ hr} \\ \text{Initial thickness of saturated zone (hi(0))} &= 10 \text{ ft} \end{aligned}$$

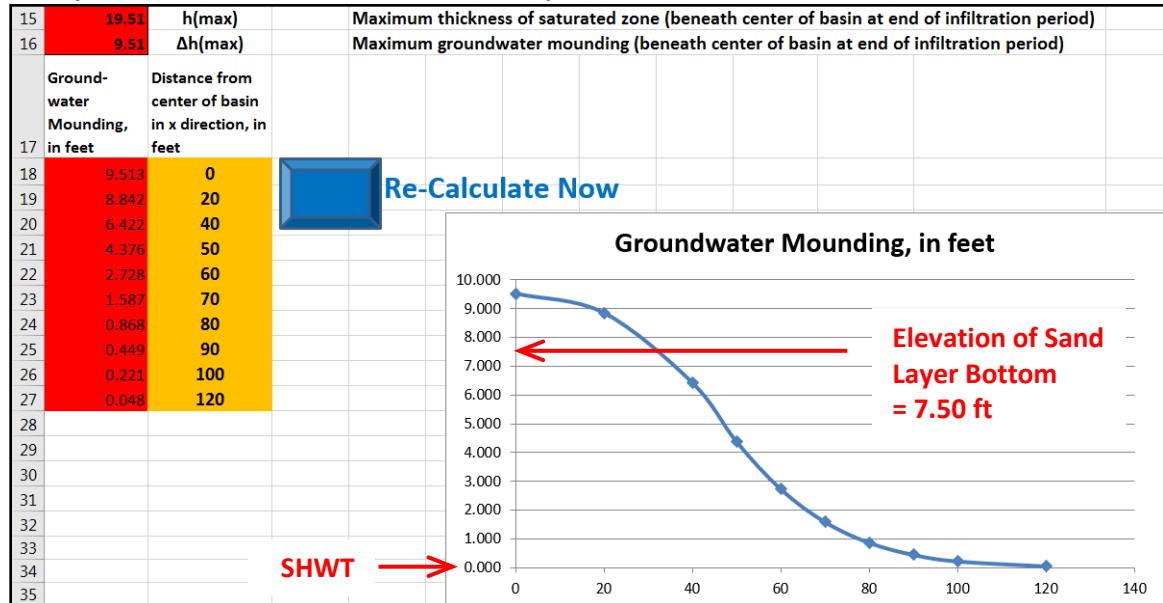
The graphic shown below depicts the input section of the *Hantush Spreadsheet* with the parameter values shown above entered.

Example 2: Input Section of the *Hantush Spreadsheet*

	A	B	C	D	E	F	G	H	I	J	K
6	Input Values										
7	2.00	R		Recharge rate (permeability rate) (in/hr)							
8	0.150	S _y		Specific yield, S _y (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted							
9	10.00	K _h		Horizontal hydraulic conductivity (in/hr) K _h = 5xRecharge Rate (R) in the costal plan; K _h =R outside the coastal plan							
10	44.000	x		1/2 length of basin (x direction, in feet)							
11	44.000	y		1/2 width of basin (y direction, in feet)							
12	11.62	t		Duration of infiltration period (hours)							
13	10.000	hi(0)		Initial thickness of saturated zone (feet)							

The results, depicted below, show the maximum height of groundwater mounding, 9.51 ft, that will occur at the end of the duration of infiltration period. Since the SHWT is 7.5 ft below the bottom of the sand layer, the temporarily elevated groundwater table, located at 9.51 ft above the SHWT elevation, intersects and exceeds the elevation of the bottom of the sand layer, interfering with the infiltration capability. Adjustments of the spreadsheet inputs are needed to reduce the height of groundwater mounding.

Example 2: Results Section of the *Hantush Spreadsheet*



Step 3: Adjust spreadsheet inputs

The height of groundwater mounding determined in Step 2 will reduce the vertical hydraulic gradient, which then slows the infiltration of runoff. Therefore, the vertical hydraulic conductivity will not be as high as expected, meaning it must be adjusted and rechecked to determine if the basin can still drain within 72 hours. For this example, the recharge rate is reduced to a smaller value of 1 in/hr. The horizontal hydraulic conductivity is not adjusted since it is not significantly affected by the reduced hydraulic gradient in the vertical direction. The duration of infiltration period must also be proportionally adjusted, as follows:

$$t = \frac{15,000 \text{ cf} \times 12 \text{ in/ft}}{7,744 \text{ sf} \times 1 \text{ in/hr}} = 23.24 \text{ hr}$$

The new adjusted parameter values, as follows, must be input into the spreadsheet:

Recharge rate (R)	= 1 in/hr
Specific yield (S _y)	= 0.15
Horizontal hydraulic conductivity (K _h)	= 10 in/hr
½ length of basin (x direction)	= 44 ft
½ length of basin (y direction)	= 44 ft
Duration of infiltration period (t)	= 23.24 hr
Initial thickness of saturated zone (h _i (0))	= 10 ft

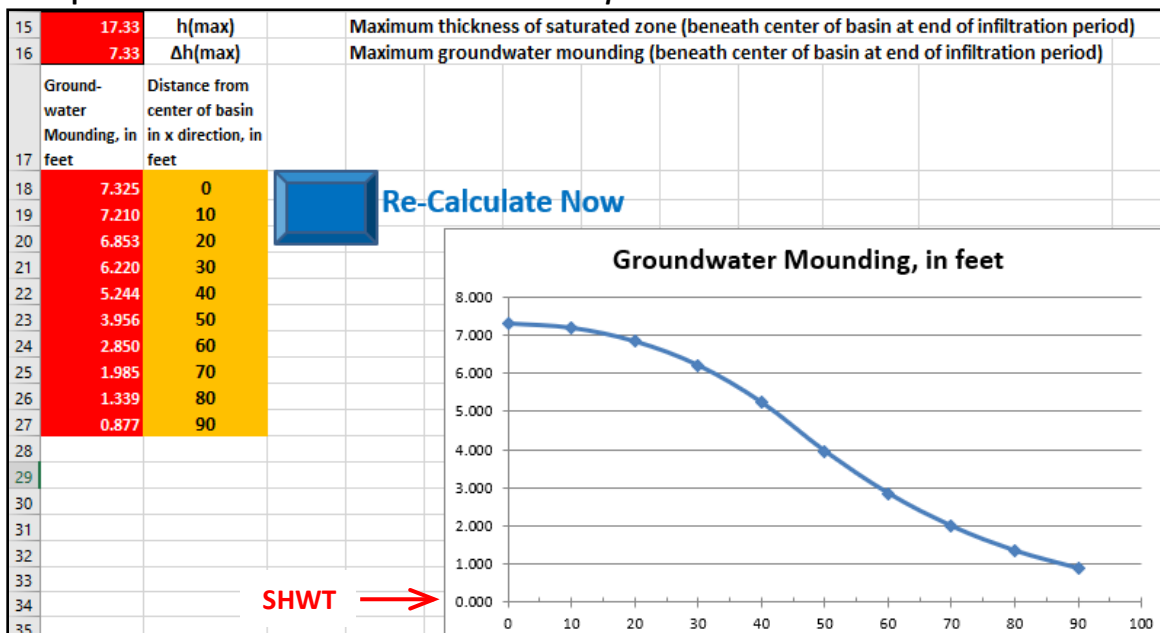
The graphic below depicts the input section of the *Hantush Spreadsheet* with the parameter values, adjusted as shown on the previous page, entered.

Example 2: Revised Input Section of the *Hantush Spreadsheet*

	A	B	C	D	E	F	G	H	I	J	K
6	Input Values										
7	1.00	R		Recharge rate (permeability rate) (in/hr)							
8	0.150	Sy		Specific yield, Sy (dimensionless)							
9	10.00	Kh		Horizontal hydraulic conductivity (in/hr)							
10	44.000	x		1/2 length of basin (x direction, in feet)							
11	44.000	y		1/2 width of basin (y direction, in feet)							
12	23.24	t		Duration of infiltration period (hours)							
13	10.000	hi(0)		Initial thickness of saturated zone (feet)							

The results, depicted below, show the maximum height of groundwater mounding, 7.33 ft, that will occur at the end of the duration of infiltration period. Since the SHWT is 7.5 ft below the bottom of the sand layer, the temporarily elevated groundwater table, located at 7.33 ft above the SHWT elevation, will not reach the bottom of the basin. Therefore, the assessment shows no adverse hydraulic impact to the groundwater table from the proposed infiltration BMP. As calculated above, the infiltration basin now needs 23.24 hours to drain. Since the drain time is still within 72 hours, the design of the proposed infiltration basin still meets the design criteria set forth in the BMP manual. Note that if there are underground structures near the BMP, an assessment of the hydraulic impact will need to be performed. See examples 5 and 6 for the assessment.

