

6. GROUNDWATER RECHARGE

This chapter presents the standards, data and procedures necessary to meet the groundwater recharge requirements of the NJDEP Stormwater Management rules at N.J.A.C. 7:8. According to these Rules, a “major development” project, which is one that disturbs at least 1 acre of land or creates at least 0.25 acres of regulated impervious surface, 0.25 acres of regulated motor vehicle surface, or a combination of regulated impervious surface and regulated motor vehicle surface that totals 0.25 acres or more must include green infrastructure (GI) stormwater management measures that prevent the loss of groundwater recharge at the project site. This requirement is included in the Rules because the loss of groundwater recharge can adversely impact the health of streams and wetlands and the yield of water supply wells. Urban redevelopment and certain linear development projects are exempt from the groundwater recharge requirements, while waivers may be obtained under certain conditions for public roadway, railroad and pedestrian walkway enlargements. Complete details can be found in Subchapter 5 of the Stormwater Management rules.

Specifically, the Stormwater Management rules require that a proposed major land development comply with one of the following two groundwater recharge requirements:

- Requirement 1:** Demonstrate through hydrologic and hydraulic analysis that the site and its stormwater management measures maintain 100 percent of the average annual pre-construction groundwater recharge volume for the site; or
- Requirement 2:** Demonstrate through hydrologic and hydraulic analysis that the increase of stormwater runoff volume from pre-construction to post-construction for the projected two-year storm, as defined and determined pursuant to N.J.A.C. 7:8-5.7(d), is infiltrated.

The Stormwater Management rules allow the site designer to select which requirement to follow. The Rules also state that compliance with either of the above alternative requirements must be demonstrated through hydrologic and hydraulic analysis. Regardless of which alternative requirement is selected, such an analysis will generally begin with a computation of the existing (or pre-developed) hydrologic conditions at the proposed development site. In the case of Requirement 1, these conditions will focus on the annual amount of groundwater recharge that occurs at the site under pre-developed conditions while, for Requirement 2, the focus will instead be on the pre-developed volume of projected 2-year site runoff.

These computations will then be followed by similar ones for the proposed (or post-developed) conditions at the site. A comparison of the results of either of these pre- and post-development computations will then yield the annual volume of groundwater that must be recharged (Requirement 1) or the projected 2-year storm runoff volume that must be infiltrated (Requirement 2) through one or more recharge or infiltration best management practices (BMPs).

Finally, once the analysis of pre- and post-development conditions has established the need for recharge (Requirement 1) or infiltration (Requirement 2) BMPs, the hydrologic and hydraulic analysis would next focus on the actual design of such facilities. This process would include answering such questions such as:

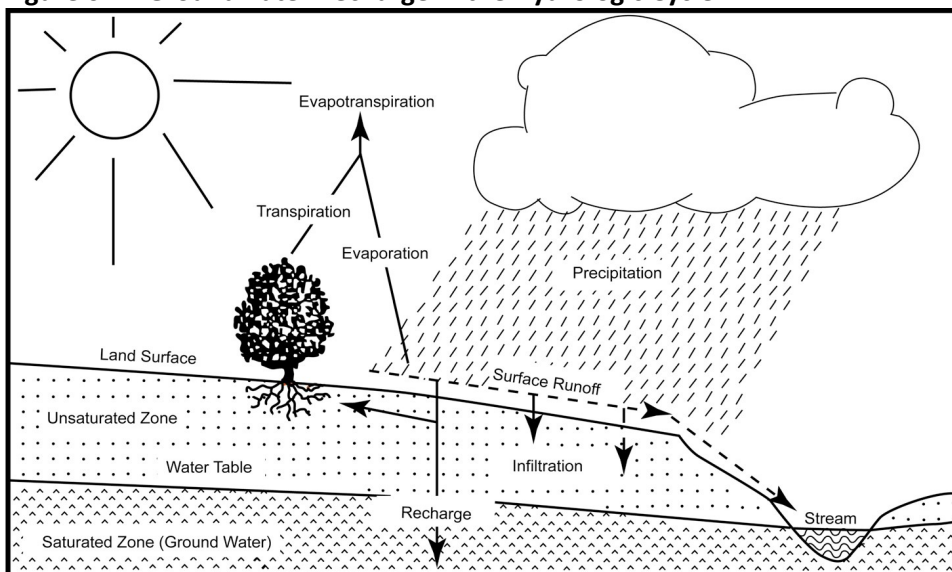
- Should the required recharge or infiltration be achieved at a single BMP or several located throughout the development site?
- Should the BMPs be located above or below ground?
- Which portions of the development site will contribute stormwater runoff to the BMPs?
- What are the BMP dimensions required to capture stormwater runoff?
- Where should the BMPs be located on the site relative to buildings, septic systems, property lines and other sensitive areas?

This chapter presents the groundwater recharge information necessary to perform the hydrologic and hydraulic analysis required for Requirement 1 (maintaining pre-developed annual recharge volumes). Information necessary for the analysis required for Requirement 2 (infiltrating the increase in projected two-year runoff volume) is presented in *Chapter 5: Stormwater Management Quantity and Quality Standards and Computations*. Design information regarding recharge and infiltration BMPs can be found in this chapter and *Chapter 9: Green Infrastructure BMPs*.

Fundamentals

In both the NJDEP Stormwater Management rules and this manual, groundwater recharge is defined as precipitation that infiltrates into the soil and is not evapotranspired. Instead, the infiltrated precipitation moves downward to a depth below the root zone of the surface vegetation, where it cannot be removed by that vegetation through uptake and evapotranspiration. At such a depth, it is considered available to enter the soil's saturated zone and become groundwater. The role of groundwater recharge in the overall hydrologic cycle is illustrated in Figure 6-1 below.

Figure 6-1: Groundwater Recharge in the Hydrologic Cycle



Source: New Jersey Geological Survey Report GSR-32.

According to the New Jersey Geological Survey (NJGS):

The potential for natural groundwater recharge begins with precipitation (rain, snow, hail, sleet). Some of the precipitation never seeps into the soil, but instead leaves the system as surface runoff. The water that seeps into the soil is infiltration. Part of the water that does infiltrate is returned to the atmosphere through evapotranspiration. Evapotranspiration refers to water that is returned to the atmosphere from vegetated areas by evaporation from the soil and plant surfaces and soil water that is taken up by plant roots and transpired through plant leaves or needles. Infiltrated water that is not returned to the atmosphere by evapotranspiration moves vertically downward and, upon reaching the saturated zone, becomes ground water. This ground water could be in a geologic material that is either an aquifer or non-aquifer, depending on whether it can yield satisfactory quantities to wells. (NJGS GSR-32)

In addition to supplying water to wells, groundwater can also provide base flow to streams, wetlands and other water bodies, directly affecting the ecology and geomorphology of these resources.

The potentially adverse impacts of land development on groundwater recharge have long been recognized. From the description presented above, it can be seen that land development activities that either cover permeable soils with impervious surfaces or reduce the soils' permeability through disturbance and compaction will reduce the rate of groundwater recharge that occurs under pre-developed site conditions. As noted above, such reductions in groundwater recharge can adversely impact streams, wetlands and other water bodies by reducing the volume and rate of base flow to them. Reductions in groundwater recharge to aquifers can also adversely impact the yield of water supply wells. As a result, the New Jersey Stormwater Management rules require that pre-developed groundwater recharge rates be maintained at land development sites under post-development conditions.

Computing Groundwater Recharge

Overview

As described above, the groundwater recharge requirements of the NJDEP Stormwater Management rules can be met by demonstrating that the average volume of precipitation that is annually recharged to the groundwater at a major land development site under pre-developed conditions will be maintained following site development. As described in detail below, this can be achieved through a combination of natural recharge over the developed site's pervious surfaces and artificial recharge through groundwater recharge BMPs constructed at the site. The BMP volume is based on an average annual distribution of runoff producing precipitation events at the site, the impervious drainage area to the BMP and the losses that may occur to the infiltrated runoff before it can travel below the root zone of surrounding vegetation and become groundwater.

