Effect of the Underlying Groundwater System on the Rate of Infiltration of Stormwater Infiltration Structures.

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INTRODUCTION

It has often been reported that stormwater infiltration facilities do not have a good record for functioning properly with time. Usually this is attributed to siltation over the infiltrative surface. However, it could also be because of an often-overlooked aspect of the design of an infiltration system. That is, the effect of the hydraulic capacity of the underlying groundwater system to accept water. This could be limited because of a shallow high groundwater table, a shallow depth to impervious soil or ledge beneath the infiltrative layer, or an inadequate thickness of the underlying saturated zone.

What does “functioning properly with time” mean? First of all, it is important for an infiltration facility to be designed to fully drain or percolate within an acceptable time period. One of the reasons is for public acceptance. When an open infiltration basin holds runoff for many days or even weeks without dissipating, there is bound to be complaints and outcries from the neighbors. Secondly, and technically more important, the infiltration facility must drain sufficiently fast enough to provide capacity for a subsequent rainfall event. Also, it is important from a standpoint of long-term viability, that such facilities rest between events to prevent sealing of the soil pores and to maintain an adequate unsaturated soil zone between the bottom of the infiltration facility and the high groundwater for contaminant attenuation. Most authorities agree that infiltration facilities must be designed conservatively to do so.[1]

COMMON DESIGN PROCEDURES

To prepare a design to address these issues, one must determine (1) the ability of the bottom of the basin to percolate water or downward infiltration, (2) the ability of the underlying soil to transport the water to the surrounding groundwater system, and (3) the ability of the groundwater system to accept the water. This will require a detailed investigation of the site.[2]

A designer must properly address these criteria. Unfortunately, it is not uncommon to find a design proposed where the designer simply calculates the volume of runoff from the design storm event and creates a basin to hold that volume. No consideration is given to the length of time that the basin will require to completely drain. There is only the hopeful expectation that it will drain eventually. This, of course, results in an unacceptable design.

Most designers will determine the size of the infiltration basin by the hydrologic routing of the design storm into the basin, using a computer program, which uses the methodology of TR-20. The outflow rate of the basin is the value of downward infiltration which is calculated by using

Darcy's Law ($Q = kiA$), where k is the Soil Conductivity, (determined by a permeability test), i is the Hydraulic Gradient (normally 1), and A is the plan area of the facility. The vertical separation to groundwater may be taken from a government agency regulation or guideline. The time to drain will be calculated from the results.

However, this design approach does not take into account the volumetric capacity of the soil in the unsaturated zone or the saturated thickness of the underlying groundwater regime as determined by impervious soil strata. As the column of dry soil below the recharge area becomes filled during a rainstorm, depending upon the amount of vertical clearance, the groundwater may mound up to, into, and around the basin. The amount of the mounding is dependent upon the overall area of infiltration, the geometry of the infiltrative surface, the hydraulic conductivity of the soil, the fillable porosity of the soil, and the saturated thickness of the soil above bedrock or other impervious layer. Should the mounding of the groundwater reach the infiltration facility, this mounding can change the outward flow from vertically downward to horizontal. Once this happens, this causes both the hydraulic gradient and the infiltrative area to be drastically changed. As a result, the basin outflow rate can becomes only a small percentage of that calculated, and the unsaturated zone for contaminant removal is effectively eliminated. The basin may not drain quickly enough to have capacity for subsequent rainfall events. (SEE FIGURES 1A and 1B.)

ADDITIONAL CONCEPTS TO BE CONSIDERED

Once preliminary estimates of the basin shape, size, and general geometry have been made using the previously indicated procedures, a mathematical solution can be performed using one of several analytical methods that have been developed for determining mound height and shape, which are based upon the work of Hantush (1967) as well as others. While in the past, this type of a calculation was too cumbersome and unwieldy for most designers; it is now a relatively simple task with the use of a solution by microcomputer. From this solution, the designer can determine (1) whether or not mounding of the groundwater is indeed a significant factor in the rate of outflow time from the facility, (2) and whether or not there is sufficient unsaturated zone for contaminant removal.

If it is shown that the mound intercepts the elevation of the bottom of the infiltration facility, then the outflow area is only that of the sidewalls and then only at the downgradient location. The solution will suggest the actual hydraulic gradient that must be used, which will be only a fraction of the original estimate. Use of flow nets can also be considered.

The following hydrological and hydrogeologic parameters are required for all of the microcomputer solutions for the groundwater mound and must be determined by the designer.