Example 2: New Results Section of the *Hantush Spreadsheet*

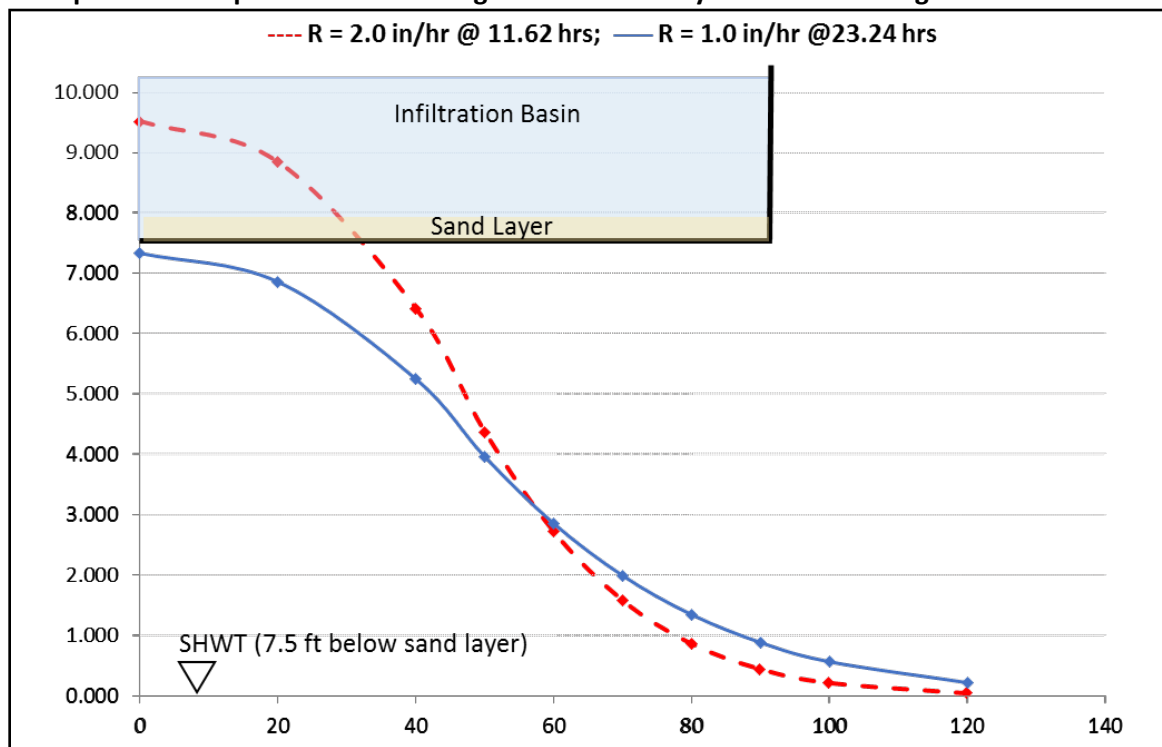


Creating a table, as mentioned in the discussion on Page 15, to record the inputs and results, may be helpful. Below is an example of such a table.

Model No.	Depth (ft)	Depth (in)	R (in/hr)	S_y	K_h (in/hr)	x (ft)	y (ft)	t (hr)	hi(0) (ft)	$\Delta h(\text{max})$ (ft)
Initial	2	24	2	0.15	10	44	44	11.62	10	9.51
Adjusted	2	24	1	0.15	10	44	44	23.24	10	7.33

A comparison of the mounding effects is shown below. The red dotted line represents the mounding effect from the infiltration basin assuming a recharge rate of 2 in/hr and infiltrating the runoff in 11.62 hr. The blue solid line represents the infiltration basin assuming a recharge rate of 1 in/hr and infiltrating the runoff in 23.24 hr.

Example 2: A Comparison of Mounding Effects Caused by Different Recharge Rates



Example 3: Adverse hydraulic impact to groundwater and adjustment of basin size scenario

A major development located outside the coastal plain proposes an infiltration basin, whose bottom footprint measures 80 ft by 80 ft, to infiltrate 12,800 cf of runoff. The maximum depth of stormwater runoff to be infiltrated is initially designed to be 2 ft. Soil testing was performed in accordance with *Chapter 12*. The soil testing report shows that the SHWT is 4 ft below the 6-in thick bottom sand layer of the basin. The tested soil permeability rate of the most restrictive soil horizon below the basin is 1 in/hr.

Step 1: Calculate the duration of infiltration period

$$\begin{aligned}\text{Duration of infiltration period, } t \text{ (hours)} &= \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ in/ft}}{\text{Infiltration area (sf)} \times \text{Recharge rate rate (in/hr)}} \\ \text{Infiltration area} &= 80 \text{ ft} \times 80 \text{ ft} = 6,400 \text{ sf} \\ \text{Design permeability rate} &= \frac{1}{2} \text{ tested permeability rate} = \frac{1}{2} \times 1 \text{ in/hr} = 0.5 \text{ in/hr} \\ t &= \frac{12,800 \text{ cf} \times 12 \text{ in/ft}}{6,400 \text{ sf} \times 0.5 \text{ in/hr}} = 48 \text{ hr}\end{aligned}$$

Step 2: Prepare the inputs for the spreadsheet

The design permeability rate, 0.5 in/hr, is used for the recharge rate in the spreadsheet. The specific yield is the default value, 0.15. The horizontal hydraulic conductivity is the same as the vertical hydraulic conductivity since the infiltration basin is located outside the coastal plain. The duration of infiltration period is obtained from Step 1. The initial thickness of saturated zone uses the default value, 10 feet.

$$\begin{aligned}\text{Recharge rate (R)} &= 0.5 \text{ in/hr} \\ \text{Specific yield (S}_y\text{)} &= 0.15 \\ \text{Horizontal hydraulic conductivity (K}_h\text{)} &= 0.5 \text{ in/hr} \\ \frac{1}{2} \text{ length of basin (x direction)} &= 40 \text{ ft} \\ \frac{1}{2} \text{ length of basin (y direction)} &= 40 \text{ ft} \\ \text{Duration of infiltration period (t)} &= 48 \text{ hr} \\ \text{Initial thickness of saturated zone (h}_i(0)\text{)} &= 10 \text{ ft}\end{aligned}$$

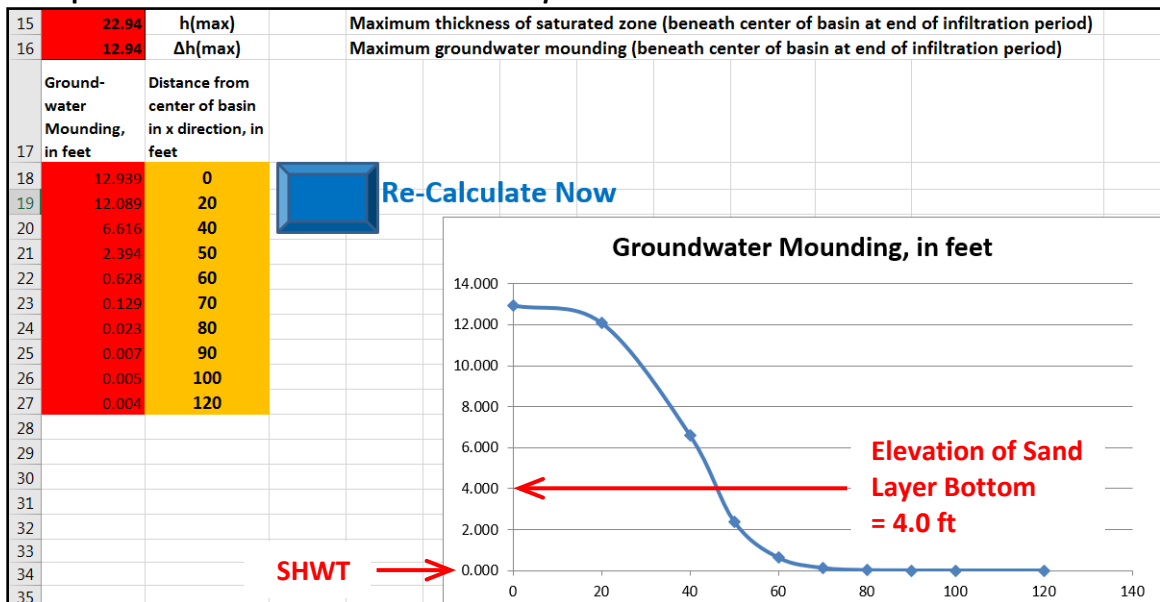
The graphic below depicts the input section of the *Hantush Spreadsheet* with the parameter values shown above entered.

Example 3: Input Section of the *Hantush Spreadsheet*

	A	B	C	D	E	F	G	H	I	J	K
6	Input Values										
7	0.50	R		Recharge rate (permeability rate) (in/hr)							
8	0.150	Sy		Specific yield, Sy (dimensionless)							
9	0.50	Kh		Horizontal hydraulic conductivity (in/hr)							
10	40.000	x		Kh = 5xRecharge Rate (R) in the coastal plan; Kh=R outside the coastal plan							
11	40.000	y		1/2 length of basin (x direction, in feet)							
12	48.00	t		1/2 width of basin (y direction, in feet)							
13	10.000	hi(0)		Duration of infiltration period (hours)							
				Initial thickness of saturated zone (feet)							

The results depicted below show the maximum height of groundwater mounding, 12.94 ft, that will occur at the end of the duration of infiltration period. Since the SHWT is 4 ft below the bottom of the sand layer, the temporarily elevated groundwater table, located at 12.94 ft above the SHWT elevation, intersects and exceeds the elevation of the bottom of the basin, interfering with the infiltration capability. Adjustment of the basin design is needed to reduce the impact of groundwater mounding.