The data and analytic procedures necessary to meet these requirements have been developed by the New Jersey Department of Environmental Protection (NJDEP) with assistance from the New Jersey Geologic Survey (NJGS), the U.S. Geologic Survey (USGS) and professional consultants and have been compiled into the New Jersey Groundwater Recharge Spreadsheet (NJGRS), a Microsoft Excel-based computer spreadsheet program. The NJGRS is intended for use by site planners, designers, engineers and reviewers to determine average annual groundwater recharge amounts under both pre- and post-development site

conditions and to design the groundwater recharge BMPs necessary to maintain 100 percent of the predeveloped site's annual groundwater recharge rate. Information regarding the NJGRS, including a detailed User's Guide, an example problem and instructions on how to download the NJGRS from the NJDEP stormwater management website, is presented below. Details of the program's theoretical basis, equations and supporting databases are also summarized.

In general, the analytic procedures utilized by the NJGRS to achieve compliance with the groundwater recharge requirements of the Stormwater Management rules (described as Requirement 1 above) can be summarized by the following computational steps:

1. Compute the average amount of annual groundwater recharge occurring over the land development site under pre-developed site conditions.
2. Compute the average amount of annual groundwater recharge occurring over the land development site under post-developed conditions.
3. Compute any resulting annual groundwater recharge deficit by subtracting the post-developed annual recharge amount in Step 2 from the pre-developed annual amount in Step 1. This deficit represents the average annual amount of groundwater recharge that must be achieved at the development site through structural groundwater recharge BMPs.
4. Determine the storage volume and related dimensions of the groundwater recharge BMP that will be required to satisfy the average annual groundwater recharge deficit computed in Step 3 above. In doing so, the BMP volume must be based on the average annual distribution of runoff-producing precipitation events at the development site, the size of the BMP's contributory drainage area over which these events will occur (and from which runoff will be collected or captured for recharge) and the infiltration, evapotranspiration and other losses that may occur to the recharged runoff in the BMP before it can actually enter the groundwater.

Theoretical Basis of Computations

Computation of the average annual groundwater recharge at a land development site under either pre- or post-developed conditions (as described above in Steps 1 and 2) can be performed with the New Jersey Groundwater Recharge Spreadsheet (NJGRS). This Microsoft Excel-based spreadsheet is based on the data and computational procedures contained in the 1993 *Geological Survey Report GSR-32: A Method for Evaluating Ground Water Recharge Areas in New Jersey* developed by the NJGS. As described in the report, GSR-32 utilizes precipitation, soil, land cover and climate data and rainfall-runoff and mass balance computations to estimate average annual groundwater recharge amounts at sites within any New Jersey municipality under a variety of surface and development conditions. All pertinent GSR-32 databases and computational algorithms have been incorporated into the NJGRS. As such, use of the NJGRS is governed, in part, by the assumptions and limitations of GSR-32.

Design of the required recharge BMP (as described in Step 4 above) to compensate for the developed site's groundwater recharge deficit (as described in Step 3 above) can also be performed with the NJGRS. The design computations in the NJGRS are based on a number of analytic techniques and databases. Conceptually, a groundwater recharge BMP will recharge the runoff it receives from its drainage area for all storms up to a particular precipitation depth, which can be referred to as the BMP's groundwater recharge design storm. While the recharge BMP will also receive runoff from larger storms, it will only

recharge that portion of the runoff that equals the Recharge Design Storm runoff. The remaining runoff from these larger storms will overflow or otherwise bypass the BMP. It is important to note that the range of precipitation depths typically involved in the design of a groundwater recharge BMP are relatively small when compared to depths associated with runoff quality or quantity control. As a result, the NJGRS requires that the entire drainage area to a recharge BMP be impervious, since pervious surfaces would typically not be able to produce a sufficient amount of rechargeable runoff from such small precipitation depths.

Assuming that all of the precipitation falling in a recharge BMP's impervious contributory drainage area can be collected and recharged (i.e., no runoff, infiltration or recharge losses), computation of the BMP's Recharge Design Storm depth can be conceptually illustrated with the following conversion equation:

$$\begin{array}{ccccccc} \text{Total Average} & & \text{Annual Sum of} & & & & \\ \text{Annual Recharge} & = & \text{Recharge Design and} & + & \left[\begin{array}{cc} \text{Recharge} & \text{Number of} \\ \text{Design Storm} & \text{Larger} \\ \text{Depth} & \text{Storms} \end{array} \right] \\ \text{Deficit} & & \text{Smaller Storm} & & & & \\ & & \text{Depths} & & & & \end{array}$$

The above equation shows that, with appropriate precipitation data and ignoring all losses, the total annual recharge deficit at a land development site can be converted to the sum of two precipitation amounts, both of which are based on a single groundwater recharge design storm. The first amount is the sum of all storm depths up to and including the Recharge Design Storm that would occur at the site in an average year. The second amount is the product of the Recharge Design Storm depth times the number of larger storms that would also occur at the site in that same average year.

Unfortunately, most of the ease and simplicity of the conversion equation shown above is gained through its two assumptions: that appropriate precipitation data is available and that all of the precipitation falling on the BMP's impervious contributory drainage area can be recharged without loss. In reality, compiling such precipitation data for a specific land development site requires considerable effort and resources and must be repeated for each new development site. In addition, precipitation losses will occur and must be taken into consideration in the design of a recharge BMP. As noted above, these losses, which will vary with the total precipitation depth, include those occurring in the conversion of precipitation to runoff, including surface storage, evaporation and infiltration through cracks, joints and seams in the contributory drainage area's impervious surface. Further losses will occur once the runoff is delivered to the recharge BMP, primarily in the form of evapotranspiration by the vegetation above, beneath and/or adjacent to the BMP. Further complications arise when one attempts to estimate these variable losses. While equations exist to predict such losses for individual storm events, there are none readily available that can do so for an annual precipitation depth.

The NJGRS addresses these problems in several ways. Regarding the need for appropriate precipitation data for all possible development site locations in New Jersey, the NJGRS developers compiled and analyzed 52 years of daily precipitation data collected at 92 precipitation stations throughout New Jersey between 1948 and 1999. To ensure a proper database, only precipitation depths greater than 0.04 inches were considered, since this depth was considered the minimum amount necessary to produce runoff from impervious surfaces. All daily values at each station were sorted for each year and then averaged over the 52 year period of record. Next, all values with the same rank were averaged across all 92 stations to produce an average annual series of 79 precipitation events for the state. Finally, this series was normalized by dividing each event value by 46.32 inches, which was the average annual precipitation for the 92 stations. This produced an average annual series of 79 precipitation events, expressed as a

percentage of total annual precipitation, that are analyzed individually by the NJGRS to compute the runoff, infiltration and recharge losses and the resulting annual groundwater recharge achieved by a recharge BMP at a land development site in any New Jersey municipality.

This average annual series of precipitation events for New Jersey is shown below in Figures 6-2 and 6-3. Figure 6-2 depicts the precipitation depth, expressed as a percentage of total average annual rainfall, of each event in the series in ascending order, while Figure 6-3 depicts, also in ascending order, the events' cumulative percentage of the average annual rainfall. More detailed information about each specific event in the average annual series is contained in the NJGRS' databases. The average annual precipitation series shown in Figure 6-2 is used by NJGRS to produce a site-specific, year-long series of design storms by multiplying each event value in the series by the average annual precipitation in the municipality where the recharge BMP is located. Since the NJGRS also contains average annual precipitation values for each New Jersey municipality, the NJGRS user can generate this site-specific average annual design series simply by specifying the municipality and county in which the development site is located.