1. Recharge Rate. (ft/day) during the recharge time. This must be simplified to be a constant value for the available Hantush method computer programs.
   Depth to High Groundwater. (ft)
2. Transmissivity (T) of the underlying saturated zone. (sq. ft. per day)
   This is the product of the soil conductivity (k) (ft/day) times the thickness of the saturated zone (ft). The soil conductivity is best determined by a standard borehole permeability test. While many designers attempt to use a simple percolation test for this parameter, it should be recognized that the same deficiencies of this test with respect to the design of septic systems

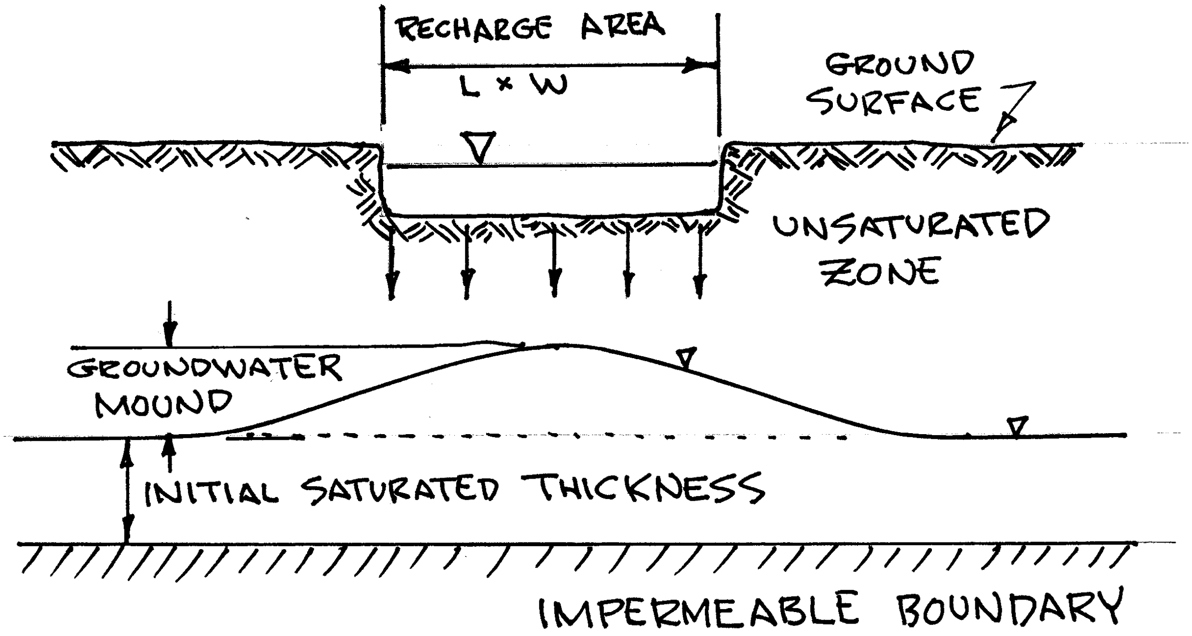


FIGURE RECHARGE BASIN w/ DEEP WATER TABLE

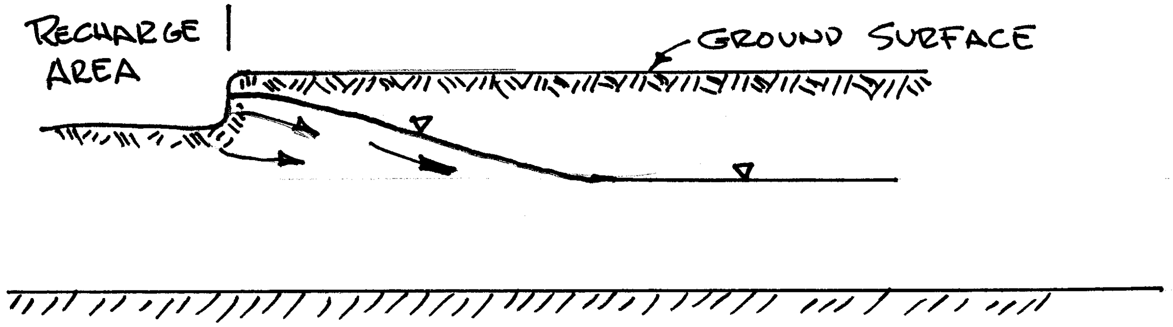


FIGURE RECHARGE BASIN IN SHALLOW WATER TABLE
OUTFLOW FROM DOWNGRADIENT SIDE ONLY

exist in this application. While some investigators have attempted to correlate the septic system percolation test to permeability, they may only be site specific.