Example 3: Results Section of the *Hantush Spreadsheet*



Step 3: Adjust basin size

The excessive height of groundwater mounding seen in the results from Step 2 indicates the design is concentrating the infiltration of runoff into a footprint that is too small. The adjustment will have to evaluate a larger basin area, which infers a shallower maximum depth of stormwater runoff to be infiltrated, in order to reduce the height of groundwater mounding under the center of the BMP. For this example, the area of the basin bottom will be increased from 80 ft by 80 ft to 160 ft by 160 ft; i.e., the area increases from 6,400 sf to 25,600 sf. Accordingly, the maximum depth of stormwater runoff to be infiltrated is proportionally decreased:

$$\begin{aligned}
 \text{Maximum depth of stormwater runoff to be infiltrated} &= \frac{\text{Volume of runoff to be infiltrated (cf)}}{\text{Infiltration area (sf)}} \\
 &= \frac{12,800 \text{ cf}}{25,600 \text{ sf}} = 0.5 \text{ ft}
 \end{aligned}$$

The duration of infiltration period must then be recalculated:

$$\begin{aligned}
 \text{Duration of infiltration period, t (hours)} &= \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ in/ft}}{\text{Infiltration area (sf)} \times \text{Recharge rate rate (in/hr)}} \\
 \text{Infiltration area} &= 160 \text{ ft} \times 160 \text{ ft} = 25,600 \text{ sf} \\
 \text{Design Permeability rate} &= \frac{1}{2} \text{ tested permeability rate} = \frac{1}{2} \times 1 \text{ in/hr} = 0.5 \text{ in/hr} \\
 t &= \frac{12,800 \text{ cf} \times 12 \text{ in/ft}}{25,600 \text{ sf} \times 0.5 \text{ in/hr}} = 12 \text{ hr}
 \end{aligned}$$

The new adjusted parameter values, as follows, must be input into the spreadsheet:

$$\begin{aligned}
 \text{Recharge rate (R)} &= 0.5 \text{ in/hr} \\
 \text{Specific yield (S}_y\text{)} &= 0.15 \\
 \text{Horizontal hydraulic conductivity (K}_h\text{)} &= 0.5 \text{ in/hr} \\
 \frac{1}{2} \text{ length of basin (x direction)} &= 80 \text{ ft} \\
 \frac{1}{2} \text{ length of basin (y direction)} &= 80 \text{ ft} \\
 \text{Duration of infiltration period (t)} &= 12 \text{ hr} \\
 \text{Initial thickness of saturated zone (hi(0))} &= 10 \text{ ft}
 \end{aligned}$$

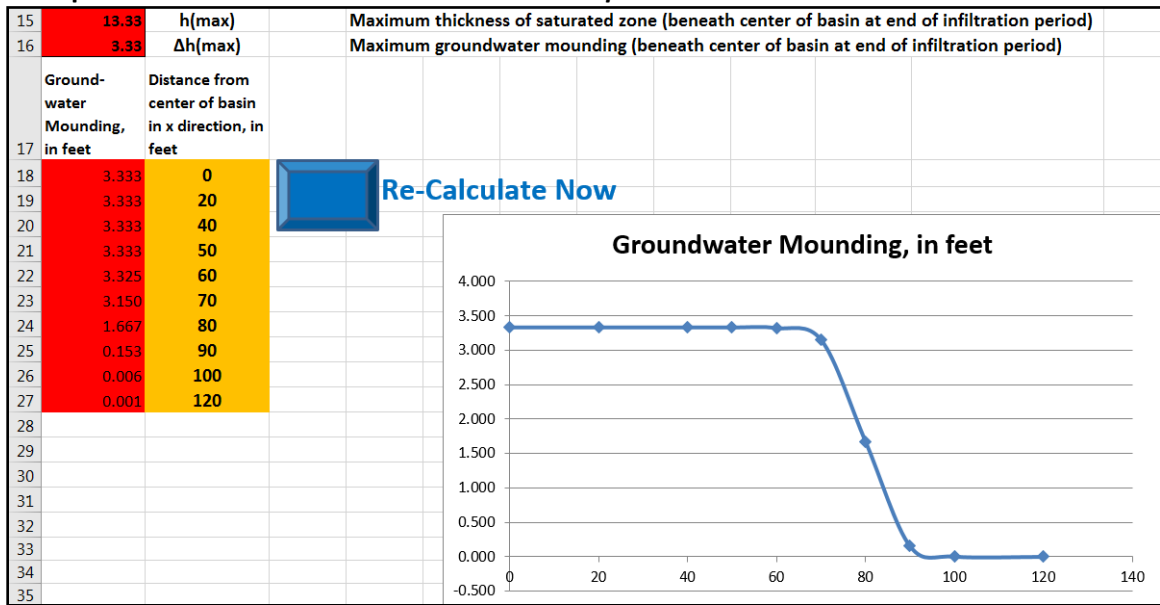
The graphic below depicts the input section of the *Hantush Spreadsheet* with the parameter values shown above entered.

Example 3: Revised Input Section of the *Hantush Spreadsheet*

6	Input Values								
7	0.50	R		Recharge rate (permeability rate) (in/hr)					
8	0.150	Sy		Specific yield, Sy (dimensionless)					
				default value is 0.15; max value is 0.2 provided that a lab test data is submitted					
9	0.50	Kh		Horizontal hydraulic conductivity (in/hr)					
				Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan					
10	80.000	x		1/2 length of basin (x direction, in feet)					
11	80.000	y		1/2 width of basin (y direction, in feet)					
12	12.00	t		Duration of infiltration period (hours)					
13	10.000	hi(0)		Initial thickness of saturated zone (feet)					

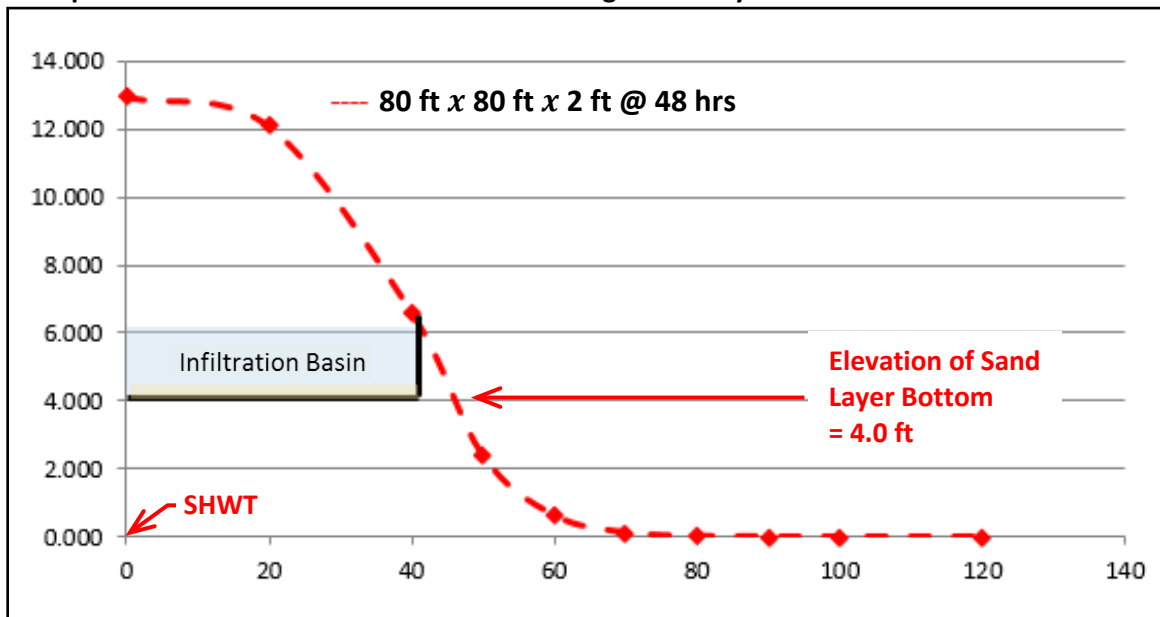
The results, depicted on the following page, show the maximum height of groundwater mounding, 3.33 ft, that will occur at the end of the duration of infiltration period. Since the SHWT is 4 ft below the bottom of the sand layer, the temporarily elevated groundwater table, located at 3.33 ft above the SHWT elevation, will not reach the bottom of the basin. Therefore, the assessment shows no adverse hydraulic impact to the groundwater table from the redesigned infiltration BMP. As calculated above, the infiltration basin now needs 12 hours to drain. Since the drain time is still within 72 hours, the design of the proposed infiltration basin still meets the design criteria set forth in the BMP manual.

Example 3: New Results Section of the *Hantush Spreadsheet*



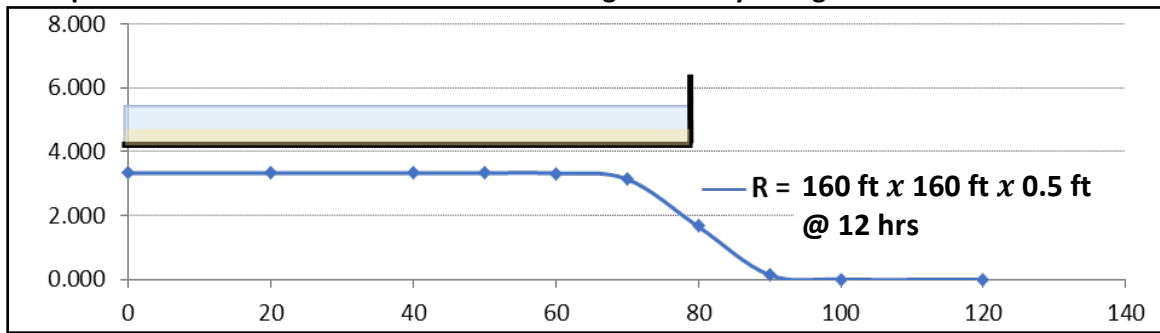
The figure below shows the initial design of a small basin with a high, i.e., 2 ft, maximum depth of stormwater runoff to be infiltrated. The mounding analysis demonstrates that concentrating the runoff volume to infiltrate in too small of an area produces an excessive height of groundwater mounding, which is depicted as the dashed red line.