Figure 6-2: Average Annual Precipitation Series in NJGRS

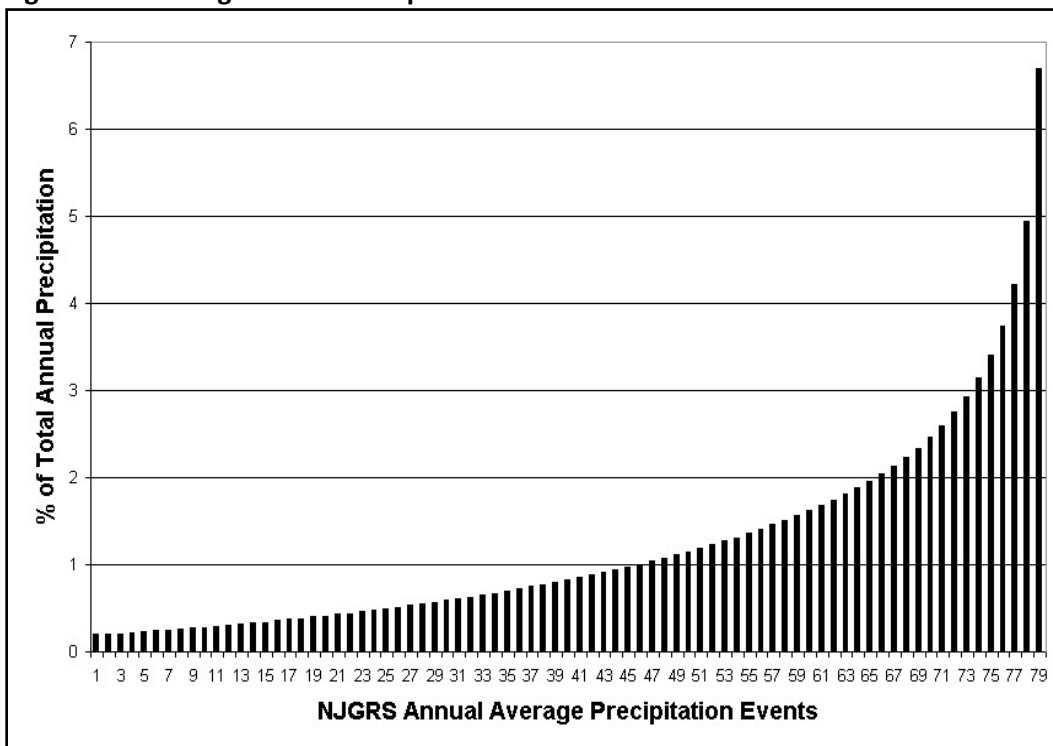
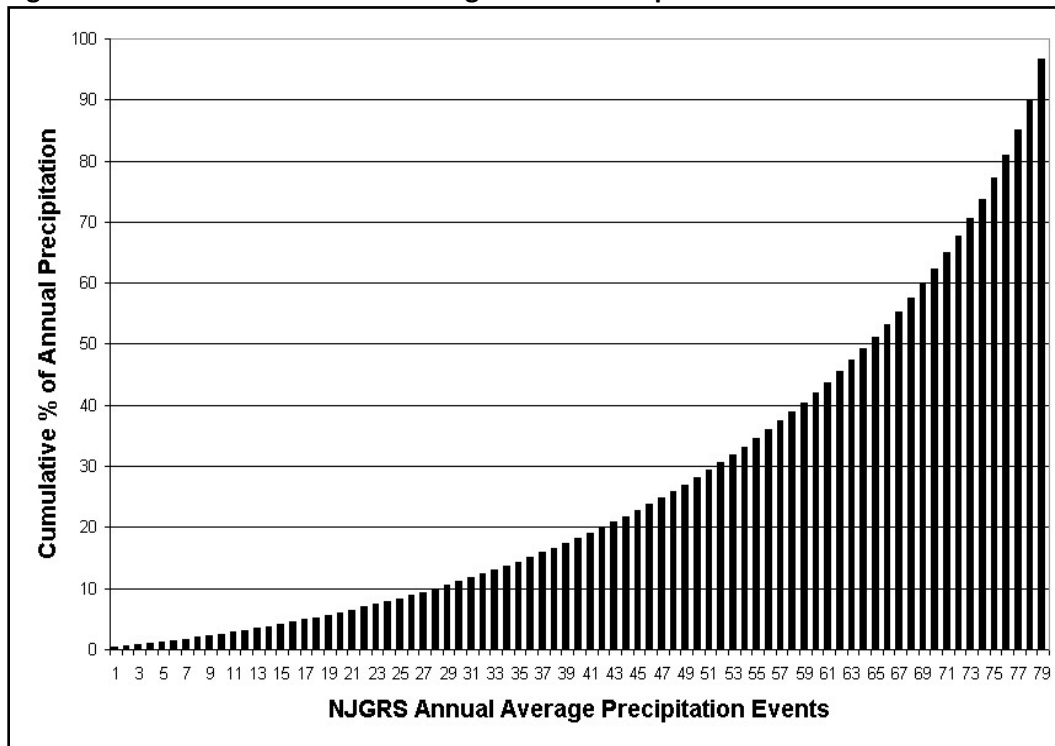


Figure 6-3: Cumulative Total of Average Annual Precipitation Series in NJGRS



Once an average annual design series is computed for the specific recharge BMP site, the NJGRS next addresses the problem of precipitation losses. As noted above, all of the possible losses that will occur, from the time the precipitation falls on the BMP's impervious contributory drainage area to when the recharged water moves below the root zone of the vegetation in or adjacent to the BMP, must be accounted for in order to accurately compute the actual volume that will be recharged. Such losses can include infiltration and surface storage losses on the drainage area surface as the precipitation is converted into runoff, as well as evapotranspiration and infiltration losses as the runoff is converted to recharge within the BMP itself. To compute runoff losses, the NJGRS uses one of three equations depending upon the total depth of the event. These equations are applied to each event in the average annual design series to compute the resultant runoff for each one. This resultant runoff is then used in additional equations that estimate the losses that will occur for each design event once the runoff enters the recharge BMP.

When computing runoff losses for design event depths less than 0.0408 inches, the NJGRS assumes that the entire precipitation depth is consumed by surface storage, infiltration and other losses and no runoff is produced.

For design event depths between 0.04 and 1.25 inches, the NJGRS uses the following equation to compute runoff:

$$Q = 0.95 \times (P - 0.0408) \times 0.90$$

where:

Q = Runoff Depth, in

P = Precipitation Depth, in

For design event depths greater than 1.25 inches, the NJGRS uses the NRCS Runoff Equation with a Runoff Curve Number (CN) of 98:

$$Q = \frac{(P - 0.04)^2}{(P + 0.16)}$$

where:

Q = Runoff Depth, in

P = Precipitation Depth, in

As noted above, the resultant runoff depth for each design event is then applied to specialized equations developed specifically for the NJGRS to estimate the losses that will occur to the runoff after it is stored in the recharge BMP. These losses will depend upon a number of factors, including the climate at the development site, the specific vegetation and soil conditions at the recharge BMP location and the depth of the BMP relative to the vegetation's root zone. A complete description of the loss equations used in the NJGRS is presented in the program's User's Guide. By subtracting these losses from the stored runoff, the amount of runoff that is actually recharged for each design event is computed. The NJGRS then adds up the recharge amounts from each design event to obtain a total annual recharge amount, which is then compared with the average annual recharge deficit created by the development to determine whether the recharge BMP's performance is adequate. Similar to the computation of the average annual design series described above, the NJGRS' loss computations are performed automatically each time the user provides new development site or recharge BMP data and then requests a BMP design update. The NJGRS will then either evaluate the performance of the proposed recharge BMP or, if requested, compute the effective BMP storage depth or surface area necessary to offset the development's annual recharge deficit.