3. Specific Yield or Drainable Porosity (dimensionless) which can range from 0.15 to 0.25 in most soils. This can be estimated from the available literature.
4. Length of Basin (ft)
5. Width of Basin (ft)
6. Depth to High Groundwater. (ft)

RECHARGE RATE:

One of the first steps in the design is to determine the runoff loading-rate to the infiltration facility. First it should be understood that this value is not the average rate of inflow over a 24-hour period. Most designers in southern New England today use the NRSCS Type III rainfall distribution. This model does not flow uniformly into the basin over a 24-hour period. To illustrate this, Figure 2a is an example of the runoff hydrograph of a Type III - NRSCS storm rainfall distribution over a 2.6 acres drainage catchment area with a time of concentration of about 15 minutes which can be typical of a developed area with significant impervious area. The volume of runoff from this storm is 27,550 cubic feet. Note that there is a peak flow over a relatively short period of time. Obviously, during that time period, the inflow to the basin surges and is much greater than the 24-hour average value. Figure 2b is a plot of the decimal fraction of the volume of runoff with respect to time. This plot shows that 80% of the storm volume occurs in about 5 hours between hour 11 and hour 16. It also shows that 60% of the storm volume occurs in a period of about 3 hours. Average recharge rate over either of these time periods is a more accurate representation of the design storm.

For this example, using the 80% scenario, the initial recharge area design has a plan area of 4588 square feet. The 5-hour average recharge rate will then be:

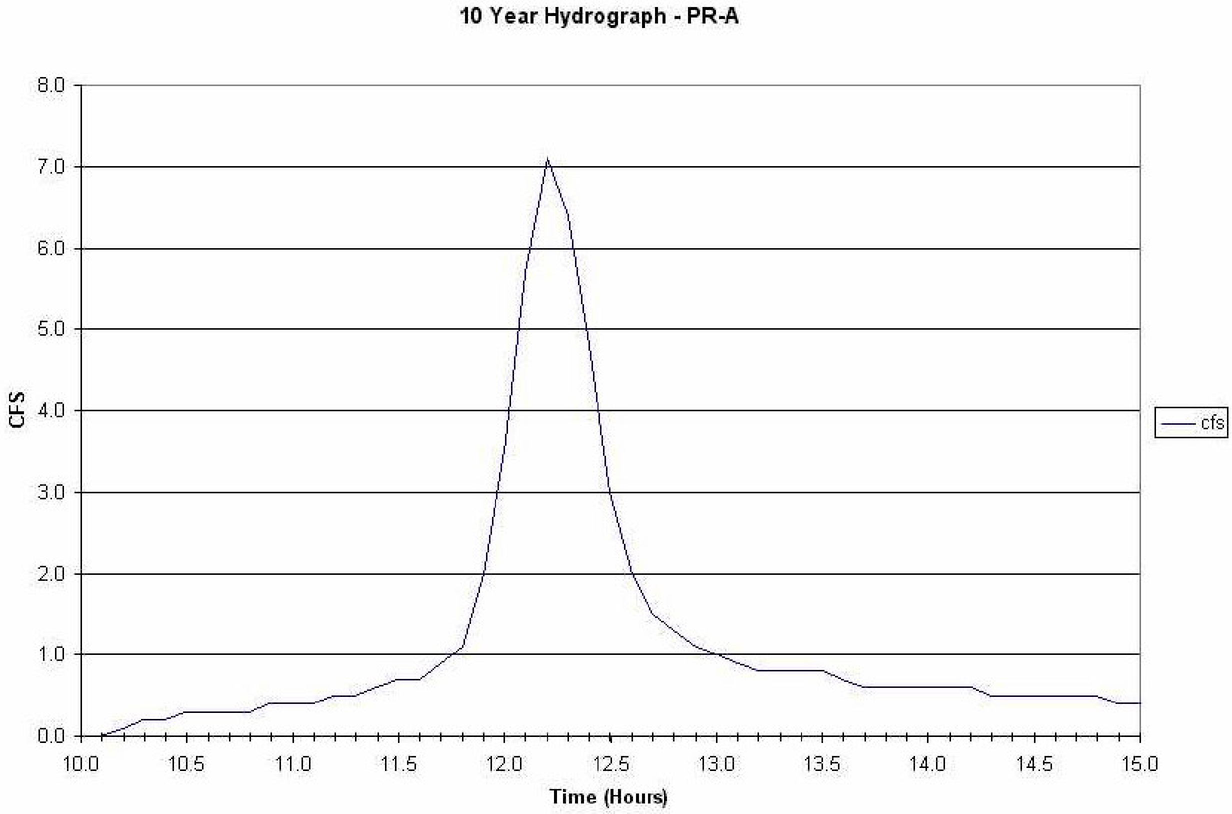
$$\frac{0.8 \text{ x } 27,\ 550 \text{ cubic feet}}{4588 \text{ sq. feet}} \text{ x } \frac{24}{5}$$