Example 3: Estimation of Groundwater Mounding Caused by a Too-small Basin Size



The figure at the top of the following page depicts a basin having a shallower depth, i.e., 0.5 ft, of stormwater runoff to be infiltrated than the one above and a 400% larger infiltration area over which to distribute the same volume of runoff. The groundwater table, depicted as a blue line, temporarily rises but does not reach to the basin bottom. Therefore, the basin can infiltrate the runoff and drain within the calculated timeframe.

Example 3: Estimation of Groundwater Mounding Caused by a Larger Basin Size



Notes on Making Adjustments to the Design of a BMP

The adjustment of the design of a BMP to avoid the intrusion of groundwater mounding into the bottom area may require several iterations involving different footprint sizes, maximum depths of stormwater runoff to be infiltrated, and durations of infiltration periods. A quick rule of thumb for an initial estimate of the footprint size is shown below, where R is the design recharge rate (in/hr) used previously:

$$\begin{aligned} \text{The initial estimate of stormwater runoff depth to be infiltrated, } d \text{ (ft)} &= \text{depth of SHWT} \times \text{specific yield, } S_y \\ \text{The basin bottom area, } A \text{ (sf)} &= \frac{\text{Volume of runoff to be infiltrated (cf)}}{d \text{ (ft)}} \\ \text{Basin bottom length, } X, \text{ if square} &= \sqrt{A \text{ (sf)}} \\ \text{The duration of infiltration period, } t \text{ (hr)} &= \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ in/ft}}{A \text{ (sf)} \times R \text{ (in/hr)}} \end{aligned}$$

Using the parameters of Example 3, the starting point in the trial run is as follows, assuming the basin is a square in plan view:

$$\begin{aligned} d &= 4 \text{ ft} \times 0.15 &= 0.6 \text{ ft} \\ A &= 12,800 \text{ cf} / 0.6 \text{ ft} &= 21,333 \text{ sf} \\ X &= \sqrt{21,333 \text{ sf}} &= 146.05 \text{ ft} \\ \frac{1}{2} \text{ length of the basin} &= 146 \text{ ft} / 2 &= 73 \text{ ft} \\ t &= \frac{12,800 \text{ cf} \times 12 \text{ in/ft}}{21,333 \text{ sf} \times 0.5 \text{ in/hr}} &= 14.4 \text{ hrs} \end{aligned}$$

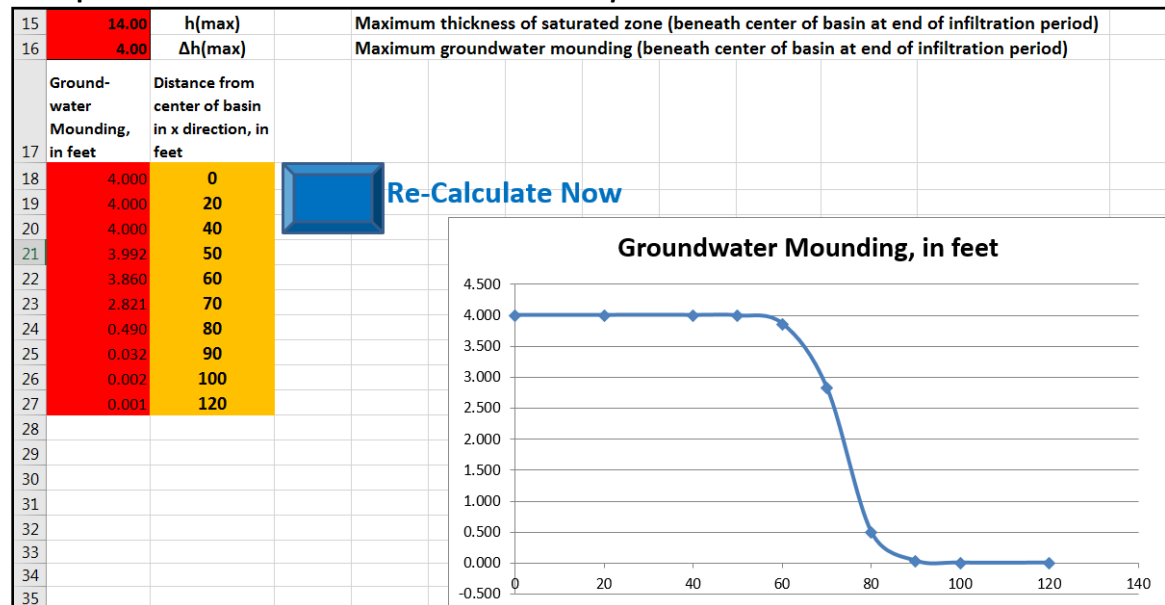
The new adjusted parameter values are entered into the *Hantush Spreadsheet*.

Example 3: Revised Input Section of the *Hantush Spreadsheet*

6	Input Values								
7	0.50	R		Recharge rate (permeability rate) (in/hr)					
8	0.150	Sy		Specific yield, Sy (dimensionless)					
				default value is 0.15; max value is 0.2 provided that a lab test data is submitted					
9	0.50	Kh		Horizontal hydraulic conductivity (in/hr)					
10	73.000	x		Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan					
11	73.000	y		1/2 length of basin (x direction, in feet)					
12	14.40	t		1/2 width of basin (y direction, in feet)					
13	10.000	hi(0)		Duration of infiltration period (hours)					
				Initial thickness of saturated zone (feet)					

The results, depicted below, show that the mounding height is 4 ft, which just reaches the bottom of the basin:

Example 3: New Results Section of the *Hantush Spreadsheet*



The initial estimate of basin size, 147 ft x 147 ft x 0.6 ft, is close to the redesigned basin size of 160 ft x 160 ft x 0.5 ft. Since this is an initial estimate, more iterations of the analysis, using a larger basin with shallower depth of stormwater runoff to be infiltrated, may be desired.

Example 4: Rectangular or round infiltration BMP scenario

Infiltration BMPs are often designed in shapes other than squares. For a round basin, the radius of the basin will be the inputs for both x and y. For rectangular basins or oval basins, half of the respective long and short sides are the inputs for x and y. However, the spreadsheet provides only the mounding height produced along the x-direction, meaning the user must swap the y-direction value for that of the x-direction, and vice versa, to assess the mounding height in the y-direction. The following example uses the data from Step 3 of Example 3, but changes the shape of the basin from 160 ft x 160 ft to 320 ft x 80 ft. Since the area of the basin bottom does not change, the duration of infiltration period remains the same.

Step 1: Prepare the inputs for the spreadsheet

The inputs for the spreadsheet are as follows and the input section of the *Hantush Spreadsheet* is depicted on the following page:

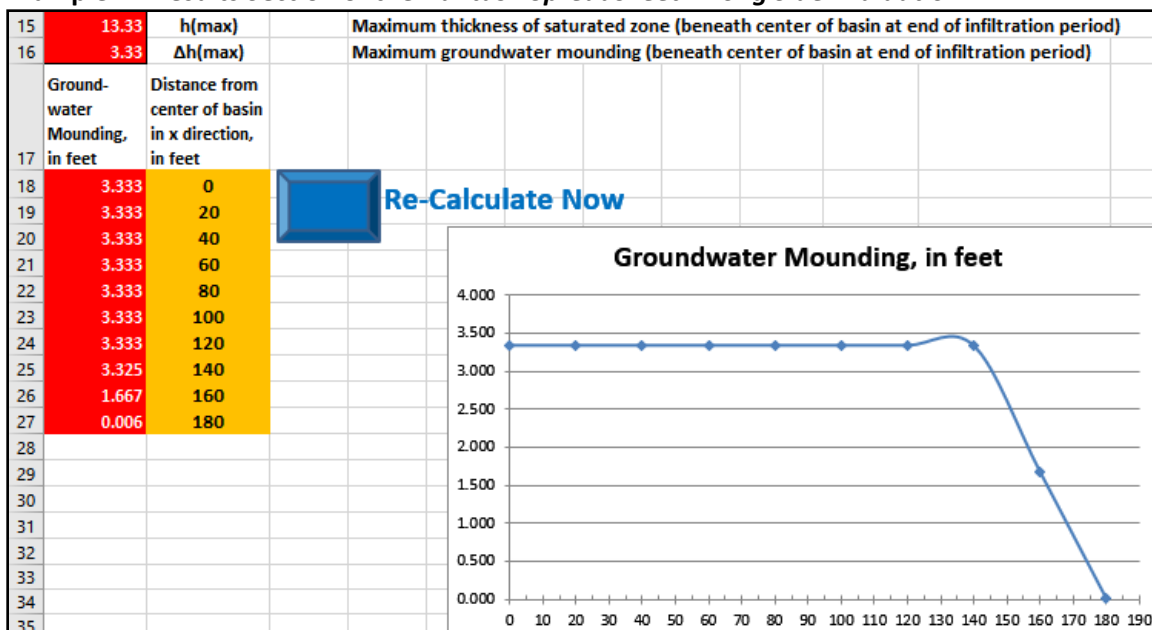
½ length of basin (x direction)	= 160 ft
½ length of basin (y direction)	= 40 ft