New Jersey Groundwater Recharge Spreadsheet (NJGRS)

General Instructions

As described above, the New Jersey Groundwater Recharge Spreadsheet (NJGRS) is a Microsoft Excel-based computer spreadsheet program. It is typically used in a two-step procedure, utilizing first the Annual Recharge worksheet and then the BMP Calculations worksheet in the program. During the first step, the average annual groundwater recharge amounts at the site under pre- and post-developed conditions are estimated based upon site data provided by the user. From these estimates, the program computes the average annual groundwater recharge deficit caused by the site development that must be offset by a groundwater recharge BMP. During the second step, this recharge BMP is sized based upon user-specified information regarding both the BMP and its location at the development site. General information regarding each step is provided below. Specific information about the program's use and computation methods are provided in the NJGRS User's Guide, which is presented at the end of this chapter.

It should be noted that, as a spreadsheet, certain cells of the program are reserved for user input while others provide intermediate and final results. All user input cells are shaded with a tan color while spreadsheet output cells are shaded with gray. Only the tan, user-input cells should be changed. In addition, the spreadsheet contains several combinations of commands known as macros. While these macros are essential to the spreadsheet's operations, they are unsigned and, as such, their presence may conflict with the Excel program's security settings in the user's computer. These conflicts would be

identified to the user through an error or warning message immediately after opening the NJGRS. If such conflicts are encountered, they can usually be addressed by setting the Excel macro security level to Medium. *The user should determine whether this level of security is acceptable for their own system.* The user would then be prompted to enable the NJGRS macros each time the spreadsheet is opened.

Finally, upon completing use of the NJGRS for a specific project, the user will be asked whether the changes made during use should be saved. While such decisions are at the discretion of each user, it may be helpful for training purposes to retain the spreadsheet original settings, which match those in the NJGRS User's Guide. In this case, a copy of the revised NJGRS with project specific data entered can be saved with a project-specific name using the *Save As* command under *File* on the Excel command line.

Annual Recharge Worksheet

Annual groundwater recharge at a land development site under both pre- and post-developed (or existing and proposed) site conditions can be estimated using the Annual Recharge worksheet in the NJGRS. As discussed above, these estimates are based on the methodology contained in *Geological Survey Report GSR32: A Method for Evaluating Ground Water Recharge Areas in New Jersey* (GSR-32) developed by the New Jersey Geological Survey. In general, use of this worksheet requires the following user input:

1. Name of municipality and county in which the project site is located (Cell C3). Upon input of this data through use of a drop-down list, the NJGRS will immediately display the average annual precipitation and climate factor for the site's municipality from the GSR-32 databases in the NJGRS. The user can also specify a project name, description and date in the lines provided (Cells K1, K2 and K3).
2. Land use and land cover (LULC) data for the site under both pre- and post-developed conditions. This data will consist of the area (in acres), LULC characteristics and soil series name for up to 15 land segments of the pre- and post-developed site. The NJGRS will issue a warning message if the total area specified under pre-developed conditions is different than post-developed. The LULC data and soil series names are listed in a drop-down list next to the respective input cells. It is important to note that the LULC categories in the drop-down list are based on those contained in Table 2-2 of the NRCS Technical Release 55 – Urban Hydrology for Small Watersheds. For a correlation between these LULC categories and those in GSR-32, upon which the NJGRS is based, see Table 6-1 below.

Table 6-1: NJGRS/TR-55 and GSR-32 LULC Descriptions

NJGRS/TR-55 LULC Descriptions	GSR-32 LULC Descriptions
Brush	Brush
Gravel, Dirt	Unvegetated
Impervious Areas	Un-landscaped Developed
Meadow, Pasture, Grassland or Range	Agricultural – Pasture
Open Space	Landscape Open Space
Residential 1 to 2 Acre	1 - 2 Acre Lots
Residential 1/2 to 1 Acre	1/2 - 1 Acre Lots
Residential 1/3 to 1/4 Acre	1/8 - 1/2 Acre Lots
Residential 1/8 Acre or Less	1/8 Acre Lots
Row Crop	Agricultural – General
Small Grain or Legumes	Agricultural – Cropland, Legume
Urban Districts	Landscaped Developed
Woods	Woods
Woods – Grass Combination	Wooded – General

As noted in the NJGRS User’s Guide, it is important to specify a site’s LULC characteristics as accurately as possible. Therefore, while a 1/4 acre residential site could be specified in the NJGRS by the “Residential 1/3 to 1/4 Acre” LULC description in Table 6-1, it is generally more accurate to divide the site into impervious and pervious areas and specify each as a separate land segment in the NJGRS. For example, at a 1/4 acre residential site with a total area of 10 acres consisting of 40 percent connected impervious and 60 percent grassed surfaces and a single soil series, it would be more appropriate to specify the site’s LULC characteristics in the program as a separate 4 acre impervious area land segment and a 6 acre open space land segment. This separation of connected impervious and pervious areas is similar to the technique for computing runoff volume using the NRCS methodology in Chapter 5. It should be noted that the total impervious area for post-developed conditions displayed in Cell M23 of the Annual Recharge worksheet will be based only on those post-developed land segments specified as impervious.

When using the above technique, it should be noted that if any impervious areas at a development site are unconnected (see *Chapter 5* for complete details and requirements), the area used in the impervious surface designations described above for these unconnected areas should be one half of the actual area. For example, if a site has 3 acres of directly connected impervious surface, but 2 acres of unconnected impervious area, the total impervious area specified in the NJGRS can be $3 + (0.5)(2)$ or 4 acres. This 50 percent reduction in the size of unconnected impervious areas accounts for the runoff re-infiltration that can occur downstream of such areas and is consistent with the runoff computations for such areas contained in TR-55. To keep the total site area correct, the user should remember to specify the “remainder” of the unconnected impervious area as a pervious one with the appropriate soil series and LULC based upon the actual pervious area downstream of the unconnected impervious area.

It should also be noted that if a proposed recharge BMP will have a specific location within a land development site with similarly specific LULC and soil characteristics, that portion of the site should be specified as a separate land segment on the Annual Recharge worksheet. This is true even if that segment will be covered with an impervious surface. Doing this will allow the NJGRS to more accurately compute the losses and resultant recharge at the BMP. More details are presented below in the NJGRS User's Guide, including the need to specify this segment on the BMP Calculation worksheet.

From the above, it can be seen that the more generalized Residential and Urban District LULC descriptions in Table 6-1 above should be used only for general planning studies of groundwater recharge requirements, particularly at sites with multiple lots of similar size and impervious coverage where each lot will have a separate groundwater recharge BMP. Since the soil series in which each BMP will be located may vary from lot to lot, the general LULC descriptions can be used to compute typical or general groundwater recharge requirements and BMP dimensions for the entire site. These general values can then be refined on a lot by lot basis during later, more detailed project phases with specific lot and BMP information.

Finally, in accordance with NJGS Report GSR-32, which is the basis of the NJGRS, zero recharge volume will be computed for any land segment specified for either pre- or post-development conditions that contain soils that are hydric. See Report GSR-32 for more details.

BMP Calculation Worksheet

The dimensions of a groundwater recharge BMP can be either determined or tested using the BMP Calculations worksheet in the NJGRS. This worksheet can be used to calculate the effective depth required at a recharge BMP if the impervious contributory drainage area and BMP area are specified. Conversely, the worksheet can also be used to calculate the required area of the BMP if the drainage area and effective BMP depth are specified. Finally, the BMP Calculations worksheet can be used to analyze a specific recharge BMP with a certain area and effective depth to see what amount of annual groundwater recharge it can provide.