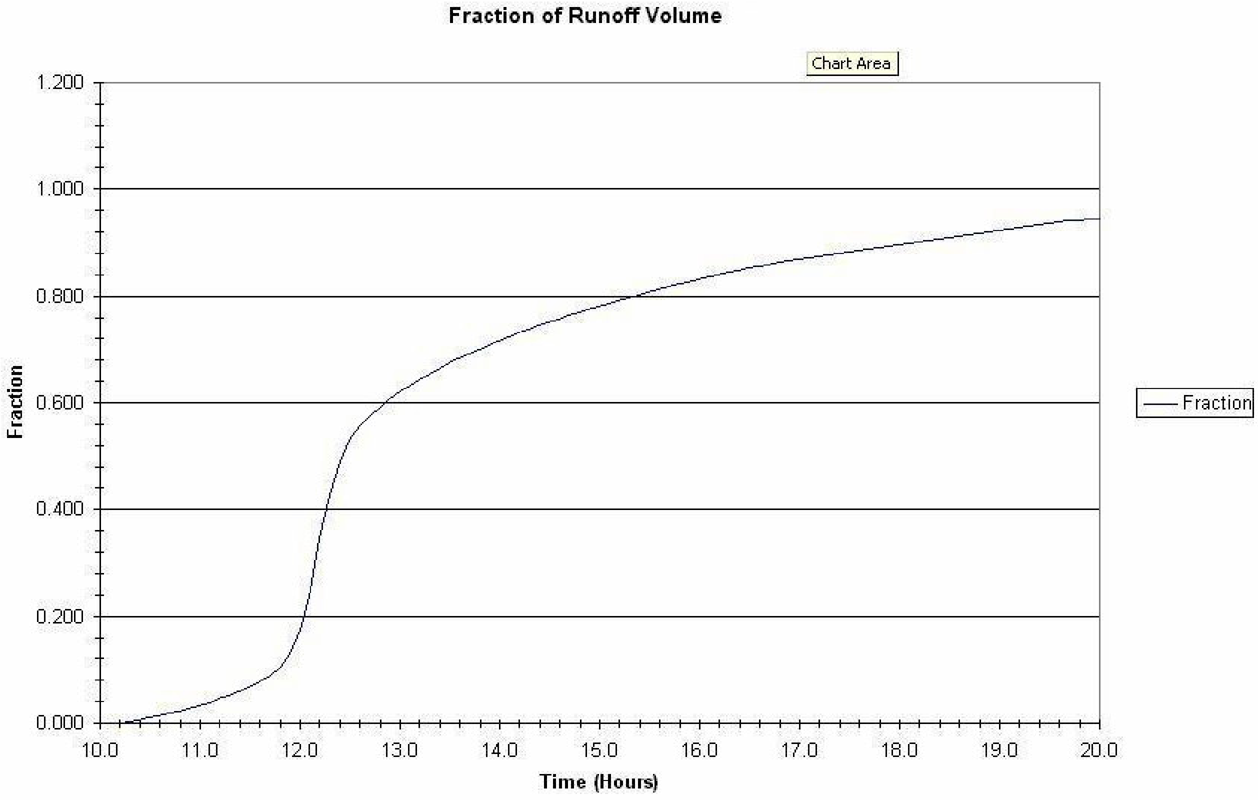
$$= \quad 23 \text{ feet per day over a 5 Hour Time Period.}$$

It should be understood that the recharge rate into the soil can not exceed the hydraulic conductivity

CALCULATION OF THE MOUND

An example of a computer model input and output is shown in Figures 3A and 3B for the example in Figure 2. Figure 3A calculates the height of the mound with respect to time. A mound of 7.3 feet is calculated by the time the recharge period ends. However, Figure 3B shows tat this is a marginal situation and indicates that, while there will be little unsaturated saturated zone, the use of Darcy’s formula will be valid for most of the recharge time as in Figure 1A. Should the mounding have reached the recharge basin sooner, the outflow rate to determine drain time would have to be re-calculated using the criteria as shown in Figure 1B.