Example 4: Input Section of the *Hantush Spreadsheet* – Long Side Evaluation

6	Input Values						
7	0.50	R	Recharge rate (permeability rate) (in/hr)				
8	0.150	Sy	Specific yield, Sy (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted				
9	0.50	Kh	Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan				
10	160.000	x	1/2 length of basin (x direction, in feet)				
11	40.000	y	1/2 width of basin (y direction, in feet)				
12	12.00	t	Duration of infiltration period (hours)				
13	10.000	hi(0)	Initial thickness of saturated zone (feet)				

The results show the extent of the mounding along the direction of the long side:

Example 4: Results Section of the *Hantush Spreadsheet – Long Side Evaluation*



Step 2: Switch the x and y inputs and re-analyze

Next, switch the x and y inputs, and evaluate the results, meaning the short side will be the x direction and the long side will be the y direction.

$$\frac{1}{2} \text{ length of basin (x direction)} = 40 \text{ ft}$$

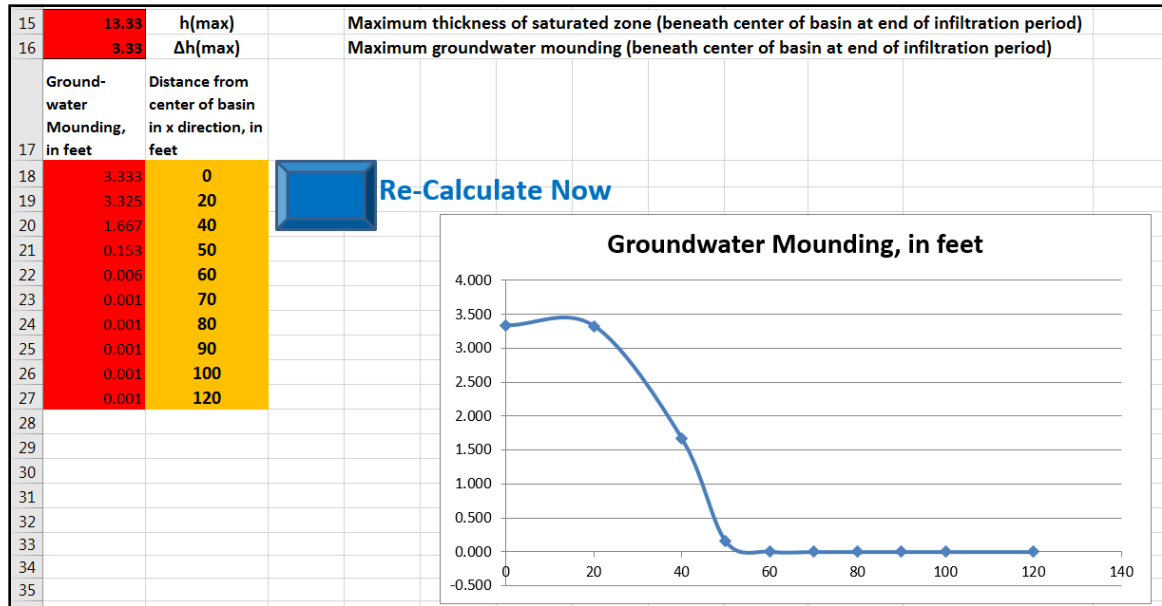
$$\frac{1}{2} \text{ length of basin (y direction)} = 160 \text{ ft}$$

Example 4: Input Section of the *Hantush Spreadsheet* – Short Side Evaluation

6	Input Values							
7	0.50	R		Recharge rate (permeability rate) (in/hr)				
8	0.150	Sy		Specific yield, Sy (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted				
9	0.50	Kh		Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan				
10	40.000	x		1/2 length of basin (x direction, in feet)				
11	160.000	y		1/2 width of basin (y direction, in feet)				
12	12.00	t		Duration of infiltration period (hours)				
13	10.000	hi(0)		Initial thickness of saturated zone (feet)				

The results show the extent of the mounding along the short side of the rectangular basin:

Example 4: Results Section of the *Hantush Spreadsheet – Short Side Evaluation*



The results show that the maximum mounding height at the center of the basin remains same as that of the square basin from Step 3 of Example 3. However, the extents of the mounding curves along long side and the short side of a rectangular basin are different.

Example 5: Underground perforated pipe scenario

A site is located in the coastal plain. A 500 ft, 36 in diameter underground perforated pipe is proposed to store and infiltrate 12,000 cf of runoff. Soil testing was performed in accordance with *Chapter 12*. The building has a basement floor located just above the groundwater table. The center of the underground pipe is 20 ft away from the building. The soil testing report shows that the SHWT is 2 ft below the pipe. The tested soil permeability rate of the most restrictive soil horizon below the pipe is 8 in/hr.

Step 1: Calculate the duration of infiltration period

In plan view, the footprint of the circular pipe is a projection, that is, a rectangle.

$$\begin{aligned}
 \text{Infiltration area} &= 500 \text{ ft} \times (36 \text{ in} / 12 \text{ in/ft}) = 1,500 \text{ sf} \\
 \text{Duration of infiltration period, } t \text{ (hours)} &= \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ in/ft}}{\text{Infiltration area (sf)} \times \text{Recharge rate (in/hr)}} \\
 \text{Design Permeability rate} &= \frac{1}{2} \text{ tested permeability rate} = \frac{1}{2} \times 8 \text{ in/hr} = 4 \text{ in/hr} \\
 t &= \frac{12,000 \text{ cf} \times 12 \text{ in/ft}}{1,500 \text{ sf} \times 4 \text{ in/hr}} = 24 \text{ hr}
 \end{aligned}$$

Step 2: Prepare the inputs for the spreadsheet

A design permeability rate, 4 in/hr, is used for recharge rate in the spreadsheet. The specific yield is the default value, 0.15. The horizontal hydraulic conductivity is five times as the vertical hydraulic conductivity since the site is located in the coastal plain. The initial thickness of saturated zone uses the default value, 10 feet.

Recharge rate (R)	=	4 in/hr
Specific yield (Sy)	=	0.15
Horizontal hydraulic conductivity (K _h)	=	20 in/hr
½ length of basin (x direction)	=	1.5 ft
½ length of basin (y direction)	=	250 ft
Duration of infiltration period (t)	=	24 hr
Initial thickness of saturated zone (hi(0))	=	10 ft

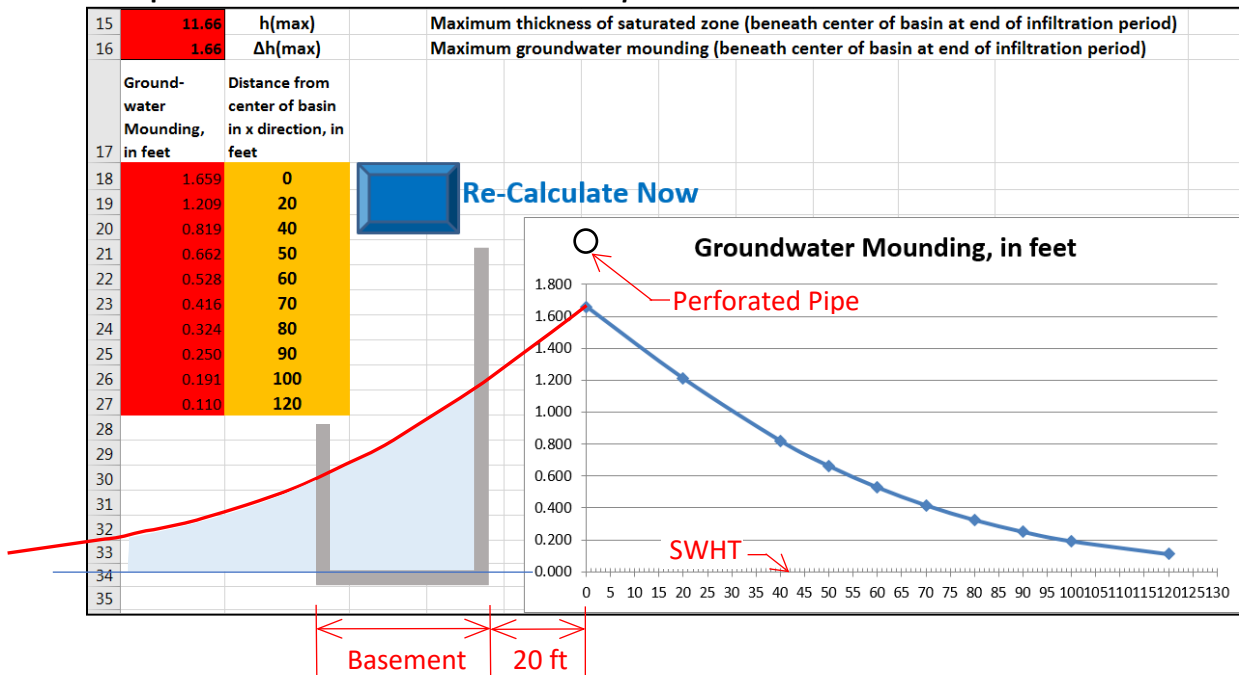
Example 5: Input Section of the *Hantush Spreadsheet*

6	Input Values								
7	4.00	R		Recharge rate (permeability rate) (in/hr)					
8	0.150	Sy		Specific yield, Sy (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted					
9	20.00	Kh		Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan					
10	1.500	x		1/2 length of basin (x direction, in feet)					
11	250.000	y		1/2 width of basin (y direction, in feet)					
12	24.00	t		Duration of infiltration period (hours)					
13	10.000	hi(0)		Initial thickness of saturated zone (feet)					

Step 3: Analyze the results

The results, depicted on the following page, show the maximum height of groundwater mounding, 1.66 ft, that will occur at the end of the duration of infiltration period. The discussion continues after the graphic.