As explained in the NJGRS User's Guide, it is critical that the surface area of a recharge BMP (variable ABMP) be specified in the program as accurately as possible. This is because the program uses the ratio of the BMP's contributory drainage area and surface area to determine the resultant depth of runoff in the BMP for each storm event analyzed. In addition, a recharge BMP's effective depth (variable dBMP) represents the maximum equivalent water depth that can be achieved in the BMP before overflow begins. Therefore, if the proposed recharge BMP will consist, for example, of a subsurface, vertical-walled chamber, dBMP will simply be the maximum achievable depth before the chamber is full and overflow occurs. However, if the proposed BMP will be filled with broken stone or other suitable material, dBMP will be the product of the BMP's actual or physical depth and the void ratio of the fill material.

For recharge BMPs that consist of a combination of filled and open areas (e.g., a perforated pipe within a stone filled trench) or for irregular-shaped BMPs with nonvertical sides, dBMP can be computed by dividing the BMP's total storage volume by its surface area (ABMP). For BMPs with varying surface areas (e.g., a trapezoidal infiltration basin with sloping sides or a perforated elliptical pipe), the user should exercise discretion in selecting the correct surface area to use. In most cases, the average surface area would be appropriate. In all cases, the user should always verify that the product of the specified surface

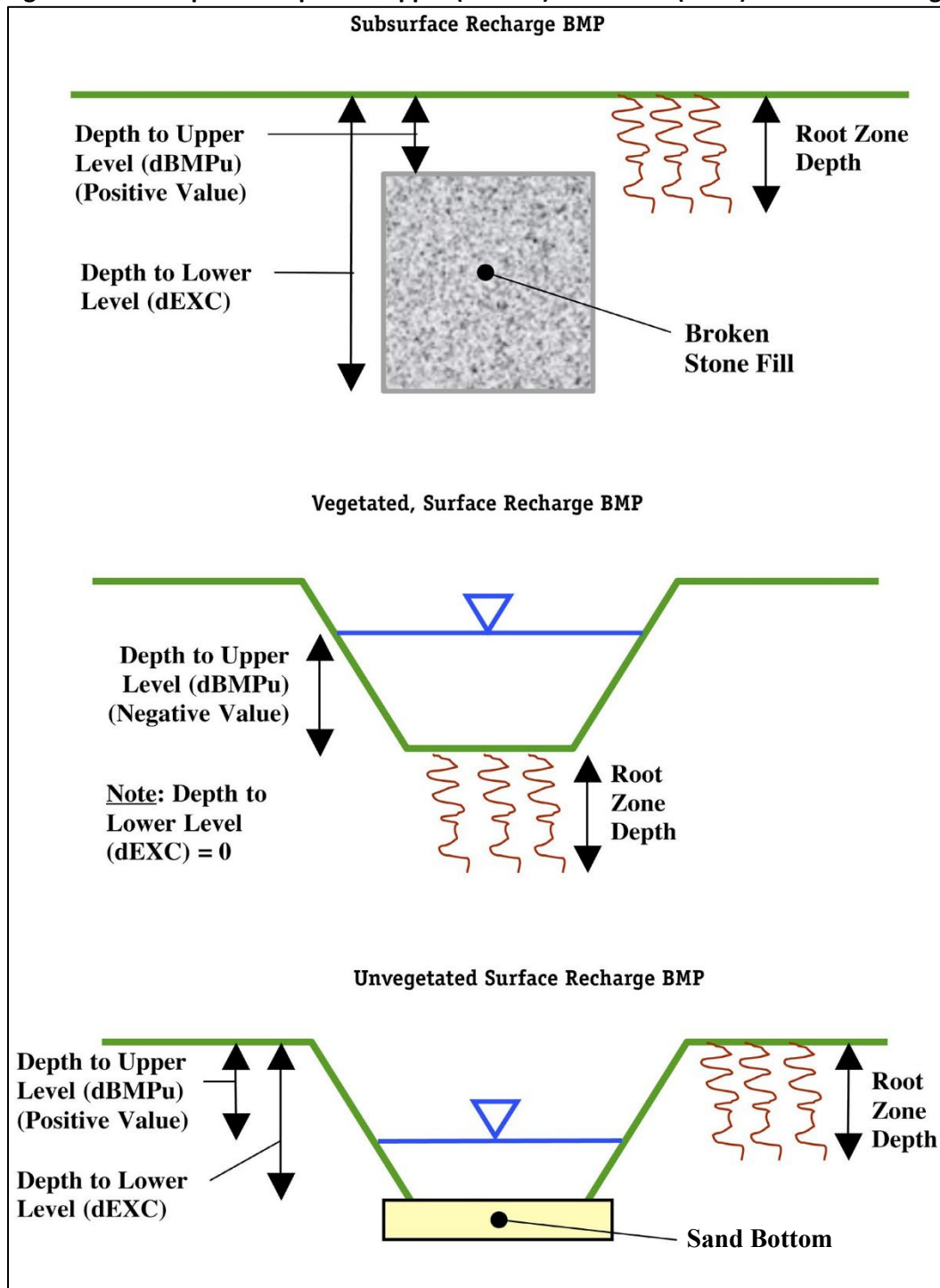
area (ABMP) and effective depth (dBMP) equals the BMP's total storage volume (variable VBMP in Cell G12). More information and recommendations can be found in the NJGRS User's Guide.

In addition to the above, it is important to note that the BMP Calculations Worksheet assumes that all runoff stored in the recharge BMP at depths at or below dBMP (i.e., the maximum storage depth in the BMP) will be infiltrated into the soils below the BMP and that any greater runoff amounts will overflow the BMP. As such, the BMP Calculations Worksheet cannot directly model a recharge BMP that will infiltrate some of its runoff while it is simultaneously discharging some through an overflow or other outlet. For such BMPs, alternative BMP calculation techniques will be required.

With regards to BMP location, if a recharge BMP will be located within a particular post-developed land segment specified on the Annual Recharge worksheet, it should be specified in Cell C9 (variable C9) of the BMP Calculations worksheet. As described earlier, doing so will allow the NJGRS to more accurately compute the losses and resultant recharge at the BMP. If this land segment is not specified on the BMP Calculations worksheet, the NJGRS will, by default, use average soil and loss factors based on all of the post-developed land segments specified on the Annual Groundwater Recharge worksheet.

The BMP Calculations worksheet can analyze a recharge BMP located either on grade or constructed below grade through excavation. An excavated BMP can be either a surface or subsurface BMP. The specific type of BMP is described in the BMP Calculations worksheet through its effective depth (dBMP) and two additional vertical distances. The first is the vertical distance from the vegetated ground surface to the maximum water surface level in the BMP (variable dBMPu in Cell C7). This value is positive if the maximum level is below the vegetated ground surface and negative if above the vegetated ground surface. The second is the vertical distance from the vegetated ground surface to the bottom of the BMP (variable dEXC in Cell C8). For example, if the top of a 36-inch deep stone-filled infiltration trench is located 24 inches below ground level, dBMPu would be 24 inches and dEXC would be 60 inches (i.e., dBMPu plus the 36-inch actual depth of the trench). It should be noted, however, that since the trench is filled with gravel with a certain void ratio, the BMP's effective depth (dBMP) would be 36 inches times that void ratio. Using the dBMPu and dEXC variables, virtually all types of recharge BMPs can be specified, including "above the surface," "semi-buried," and "completely buried" BMPs. See Figure 6-4 below and the NJGRS User's Guide for more information.