10 Year Hydrograph - PR-A
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
CFS
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
Time (Hours)
cfs


Fraction of Runoff Volume
Chart Area
1.200
1.000
0.800
0.600
0.400
0.200
0.000
Fraction
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
Time (Hours)
Fraction

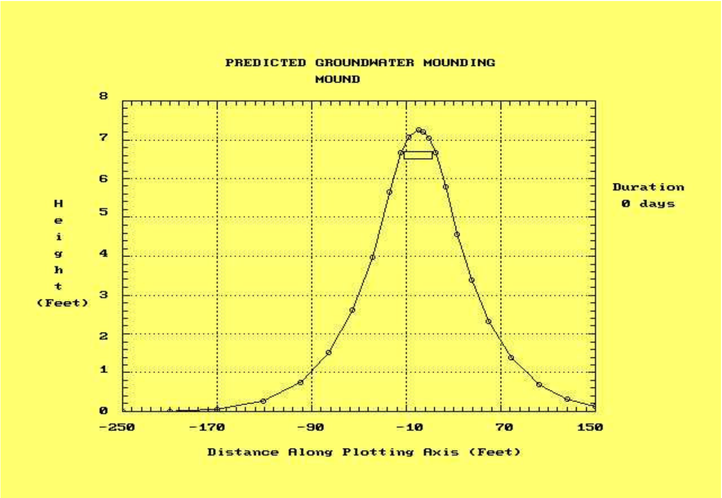
Groundwater Mounding Analysis (Hantush's Method using Glover's Solution) Mound on AXIS

INPUT PARAMETERS

Application rate: 23.0000 cFeet/day/sFeet
Duration of application: 0 days
Fillable porosity: 0.20
Hydraulic conductivity: 91.00 Feet/day
Initial saturated thickness: 30.0 Feet
Length of application area: 95 Feet
Width of application area: 48 Feet
No constant head boundary used
Plotting axis from Y-Axis: 90 degrees
Edge of recharge area:
positive X: 24 Feet
positive Y: 0 Feet
Total volume applied: 209.8D+02 cFeet

MODEL RESULTS

X (Feet)	Y (Feet)	Plot Axis (Feet)	Mound Height (Feet)
-250	-0	-250	0.00
-210	-0	-210	0.01
-170	-0	-170	0.06
-131	-0	-131	0.27
-99	-0	-99	0.76
-75	-0	-75	1.53
-55	-0	-55	2.61
-39	-0	-39	3.98
-24	-0	-24	5.65
-15	-0	-15	6.68
-8	-0	-8	7.08
0	0	0	7.25
5	0	5	7.19
9	0	9	7.04
15	0	15	6.68
23	0	23	5.78
33	0	33	4.55
45	0	45	3.39
60	0	60	2.33
78	0	78	1.40
102	0	102	0.69
126	0	126	0.32
150	0	150	0.14



Groundwater Mounding Analysis (Hantush's Method Using Glover's Solution)