Example 5: Results Section of the *Hantush Spreadsheet*



Since the calculated mounding height is 1.66 ft, the temporary rise in the groundwater table cause by the infiltration of stormwater will not reach the perforated pipe. However, the effect of the proposed infiltration on the adjacent structures must also be analyzed. The vertical axis shown in the results figure is situated at the centerline of the perforated pipe, and the groundwater mounding curve is symmetrical on both sides of the vertical axis. The building is horizontally separated by 20 ft from the centerline of the pipe, meaning it sits to the left of the vertical axis shown in the preceding figure, and the height of groundwater mounding temporarily rises roughly 1.21 feet at this distance. Therefore, the basement floor will be inundated by about 1.21 ft of water from the localized rise in the groundwater table. Even if the center of the pipe is moved to a lateral separation of 40 ft, the analysis shows the basement floor will still be inundated by about 0.82 ft of water, which may increase the chance of groundwater seepage into the basement.

As stated earlier, the Stormwater Management rules at N.J.A.C. 7:8-5.2(h) require that “*Whenever the stormwater management design includes one or more BMPs that will infiltrate stormwater into subsoil, the design engineer shall assess the hydraulic impact on the groundwater table and design the site, so as to avoid adverse hydraulic impacts. Potential adverse hydraulic impacts include, but are not limited to, exacerbating a naturally or seasonally high water table, so as to cause surficial ponding, flooding of basements, or interference with the proper operation of subsurface sewage disposal systems or other subsurface structures within the zone of influence of the groundwater mound, or interference with the proper functioning of the stormwater management measure itself.*” This example shows that the groundwater mounding effect from an underground infiltration BMP needs to be carefully evaluated since it may have the potential to cause flooding of a basement even though the underground infiltration BMP itself is not affected by the elevated groundwater table.

Example 6: Drywell scenario

A site is located outside the coastal plain. A 7 ft high by 5 ft diameter drywell is proposed to store and infiltrate 137.4 cf of roof runoff from a single-family home for the Water Quality Design Storm (WQDS). The proposed duration of infiltration period is 42 hours. Soil testing was performed in accordance with *Chapter 12*. The house has a basement floor located just above the groundwater table. The edge of the drywell is 10 feet away from the house. The soil testing report shows the SHWT is 2 feet below the bottom of the drywell. The tested soil permeability rate of the most restrictive soil horizon below the drywell is 4 in/hr.

Step 1: Prepare the inputs for the spreadsheet

The design permeability rate, 2 in/hr, is used for the recharge rate in the spreadsheet. The specific yield is the default value, 0.15. The horizontal hydraulic conductivity is the same as the vertical hydraulic conductivity since the site is located outside the coastal plain. The duration of infiltration period is 42 hours, as stated above. The initial thickness of saturated zone uses the default value, 10 feet. The parameters to be entered into the spreadsheet are shown below:

Recharge rate (R)	=	2 in/hr
Specific yield (S_y)	=	0.15
Horizontal hydraulic conductivity (K_h)	=	2 in/hr
½ length of basin (x direction)	=	2.5 ft
½ length of basin (y direction)	=	2.5 ft
Duration of infiltration period (t)	=	42 hr
Initial thickness of saturated zone ($h_i(0)$)	=	10 ft

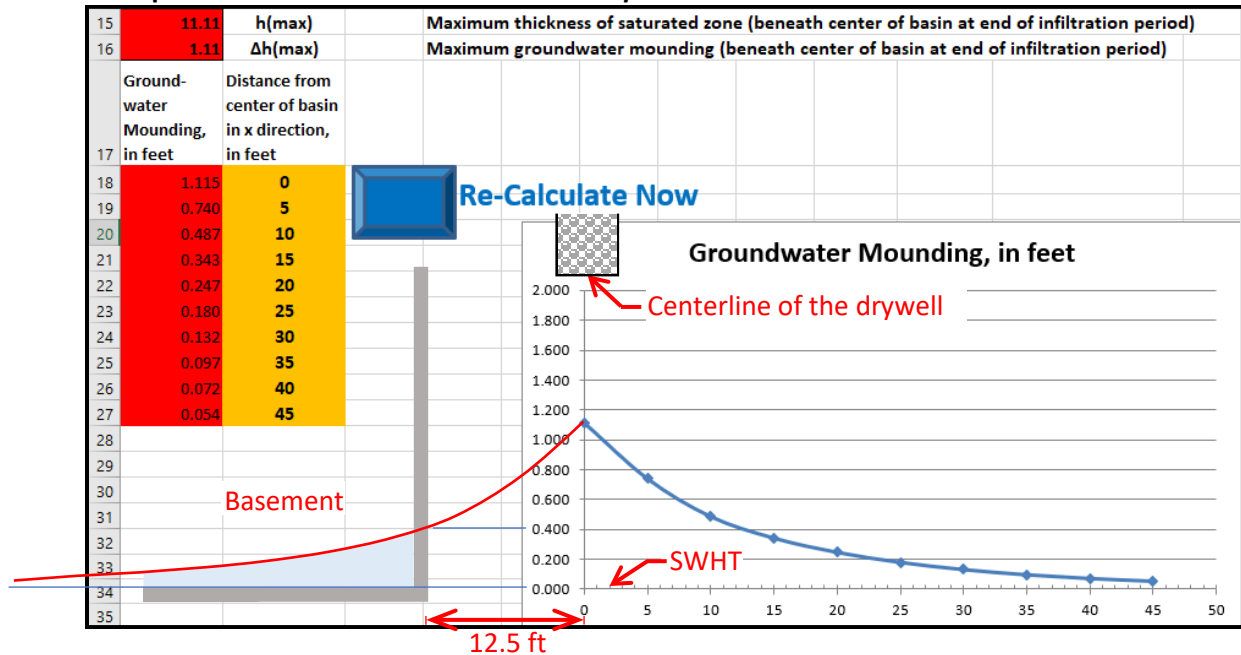
Example 6: Input Section of the *Hantush Spreadsheet*

Input Values			
2.00	R	Recharge rate (permeability rate) (in/hr)	
0.150	S_y	Specific yield, S_y (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted	
2.00	K_h	Horizontal hydraulic conductivity (in/hr) $K_h = 5 \times \text{Recharge Rate (R)}$ in the coastal plan; $K_h = R$ outside the coastal plan	
2.500	x	1/2 length of basin (x direction, in feet)	
2.500	y	1/2 width of basin (y direction, in feet)	
42.00	t	Duration of infiltration period (hours)	
10.000	$h_i(0)$	Initial thickness of saturated zone (feet)	
11.11	h(max)	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)	
1.11	$\Delta h(\text{max})$	Maximum groundwater mounding (beneath center of basin at end of infiltration period)	

Step 2: Analyze the results

The results, depicted on the following page, show the maximum height of groundwater mounding, 1.11 ft, that will occur at the end of the duration of infiltration period at the center of the drywell. The temporary groundwater mounding does not encroach upon the bottom of the drywell, where it would have impaired infiltration. The discussion continues below the figure.

Example 6: Results Section of the *Hantush Spreadsheet*



The effect of the proposed infiltration on the adjacent structures must also be analyzed. The vertical axis shown in the results figure is situated at the centerline of the drywell, and the groundwater mounding curve is symmetrical on both sides of the vertical axis. The basement is 10 ft away from the edge of the drywell, which is 12.5 ft to the left of the center of the drywell. The spreadsheet results indicate the water table is also temporarily raised approximately 0.4 ft at the basement location by this infiltration BMP, which may cause an adverse impact. Therefore, the drywell may need to be moved farther from the building to avoid the adverse impact caused by the proposed infiltration. Locating the drywell at a distance farther away from the building may avoid the adverse impact on the basement. This example shows that even a small infiltration BMP may have an adverse impact on nearby underground structures.

Example 7: Replacement of soil below an infiltration BMP scenario

This example highlights a practice used where the native soils have lower permeability rates. In some instances, the area below the proposed basin bottom is further excavated and replaced with a sand with a known permeability rate.

A major development, located outside the coastal plain, proposes to infiltrate 2,450 cf of runoff generated by the Water Quality Design Storm (WQDS) via an infiltration basin whose bottom area measures 35 ft by 35 ft. The maximum depth of stormwater runoff to be infiltrated is initially designed at 2 feet. Soil testing was performed in accordance with *Chapter 12*. The soil testing report shows that the SHWT is 7 ft below the 6 in sand layer at the bottom of the basin. The tested permeability rate of the most restrictive soil horizon below the basin is 0.5 in/hr. K5 sand is proposed to replace the soil directly below the basin bottom, down to the SHWT elevation. The tested permeability rate of the proposed K5 sand is greater than 20 in/hr.

the length and width of the basin to 50 ft each creates 2,500 sf of area for infiltration. Assuming the recharge rate is 0.5 in/hr, the duration of infiltration period can be recalculated for the new basin configuration:

$$\begin{aligned} \text{Maximum depth of stormwater runoff to be infiltrated} &= \frac{\text{Volume of runoff to be infiltrated (cf)}}{\text{Infiltration area (sf)}} \\ &= \frac{2,450 \text{ cf}}{2,500 \text{ sf}} = 0.98 \text{ ft} \end{aligned}$$

$$\begin{aligned} \text{Duration of infiltration period, t (hours)} &= \frac{\text{Volume of runoff to be infiltrated (cf)} \times 12 \text{ ft/in}}{\text{Infiltration area (sf)} \times \text{Recharge rate (in/hr)}} \\ t &= \frac{2,450 \text{ cf} \times 12 \text{ ft/in}}{2,500 \text{ sf} \times 0.5 \text{ in/hr}} = 23.52 \text{ hr} \end{aligned}$$

The inputs and resulting height of groundwater mounding are depicted below.