Figure 6-4: Examples of Depths to Upper (dBMPu) and Lower (dEXC) Levels of Recharge BMP



In using the BMP Calculations worksheet, it is important to note that, by default, the NJGRS takes the values from the Annual Recharge worksheet for the Post-Development Recharge Deficit Volume (Cell K24) and the Total Impervious Area (Cell M23) and specifies them as initial values on the BMP Calculations worksheet for the Post-Development Deficit Recharge (variable Vdef in Cell C14) and Post-Development Impervious Area (variable Aimp in Cell C15). This allows solution of the site's total recharge deficit by a

single groundwater recharge BMP that will receive runoff from a developed site's entire impervious area (if specified as impervious land segments). However, in many instances, the single groundwater recharge BMP will receive runoff from only a portion of the site's impervious area (e.g., only roof runoff). In such cases, the user must specify the exact size of Aimp (impervious area to the BMP) in Cell C15. Failure to do this for such BMPs will result in an overestimation of the amount of runoff captured by the BMP and erroneous BMP dimensions and/or recharge amounts.

At other sites, it may be necessary or desirable to utilize more than one groundwater recharge BMP to meet the site's recharge requirements. In such cases, each BMP will not only receive runoff from a portion of the site's impervious surface, but each will also seek to provide only a portion of the site's total recharge deficit. In such cases, the user must specify both the exact Aimp and Vdef (Post-Development Deficit) for each BMP in Cells C14 and 15 of the BMP Calculations worksheet. *In such cases, the user must also use a separate NJGRS spreadsheet for each BMP. Using multiple copies of the BMP Calculations worksheet within a single spreadsheet can yield erroneous results.*

In addition, computational problems can occur if, in designing a recharge BMP, the user selects either an initial BMP surface area (ABMP) or effective depth (dBMP) that is drastically different than the actual value needed to meet the required recharge deficit. If this occurs, the NJGRS may not be able to compute the correct value and will, instead, display excessive large answers or divide by zero messages. If this occurs, the user should adjust the initial value to one that more closely approximates the final answer and rerun the worksheet.

The BMP Calculations worksheet will also present various characteristics of the recharge BMP, including its effectiveness in converting runoff to infiltrated water and then recharged groundwater. See the NJGRS User's Guide presented at the end of this chapter for more information.

BMP Calculation Messages

The BMP Calculations worksheet provides three important messages to check the validity of the computed results. The Volume Balance message (Cell J11) is a check of the Annual BMP Recharge Volume in Cell G14 against the Post-Development Deficit Recharge (variable Vdef in Cell C14). If these values are equal, the problem is solved successfully and the message in this section will read "OK." However, if the BMP's annual recharge volume does not equal Vdef, the message instructs the user to continue to solve the problem. This may also occur if the user changes any of the BMP design parameters and forgets to solve the problem by clicking on any of the two solve buttons.

The dBMP Check message (Cell J12) checks the validity of the value inputted for the dBMP, the BMP's effective depth in Cell C6. If this value is greater than the difference between the depths to the BMP's upper and lower surfaces (variables dBMPu and dEXC in Cells C7 and C8, a warning message is issued telling the user to adjust dBMP. dEXC Check (Cell J13) is the third message. It checks the validity of dEXC to ensure it is larger than dBMPu. If it is not, a message will appear instructing the user to make dEXC larger than dBMPu.

Below these messages is a report on the location of the BMP as specified by the user in Cell C9 (variable segBMP). If the user has entered a valid segment number for segBMP, the message will read "OK." If the user enters a zero for segBMP, the message will read "Location is selected as distributed or undetermined." However, if the user enters a land segment number that was not previously defined in

the Annual Recharge worksheet under Post-Developed Conditions, the message will say: “Land Segment Number Selected for BMP is not Defined.” The user should then make appropriate corrections to segBMP.

See the NJGRS User’s Guide for more information regarding calculation check messages and warnings.

Additional Information

In addition to the above, the following important features and characteristics of the NJGRS should be noted:

1. The NJGRS gives the user the opportunity to specify what percentage of a development site’s annual groundwater recharge deficit must be retained (Cell K23 of the Annual Recharge worksheet). However, it should be noted that the program’s default value is 100 percent which, as noted above, is the amount required by the NJDEP Stormwater Management rules.
2. The pre- and post-development average annual recharge at a development site is a function, in part, of the municipality in which the site is located. Therefore, changing the name of the municipality in Cell C3 of the Annual Recharge worksheet will change both the pre- and post-development recharge volumes. Similarly, if the user wishes to analyze a site in a different municipality, the new municipality’s name must be entered through the drop-down list in Cell C3 in order to accurately compute pre-and post-development recharge amounts.
3. In Cell K6 of the BMP Calculations worksheet, the NJGRS will display the “Inches of Rainfall to Capture.” This value is also displayed graphically in Chart 1 of the NJGRS along with other pertinent BMP performance information. This value specifies the minimum depth of rainfall over the BMP’s impervious contributory drainage area that must be collected to meet the development site’s average annual recharge deficit. It is also the maximum event rainfall that the BMP can store without overflowing and, as such, it is equal to the BMP’s Recharge Design Storm depth described previously in “Theoretical Basis of Calculations.” This design storm depth is important, as it can be used to estimate the resultant groundwater recharge design storm runoff from a development site with groundwater recharge BMPs.
4. At the time of the NJGRS’ development, all soil series mapped in New Jersey were included in its databases. Nevertheless, instances may arise where a soil series identified at a land development site has not been included. In such instances, the user should select a similar soil series from the program’s database. In doing so, the following criteria should be utilized, generally in the order presented:
 - Select a NJGRS soil series within the same Hydrologic Soil Group (HSG) as the site soil.
 - Within the same HSG, select an NJGRS soil series with similar textural characteristics and classification as the soil.
 - If the site soil includes a fragipan, bedrock or other restrictive layer below its surface, select an NJGRS soil series with a similar restrictive depth.
 - If more than one choice of NJGRS soil series appears reasonable, the user may then analyze and compare the annual groundwater recharge amounts for each using the NJGRS program to help make a final selection.

Recharge BMP Design Guidelines

In general, the design of a groundwater recharge BMP to offset a development site's groundwater recharge deficit should follow the standards and guidelines identified in the BMP's respective chapter of the BMP Manual, which includes utilizing soil permeability data obtained from tests such as those contained in *Chapter 12: Soil Testing Criteria* at the site of the proposed recharge BMP. In addition, the recharge BMP design must be based on the following guidelines:

1. Computation of the pre- and post-development annual groundwater recharge rate and the annual recharge deficit should be based upon the New Jersey Geological Survey *Report GSR-32: A Method for Evaluating Ground Water Recharge Areas in New Jersey*, which is incorporated into the NJGRS.
2. Only the directly connected impervious portions of a recharge BMP's drainage area can be used to compute runoff to the BMP. In the NJGRS, the input parameter *Aimp*, which is the size of the recharge BMP's drainage area, must represent only directly connected impervious surfaces. This is particularly relevant for infiltration basins and pervious paving systems used for groundwater recharge that may also have pervious and unconnected impervious areas draining to them.
3. Runoff collected from roofs and other above-grade surfaces can be directly conveyed to a recharge BMP. However, refer to the recharge BMP's respective BMP Manual chapter for information regarding pre-treatment requirements.
4. Runoff collected from parking lots, driveway, roads and other on-grade impervious surfaces and conveyed to a subsurface recharge BMP must be pretreated to remove 80 percent of TSS in order to prevent the loss of storage volume and/or recharge capacity due to sedimentation and clogging. Exceptions may be possible for patios, tennis courts and similar on-grade impervious surfaces with minimal TSS loadings on case-by-case basis. Such treatment can also be used to meet the site's overall TSS removal requirements. In addition, all on-grade drainage areas to a subsurface recharge BMP should consist only of impervious surfaces. Exceptions to this requirement may include roadway rights-of-ways, vegetated parking lot medians, planting and landscape beds and other pervious surfaces provided that they comprise only a small percentage of the total drainage area and will not generate an excessive amount of TSS or other material that might adversely impact the subsurface recharge BMP. As noted above, if such areas are part of the actual drainage area, they must not be included in the drainage area size (variable *Aimp*) used in the NJGRS' BMP Calculations worksheet to design the recharge BMP.