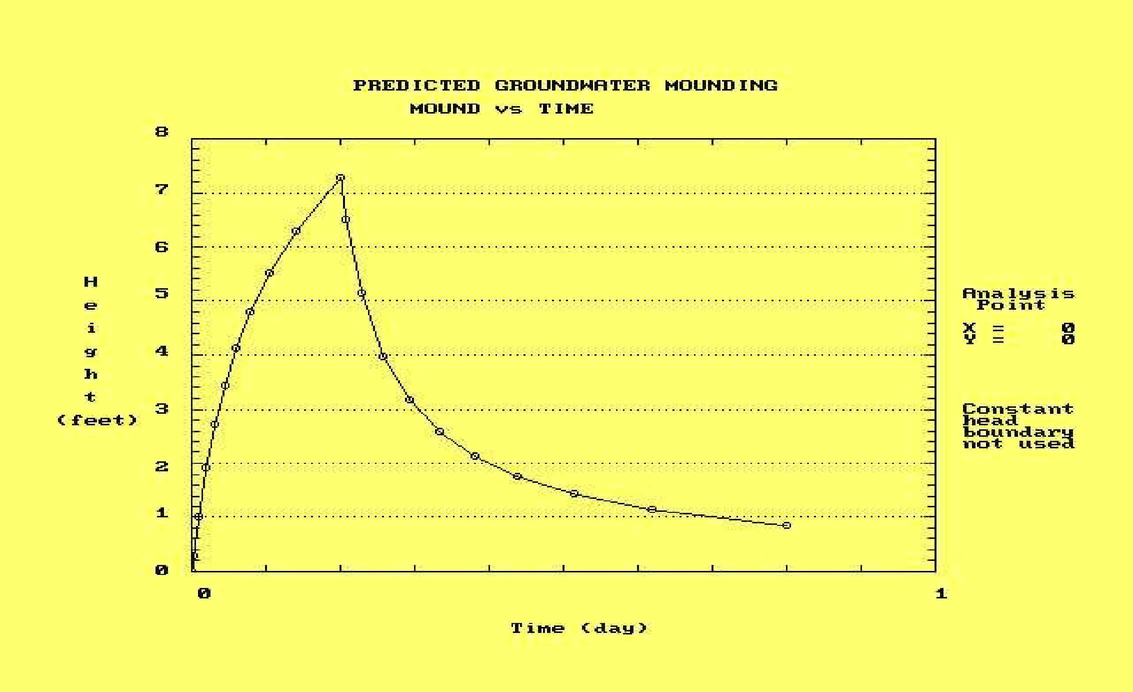
MOUND vs TIME

INPUT PARAMETERS

Application rate: 23.0000 cfeet/day/sfeet
Duration of application: 0.2 days
Total simulation time: 0.8 days
Fillable porosity: 0.20
Hydraulic conductivity: 91.00 feet/day
Initial saturated thickness: 30.0 feet
Width of application area: 48 feet
Length of application area: 95 feet
No constant head boundary used
Groundwater mounding @
X coordinate: 0 feet
Y coordinate: 0 feet
Total volume applied: 211.1D+02 cfeet

MODEL RESULTS

Time (day)	Mound Height (feet)	Time (day)	Height (feet)
0.0	0.00	0.2	6.51
0.0	0.30	0.2	5.16
0.0	1.00	0.3	3.96
0.0	1.91	0.3	3.17
0.0	2.71	0.3	2.59
0.0	3.44	0.4	1.77
0.1	4.13	0.5	1.45
0.1	4.81	0.6	1.15
0.1	5.51	0.8	0.86
0.1	6.29		
0.2	7.28		



REDUCING THE GROUNDWATER MOUND

If the groundwater mound penetrates the recharge basin and causes outflow difficulties, there are ways to prevent it as follows.

1. **Change the Basin Geometry** – In general, there is a higher groundwater mound underneath a recharge basin with square, circular, hexagonal, and triangular shapes than when compared with a rectangular shape basin. In other words, a long narrow recharge basin will have a smaller mound than a square one. For example, for this example, if this 4560 square feet recharge basin had been 10 feet by 456 feet, the mound would be 2.4 feet. If it were 20 feet by 228 feet, the mound would have been 4.5 feet.
2. **Increase the Plan Area**. For example, if this basin plan area were increased 50%, the mound would be reduced from 7.3 feet to 6.2 feet.
3. **Reduce the Depth of the Recharge Facility** – Underground recharge are often designed to be up to 5 to 6 feet deep using various configurations of plastic and concrete chambers. A shallower depth should be considered to raise the elevation above the elevation of the mounded water table.

ALLOWABLE DRAIN TIME

Also to be considered in the design procedure, is the allowable time required to drain so that a basin will be able to handle consecutive-day storm events. It is reasonable to expect that where complete infiltration of runoff must be performed and no other outlet is available, the system should be designed to completely drain in 24 hours for the 10-year event or smaller and 72 hours for the 100-year storm.

CONCLUSIONS

A straightforward method of design for an infiltration facility is available using an analytical model microcomputer solution. This can provide greater assurance that the soil and groundwater conditions are amenable to the infiltration of stormwater. The effect of the groundwater mound on outflow rate and contaminant removal can be easily evaluated. By placing the bottom infiltrative soil interface sufficiently above the high groundwater when mounded, optimal contaminant removal can be provided. The determination of the outflow rate will be more reliable, so that the time to drain will be able to accommodate subsequent rainfall events, and will also not cause a safety hazard from too lengthy a detention time in residential subdivisions. The designer can readily evaluate and compare the use of alternative shapes and geometry to minimize the adverse effects that the groundwater mound will impact.

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