Example 7: Further Revised Input Section of the *Hantush Spreadsheet*

6	Input Values								
7	0.500	R	Recharge rate (permeability rate) (in/hr)						
8	0.150	Sy	Specific yield, Sy (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted						
9	0.50	Kh	Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan						
10	25.000	x	1/2 length of basin (x direction, in feet)						
11	25.000	y	1/2 width of basin (y direction, in feet)						
12	23.52	t	Duration of infiltration period (hours)						
13	10.000	hi(0)	Initial thickness of saturated zone (feet)						
14									
15	16.34	h(max)	Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)						
16	6.34	$\Delta h(\max)$	Maximum groundwater mounding (beneath center of basin at end of infiltration period)						

The redesigned basin with a bottom area measuring 50 ft x 50 ft, a maximum depth of stormwater runoff to be infiltrated of 0.98 ft and a drain time of 23.52 hr may work since the SHWT is 7 ft below the proposed bottom of the basin and the height of the groundwater mounding is 6.34 ft. This exercise demonstrates that replacement of the underlying soil below an infiltration basin may work for a site having low permeability soils. If a shallower depth of native soils were replaced, the lowest tested field permeability rate of the remaining native soil would be used in calculating the recharge rate as it would be the limiting factor.

Regardless, one must always remember that **soil replacement does not change the horizontal hydraulic conductivity of the soils outside the basin**. The low horizontal hydraulic conductivity will still limit the ability of the runoff to be dissipated into the saturated zone and may result in high groundwater mounding in the unsaturated zone. Therefore, the use of sand replacement in basin designs must still be carefully evaluated with a groundwater mounding analysis.

Example 8: Small-scale Infiltration Basin (Green Infrastructure BMP) in ‘B’ Soils scenario

A major development located in Ocean County proposes a small-scale infiltration basin to meet the water quality, quantity and groundwater recharge standards for the runoff from a 2.5 ac impervious parking lot. Small-scale infiltration basins are designed to infiltrate runoff generated by the Water Quality Design Storm (WQDS) and to attenuate the runoff from the 2-, 10- and 100-year Design Storms through one or more discharge outlets. Additionally, in a small-scale infiltration basin, exfiltration is allowed for routing all storm events. The proposed 2.5 ac parking lot measures 330 ft by 330 ft and will be located on an existing wooded area where hydrologic soil group (HSG) ‘B’ soils are present. Soil testing was performed in accordance with *Chapter 12*, and the report shows that the SHWT is 20 ft below the proposed bottom sand layer of the basin. The tested soil permeability rate of the most restrictive soil horizon below the basin is 10 in/hr. Testing confirmed the initial thickness of the saturated zone is 30 ft. Assume the sides of the basin are vertical in all calculations.

Step 1: Calculate the volume and basin size for the WQDS

The WQDS consists of 1.25 inches of rain falling over 2 hours. The rainfall depths for the 2-, 10- and 100-year design storms are 3.42, 5.33 and 9.2 in, respectively. The Curve Number for woods in ‘good’ condition, as required in N.J.A.C. 7:8-5.7(a)2, on ‘B’ Soils is 55. The hydraulically most distant point in the existing woods is determined to be 405 ft from the point of analysis. The existing land has an average slope of 5%. The Manning’s roughness coefficient for woods is 0.4. The sheet flow length is assumed to be 100 feet for the pre-construction condition.

The time of concentration (T_c) for the existing condition is calculated to be 23.7 minutes, of which 14.6 minutes is the sheet flow segment using a Manning’s roughness coefficient of 0.4 and 14.5 minutes is the remaining segment, i.e., 305 ft, of shallow concentrated flow. For the post-construction condition, a T_c of 6 minutes is assumed for the impervious parking lot. In accordance with the information provided above, runoff volumes and rates for the pre- and post-construction conditions are calculated using hydrologic modeling software and shown in the table found below:

Design Storm	Pre-Construction Flow Rates	Post-Construction Allowable Discharge		Post-Construction (without Quantity Control)	
	Peak flow (cfs)	Allowable % of Existing	Peak flow (cfs)	Peak flow (cfs)	Volume (cf)
2-year	0.30	50%	0.15	9.51	28,920
10-year	1.76	75%	1.32	14.93	46,216
100-year	6.49	80%	5.19	25.85	81,308

The proposed 2.5 acres of regulated motor vehicle impervious surface produces 9,388.74 cf of stormwater runoff generated by the WQDS and this specific volume is therefore used to initially size the small-scale infiltration basin. The tested permeability rate of the soil is 10 in/hr, which is converted to the design infiltration rate, as well as the exfiltration rate, of 5 in/hr.

For the WQDS, a small-scale surface infiltration basin has a maximum allowable depth of stormwater runoff to be infiltrated of 2 ft. With exfiltration incorporated into the routing calculation, the basin bottom area, or footprint, required is 5,000 sf. When modeling the BMP, the invert elevation of the

first orifice is therefore set at a distance of 2 ft above the bottom of the basin and the diameter of this orifice is set at the minimum allowable of 2.5 in. Note that flow through the outlet control structure is labeled as "Primary" in the graphic below and "Discarded" is used to denote runoff that is exfiltrated. Results for the WQDS are shown below as reprints from a hydrologic modelling software package using the NRCS methodology:

Initial WQDS Summary Report

Inflow Area =	108,900 sf, 100.00% Impervious, Inflow Depth = 1.03" for Custom event
Inflow =	7.240 cfs @ 1.09 hrs, Volume= 9,389 cf
Outflow =	0.428 cfs @ 0.85 hrs, Volume= 9,389 cf, Atten= 94%, Lag= 0.0 min
Discarded =	0.428 cfs @ 0.85 hrs, Volume= 9,389 cf
Primary =	0.000 cfs @ 0.00 hrs, Volume= 0 cf

Routing by Stor-Ind method, Time Span= 0.00-72.00 hrs, dt= 0.05 hrs
Peak Elev= 1.46' @ 1.86 hrs Surf.Area= 5,000 sf Storage= 7,282 cf

Plug-Flow detention time= 151.0 min calculated for 9,382 cf (100% of inflow)
Center-of-Mass det. time= 151.1 min (221.4 - 70.3)

Volume	Invert	Avail.Storage	Storage Description
#1	0.00'	38,796 cf	Custom Stage Data (Prismatic) Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
0.00	5,000	0	0
1.00	5,000	5,000	5,000
2.00	5,000	5,000	10,000
3.00	5,776	5,388	15,388
4.00	7,056	6,416	21,804
5.00	8,464	7,760	29,564
6.00	10,000	9,232	38,796

Device	Routing	Invert	Outlet Devices
#1	Primary	2.00'	2.5" Vert. Orifice/Grate C= 0.600
#2	Discarded	0.00'	0.428 cfs Exfiltration at all elevations
#3	Primary	5.71'	20.0' long x 0.5' breadth Broad-Crested Rectangular Weir Head (feet) 0.20 0.40 0.60 0.80 1.00 Coef. (English) 2.80 2.92 3.08 3.30 3.32
#4	Primary	3.00'	6.0" Vert. Orifice/Grate C= 0.600

Discarded OutFlow Max=0.428 cfs @ 0.85 hrs HW=0.08' (Free Discharge)
2=Exfiltration (Exfiltration Controls 0.428 cfs)

Primary OutFlow Max=0.000 cfs @ 0.00 hrs HW=0.00' (Free Discharge)
1=Orifice/Grate (Controls 0.000 cfs)
3=Broad-Crested Rectangular Weir (Controls 0.000 cfs)
4=Orifice/Grate (Controls 0.000 cfs)

Source: HydroCAD® Summary Report; HydroCAD is a register trademark of HydroCAD Software Solutions LLC. Used with permission.

Step 3: Design the outflow structure to attenuate the 100-year design storm with exfiltration

The allowable peak flow rate for 100-year storm is 5.19 cfs. A second outlet for controlling the discharge of runoff produced by the 100-year storm must be designed. After trials of different types of outlets at various elevations, it is determined that the footprint of the 5,000 sf basin must be expanded in order to provide sufficient volume, even with exfiltration, to detain the volume of stormwater runoff generated by the 100-year design storm. A 6 inch orifice is added at an elevation of 3 ft above the basin bottom. A broad-crested weir, located 5.71 ft above the basin bottom, is also proposed. The weir opening is 20 ft long in that it is comprised of 4 sides, each 5 ft in length. The depth of the weir, i.e., the outlet structure wall thickness, is 0.5 ft.

Take note that the exfiltration can be credited only on the infiltration area, which is the footprint of the BMP. The side slopes of the BMP cannot be used for exfiltration. Therefore, the routing, with exfiltration, must only use the design permeability rate of the most restrictive soil layer under the BMP and the footprint, i.e., the exfiltration area, of the BMP to determine the maximum exfiltration flow rate (cfs) in the BMP. In the current example, the footprint of proposed basin is 5,000 sf. The permeability rate of the most restrictive soil layer is 5 in/hr. The maximum exfiltration (discarded) flow rate is calculated to be 0.4282 cfs.