In addition, it should be noted that, since the BMP Calculations Worksheet assumes that all runoff from a recharge BMP's impervious drainage area will be delivered to the BMP, it cannot directly account for runoff losses incurred at a pretreatment measure located between the drainage area and the recharge BMP. If such losses will occur due to the selected pretreatment measure, appropriate compensating adjustments may be attempted in the BMP Calculations Worksheet input data or alternative BMP calculation techniques utilized.

5. The NRCS Web Soil Survey, which can be found online at <https://websoilsurvey.nrcs.usda.gov/app/>, is typically used to obtain the soil series data required for the determination of annual land development site recharge rates and deficits and the dimensions of recharge BMPs using the NJGRS program. However, site soil tests will be required at the actual location of a proposed recharge BMP

in order to confirm the BMP's ability to function properly without failure. Such tests should include a determination of the textural classification and permeability of the soil at the bottom of the proposed recharge BMP. As noted above, permeability testing must be conducted in accordance with *Chapter 12: Soil Testing Criteria*.

Depending upon the type, location, use and maximum design storm of the selected recharge BMP, minimum design soil permeability rates will vary from 0.2 to 0.5 inches per hour and that a factor of safety of 2 must be applied when converting a tested permeability rate to a design rate. In addition, the soil permeability rate must allow the recharge BMP to fully drain its maximum design storm runoff volume within 72 hours. Recharge BMP locations that fail to meet these two requirements should be rejected and alternative onsite locations selected. A groundwater recharge waiver may be sought from the applicable reviewing agencies if suitable permeability rates cannot be found at any recharge BMP locations on the development site.

See Chapter 9 for details on GI best management practices that can be used as recharge BMPs, including minimum design permeability rates. Such BMPs include dry wells (Chapter 9.2), certain types of pervious paving systems (Chapter 9.6) and infiltration basins (Chapter 9.8).

6. The results of the BMP site soil testing should be compared with NRCS Web Soil Survey data used in the NJGRS' annual recharge and BMP design computations to ensure reasonable data consistency. If significant differences exist between the BMP site soil test results and NRCS Web Soil Survey data, additional development site soil tests are recommended to determine and evaluate the extent of the data inconsistency and the need for revised annual recharge and BMP design computations based upon the site soil test results. All significant inconsistencies should be discussed with the local Soil Conservation District prior to proceeding with such redesign to help ensure that the site soil data is accurate. It should also be noted that significant inconsistencies between development site soil tests and the NRCS Web Soil Survey may warrant revisions to the site's stormwater runoff quality and quantity computations.
7. The development site areas that extensive site soil testing determine to have permeability rates less than 0.2 inches per hour may be considered to belong to Hydrologic Soil Group D in the NJGRS program. For such areas, the user may use any HSG D soil in the NJGRS soil series database to define such site areas in the NJGRS' Annual Recharge worksheet. In accordance with the assumptions of both the NJGRS program and N.J. Geological Survey's Geological Survey Report GSR-32: A Method for Evaluating Ground Water Recharge Areas in New Jersey, such areas will not produce any groundwater recharge. Once again, the assignment of HSG D to any development site areas should be discussed with the local Soil Conservation District prior to proceeding to help ensure that the site soil data is accurate.

THE NEW JERSEY GROUNDWATER RECHARGE SPREADSHEET (NJGRS) USER'S GUIDE

Version 2.0 – November 2003

There are two computational worksheets in the NJGRS spreadsheet:

- **Annual Recharge:** This worksheet, which resides on the first page of the spreadsheet, is used to estimate the annual groundwater recharge volumes that occur naturally under the Pre-Developed and Post-Developed Conditions. Based on the value of “percent of Pre-Developed Annual Recharge to Preserve” that the user provides (NJDEP currently requires 100 percent for this parameter), the worksheet calculates the “Post-Development Annual Recharge Deficit” in cubic feet. This is the annual recharge volume that must be provided by one or more groundwater recharge BMPs.
- **BMP Calculations:** This worksheet, which resides on the second page of the spreadsheet, is used to design the required size and configuration of one or more groundwater recharge BMPs to satisfy the “Post-Development Annual Recharge Deficit” calculated in the Annual Recharge worksheet.

NOTE: Only the above worksheets in the NJ Groundwater Recharge Spreadsheet are for user input. Charts 1 through 3 can be viewed for visual inspection of the results. Other worksheets in the spreadsheet are either for internal calculations or contain the databases used by calculations. The user should refrain from changing anything in these worksheets.

Part 1: Using the Annual Recharge Worksheet

Figure 1: Screen Capture Showing the Annual Recharge Worksheet

New Jersey Groundwater Recharge Spreadsheet Version 2.0 November 2003		Annual Groundwater Recharge Analysis (based on GSR-32)				Project Name: Sample Project					
Select Township ↓		Average Annual P (in)	Climatic Factor	Description: This is a test application		Analysis Date: 09/01/03					
MIDDLESEX CO., PERTH AMBOY CITY		47.8	1.53								
Pre-Developed Conditions						Post-Developed Conditions					
Land Segment	Area (acres)	TR-55 Land Cover	Soil	Annual Recharge (in)	Annual Recharge (cu.ft)	Land Segment	Area (acres)	TR-55 Land Cover	Soil	Annual Recharge (in)	Annual Recharge (cu.ft)
1	1.4	Open space	Woodstown	12.9	65,498	1	1.5	Impervious areas	Keyport	0.0	-
2	0.3	Gravel, dirt	Woodstown	6.9	7,536	2	1.6	Gravel, dirt	Woodstown	6.9	40,191
3	3.5	Woods-grass combination	Woodstown	13.5	171,255	3	3.65	Open space	Keyport	13.4	177,667
4	1.4	Open space	Keyport	13.4	68,146	4	3.65	Open space	Woodstown	12.9	170,762
5	0.5	Gravel, dirt	Keyport	7.5	13,657	5	0				
6	3.3	Woods-grass combination	Keyport	13.9	165,963	6	0				
7	0					7	0				
8	0					8	0				
9	0					9	0				
10	0					10	0				
11	0					11	0				
12	0					12	0				
13	0					13	0				
14	0					14	0				
15	0					15	0				
Total =	10.4			Total Annual Recharge (in)	Total Annual Recharge (cu-ft)	Total =	10.4			Total Annual Recharge (in)	Total Annual Recharge (cu-ft)
				13.0	492,054					10.3	388,620
Procedure to fill the Pre-Development and Post-Development Conditions Tables						Annual Recharge Requirements Calculation				Total Impervious Area (sq.ft)	
						% of Pre-Developed Annual Recharge to Preserve =		100%		65,340	
						Post-Development Annual Recharge Deficit=		103,435		(cubic feet)	
						Recharge Efficiency Parameters Calculations (area averages)					
						RWIC= 3.94 (in)		DRWC= 3.94 (in)			
						ERWC= 0.93 (in)		EDRWIC= 0.93 (in)			

- Figure 1 is a screen capture from an example application of the Annual Recharge Worksheet. All user-input cells are tan colored. All gray colored cells are used to show calculation results or internal validity checks and must *not* be changed by the user. The three cells at the upper right corner of the sheet are where the user can input project information. These inputs are optional, but they can help in identifying the project and the alternative being analyzed.
- As the first step, the user must select the project's municipality. Click once on the municipality cell (Cell C3) and select the project's county and municipality from the drop-down list of all New Jersey municipalities, which is arranged by county in alphabetical order. Once the user has selected a municipality, the values of average annual precipitation and the climate factor are set for that municipality in the two cells to the immediate right of the municipality's name (Cells D3 and E3).
- The next step is to provide information about pre-developed site conditions. The first column is the land segment number (Cells A6 to A20). Up to 15 different land segments can be inputted in this table.