With this configuration, the discharge rate, i.e., marked as “Primary” in the following summary report, from the outlet control structure in the basin is 5.17 cfs, which is less than the allowable 100-year design storm peak flow rate listed in the table on Page 39. The highest water surface elevation produced by the routing of the 100-year design storm is 5.84 ft, with 42,739 cf of stormwater runoff exfiltrated, as shown in the summary report depicted on the next page.

100-year Design Storm Summary Report

Inflow Area = 108,900 sf, 100.00% Impervious, Inflow Depth = 8.96" for 100 year event
 Inflow = 22.062 cfs @ 12.09 hrs, Volume= 81,308 cf
 Outflow = 4.917 cfs @ 12.49 hrs, Volume= 81,308 cf, Atten= 78%, Lag= 24.4 min
 Discarded = 0.428 cfs @ 7.00 hrs, Volume= 42,739 cf
 Primary = 4.489 cfs @ 12.49 hrs, Volume= 38,569 cf

Routing by Stor-Ind method, Time Span= 0.00-72.00 hrs, dt= 0.05 hrs
 Peak Elev= 5.84' @ 12.49 hrs Surf.Area= 9,753 sf Storage= 37,209 cf

Plug-Flow detention time= 237.8 min calculated for 81,308 cf (100% of inflow)
 Center-of-Mass det. time= 237.7 min (977.3 - 739.6)

Volume	Invert	Avail. Storage	Storage Description
#1	0.00'	38,796 cf	Custom Stage Data (Prismatic) Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
0.00	5,000	0	0
1.00	5,000	5,000	5,000
2.00	5,000	5,000	10,000
3.00	5,776	5,388	15,388
4.00	7,056	6,416	21,804
5.00	8,464	7,760	29,564
6.00	10,000	9,232	38,796

Device	Routing	Invert	Outlet Devices
#1	Primary	2.00'	2.5" Vert. Orifice/Grate C= 0.600
#2	Discarded	0.00'	0.428 cfs Exfiltration at all elevations
#3	Primary	5.71'	20.0' long x 0.5' breadth Broad-Crested Rectangular Weir Head (feet) 0.20 0.40 0.60 0.80 1.00 Coef. (English) 2.80 2.92 3.08 3.30 3.32
#4	Primary	3.00'	6.0" Vert. Orifice/Grate C= 0.600

Discarded OutFlow Max=0.428 cfs @ 7.00 hrs HW=0.06' (Free Discharge)
 ↑ **2=Exfiltration** (Exfiltration Controls 0.428 cfs)

Primary OutFlow Max=4.415 cfs @ 12.49 hrs HW=5.84' (Free Discharge)
 ↑ **1=Orifice/Grate** (Orifice Controls 0.317 cfs @ 9.30 fps)
 — **3=Broad-Crested Rectangular Weir** (Weir Controls 2.577 cfs @ 1.00 fps)
 — **4=Orifice/Grate** (Orifice Controls 1.521 cfs @ 7.75 fps)

Source: HydroCAD® Summary Report; HydroCAD is a register trademark of HydroCAD Software Solutions LLC. Used with permission.

Step 5: BMP Stormwater Routings for the 2- and 10-year design storms and Groundwater Mounding Analysis

We must perform the routing analyses for the 2- and, 10-year design storms to check if the primary discharge flows exceed the respective allowable design storm peak flow rates:

2-year Design Storm Summary Report

Inflow Area =	108,900 sf, 100.00% Impervious, Inflow Depth = 3.19" for 2 year event
Inflow =	8.118 cfs @ 12.09 hrs, Volume= 28,920 cf
Outflow =	0.531 cfs @ 13.55 hrs, Volume= 28,920 cf, Atten= 93%, Lag= 88.0 min
Discarded =	0.428 cfs @ 10.45 hrs, Volume= 27,610 cf
Primary =	0.103 cfs @ 13.55 hrs, Volume= 1,309 cf

Routing by Stor-Ind method, Time Span= 0.00-72.00 hrs, dt= 0.05 hrs
Peak Elev= 2.50' @ 13.55 hrs Surf.Area= 5,388 sf Storage= 12,598 cf

Plug-Flow detention time= 223.5 min calculated for 28,899 cf (100% of inflow)
Center-of-Mass det. time= 223.5 min (978.5 - 755.0)

Volume	Invert	Avail.Storage	Storage Description
#1	0.00'	38,796 cf	Custom Stage Data (Prismatic) Listed below (Recalc)
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
0.00	5,000	0	0
1.00	5,000	5,000	5,000
2.00	5,000	5,000	10,000
3.00	5,776	5,388	15,388
4.00	7,056	6,416	21,804
5.00	8,464	7,760	29,564
6.00	10,000	9,232	38,796

Device	Routing	Invert	Outlet Devices
#1	Primary	2.00'	2.5" Vert. Orifice/Grate C= 0.600
#2	Discarded	0.00'	0.428 cfs Exfiltration at all elevations
#3	Primary	5.71'	20.0' long x 0.5' breadth Broad-Crested Rectangular Weir Head (feet) 0.20 0.40 0.60 0.80 1.00 Coef. (English) 2.80 2.92 3.08 3.30 3.32
#4	Primary	3.00'	6.0" Vert. Orifice/Grate C= 0.600

Discarded OutFlow Max=0.428 cfs @ 10.45 hrs HW=0.06' (Free Discharge)
↑ **2=Exfiltration** (Exfiltration Controls 0.428 cfs)

Primary OutFlow Max=0.103 cfs @ 13.55 hrs HW=2.50' (Free Discharge)
↑ **1=Orifice/Grate** (Orifice Controls 0.103 cfs @ 3.03 fps)
— **3=Broad-Crested Rectangular Weir** (Controls 0.000 cfs)
— **4=Orifice/Grate** (Controls 0.000 cfs)

Source: HydroCAD® Summary Report; HydroCAD is a register trademark of HydroCAD Software Solutions LLC. Used with permission.

10-year Design Storm Summary Report

Inflow Area =	108,900 sf, 100.00% Impervious, Inflow Depth = 5.09" for 10 year event
Inflow =	12.738 cfs @ 12.09 hrs, Volume= 46,216 cf
Outflow =	1.352 cfs @ 12.79 hrs, Volume= 46,216 cf, Atten= 89%, Lag= 42.2 min
Discarded =	0.428 cfs @ 9.00 hrs, Volume= 35,289 cf
Primary =	0.924 cfs @ 12.79 hrs, Volume= 10,927 cf

Routing by Stor-Ind method, Time Span= 0.00-72.00 hrs, dt= 0.05 hrs
Peak Elev= 3.81' @ 12.79 hrs Surf.Area= 6,817 sf Storage= 20,510 cf

Plug-Flow detention time= 248.3 min calculated for 46,184 cf (100% of inflow)
Center-of-Mass det. time= 248.3 min (995.3 - 747.0)

Volume	Invert	Avail.Storage	Storage Description
#1	0.00'	38,796 cf	Custom Stage Data (Prismatic) Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
0.00	5,000	0	0
1.00	5,000	5,000	5,000
2.00	5,000	5,000	10,000
3.00	5,776	5,388	15,388
4.00	7,056	6,416	21,804
5.00	8,464	7,760	29,564
6.00	10,000	9,232	38,796

Device	Routing	Invert	Outlet Devices
#1	Primary	2.00'	2.5" Vert. Orifice/Grate C= 0.600
#2	Discarded	0.00'	0.428 cfs Exfiltration at all elevations
#3	Primary	5.71'	20.0' long x 0.5' breadth Broad-Crested Rectangular Weir Head (feet) 0.20 0.40 0.60 0.80 1.00 Coef. (English) 2.80 2.92 3.08 3.30 3.32
#4	Primary	3.00'	6.0" Vert. Orifice/Grate C= 0.600

Discarded OutFlow Max=0.428 cfs @ 9.00 hrs HW=0.06' (Free Discharge)
↑ **2=Exfiltration** (Exfiltration Controls 0.428 cfs)

Primary OutFlow Max=0.924 cfs @ 12.79 hrs HW=3.81' (Free Discharge)
↑ **1=Orifice/Grate** (Orifice Controls 0.215 cfs @ 6.29 fps)
— **3=Broad-Crested Rectangular Weir** (Controls 0.000 cfs)
— **4=Orifice/Grate** (Orifice Controls 0.710 cfs @ 3.61 fps)

Source: HydroCAD® Summary Report; HydroCAD is a register trademark of HydroCAD Software Solutions LLC. Used with permission.

The peak, or primary, flow rates for the 2- and 10-year design storms are 0.103 cfs and 0.924 cfs, respectively, which are less than the allowable peak flow rates, i.e., 0.15 cfs and 1.32 cfs, respectively. Therefore, the stormwater runoff quantity control requirements are met.

In Step 4, the groundwater mounding analysis for the 100-year design storm shows that the elevated groundwater level resulting from the 100-year design storm runoff does not have an adverse impact to the proposed BMP. Since the 2- and 10-year design storms produce lower runoff volumes to be infiltrated by the BMP, the mounding heights will each be less than the mounding height produced by infiltration of stormwater runoff generated by the 100-year design storm. Therefore, the calculations using the *Hantush Spreadsheet* are not necessary.

Note that the outlet types and locations selected in the steps above are for demonstration purposes only. Design engineers may design other types of outlets at different elevations to meet the quantity control requirements and the standards for structural stormwater management measures in N.J.A.C. 7:8-5 or the municipal stormwater management ordinance(s), as appropriate.