NOTE: If you have more than 15 different land segments, try to combine similar segments together or subdivide your area into smaller areas not consisting of more than 15 land segments.

- For each land segment, first enter the area in acres. Then select an appropriate TR-55 land cover description from the drop-down list of standard NRCS land cover descriptions. Finally, select the segments soil series from the drop-down list. Note that, as soon as the area for a segment is entered, the entries for other columns become visible and selectable. Start from the top of the table and proceed downward. Do not leave blank rows (with zero area) between land segment entries; rows with zero areas will not be displayed or used in calculations.

NOTE: Once you click on any of these cells a pop-up help message will appear to briefly tell you about the required input for that cell.

- As can be seen from the list of available TR-55 land cover descriptions in the drop-down list, there may be more than one way to describe the pre-developed land cover at a project site, particularly when that cover is a mixture of pervious and impervious surfaces such as a single family residential development. For assistance, see the guidelines in the New Jersey Groundwater Recharge Spreadsheet (NJGRS) section of Chapter 6 for selecting segment limits and land cover descriptions. Finally, it should be noted that, under the Pre-Developed Conditions section, it is not necessary to specify the soil series for site segments with impervious land cover, since the natural recharge in these segments is set at zero.

NOTE: If the soil you select for a land segment is hydric, recharge will be set to zero for that segment.

- Once the user has completed inputting all land covers in the table for the Pre-Developed Conditions, check the total area in acres (Cell B21) to ensure that the total project area is correct. The last two columns of this table show the naturally occurring average annual recharge amount as a depth (in inches over the segment area) and a volume (in cubic feet) for each land segment. At the bottom of these columns (Cells E22 and F22), the average recharge depth (in inches) and the total annual recharge volume (in cubic feet) over the total area under Pre-Developed Conditions is given. This number is later used in the calculation of any post-development recharge deficit.

- The above procedure can also be used to enter the required data for the post-developed site conditions. In doing so, please note the following additional requirements:
 1. To correctly compute the performance and/or required size of a proposed groundwater recharge BMP, the area in which the BMP will be located must be entered as a separate site segment with its associated soil series. The number of this segment must also be specified on the BMP Calculations spreadsheet (see below).
 2. As noted above, it is normally not necessary to specify the soil series within an impervious site segment. However, the soil series of the impervious segment must be specified if a proposed groundwater recharge BMP will be located within or below it (e.g., a stone-filled infiltration trench below a parking lot). As noted in 1 above, the soil series is necessary in order to accurately compute the performance and/or required size of the proposed BMP.
- Finally, as noted above, see the guidelines in the New Jersey Groundwater Recharge Spreadsheet (NJGRS) section of Chapter 6 for further assistance in selecting appropriate segment limits and TR-55 land cover descriptions for post-developed site conditions.

NOTE: Soil series selected for the impervious areas in the Post-Developed Conditions table are automatically displayed in orange, signifying that they have no effect on the site's natural annual recharge calculation (i.e., recharge set to zero for all land segments classified as "Impervious areas" regardless of the soil type), but that they can affect the artificial annual recharge volume of any groundwater recharge BMP set below them.

- Once the user has completed inputting all land segment information in the table for the Post-Developed Conditions, once again check the total project area (Cell I21) to ensure that the total post-development project area is correct.

NOTE: If the total area in the Post-Developed Conditions is different from the total area in the Pre-Developed Conditions, a warning message will appear to the right of the total Post-Developed project area (Cell J21).

- As an additional check, the total impervious area (in square feet) under Post-Developed conditions will be shown at the bottom right of this table (Cell M23). Please note that this value reflects only those impervious areas specified as separate project segments and does not include any impervious areas within those segments specified by the standard TR-55 residential or urban land descriptions. The last two columns of this table show the naturally occurring average annual recharge depth (in inches) and volume (in cubic feet) for each land segment. At the bottom of these columns (Cells L22 and M22), the average recharge depth (in inches) and the total annual recharge volume (in cubic feet) over the total area under Post-Developed Conditions is given. This number is also used later in the calculation of any Post-Development recharge deficit.
- Immediately below the Post-Developed Conditions table is the Annual Recharge Requirements Calculation section. The user needs to input the "percent of Pre-Developed Annual Recharge to Preserve" (Cell K23) to set the percentage of the recharge under Pre-Developed Conditions that must be maintained under the Post-Developed Conditions. The NJDEP Stormwater Management rules at N.J.A.C. 7:8 currently requires this value to be 100 percent, which is the spreadsheet's default value. The spreadsheet then computes the difference between the total annual recharge volumes for Pre- and Post-Developed Conditions and multiplies it by the "percent of Pre-Developed Annual Recharge

to Preserve.” The resulting value is shown as the “Post-Development Annual Recharge Deficit” in the worksheet (Cell K24). This amount is 103,435 cubic feet in the case of the example in Figure 1. This is the volume of groundwater recharge that must be artificially recharged under Post-Developed Conditions annually through groundwater recharge BMPs.

- The “Recharge Efficiency Parameter Calculations” table shown below the “Post-Development Annual Recharge Deficit” show the parameters calculated by this worksheet that are later used in the BMP Calculations worksheet.

NOTE: The Appendix to this guide provides the basic equations and defines the variables used in Recharge Efficiency Parameter Calculations.

Part 2: Using the BMP Calculations Worksheet

This worksheet allows the proper sizing of groundwater recharge BMPs to provide the desired or required volume of annual groundwater recharge. Alternatively, it can be used to evaluate the performance of a user specified recharge BMP. As described in Chapter 2, groundwater recharge BMPs can also be referred to as Low Impact Development BMPs (or LID-BMPs), depending on their size and location in the project site.

Figure 2: Screen Capture from the BMP Calculations Worksheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Project Name		Description			Analysis Date		BMP or LID Type						
2	Sample Project		This is a test application			09/01/03								
3	Infiltration BMP Input Parameters				Root Zone Water capacity Calculated Parameters				Recharge Design Parameters					
4	Parameter	Symbol	Value	Unit	Parameter	Symbol	Value	Unit	Parameter	Symbol	Value	Unit		
5	BMP Area	ABMP	6656.0	sq.ft	Empty Portion of RWC under Post-D Natural Recharge	ERWC	0.93	in	Inches of Runoff to capture	Qdesign	0.54	in		
6	BMP Effective Depth, this is the design variable	dBMP	5.2	in	ERWC Modified to consider dEXC	EDRWC	0.93	in	Inches of Rainfall to capture	Pdesign	0.67	in		
7	Upper level of the BMP surface (negative if above ground)	dBMPu	-5.2	in	Empty Portion of RWC under Infiltr. BMP	RERWC	0.74	in	Recharge Provided Avg. over Imp. Area		19.0	in		
8	Depth of lower surface of BMP, must be >= dBMPu	dEXC	0.0	in					Runoff Captured Avg. over imp. Area		24.8	in		
9	Post-development Land Segment Location of BMP Input Zero if Location is distributed or undetermined	SegBMP	0	unitless										
10	Solve for ABMP to provide Vdef	Solve for dBMP to provide Vdef	Default Vdef & Aimp		BMP Calculated Size Parameters				CALCULATION CHECK MESSAGES					
11					ABMP/Aimp	Aratio	0.10	unitless	Volume Balance-->	OK				
12					BMP Volume	VBMP	2.873	cu.ft	dBMP Check-->	OK				
13	Parameters from Annual Recharge Worksheet				System Performance Calculated Parameters				dEXC Check-->	OK				
14	Post-D Deficit Recharge (or desired recharge volume)	Vdef	103,435	cu.ft	Annual BMP Recharge Volume		103,435	cu.ft	BMP Location-->	Location is selected as distributed or undetermined				
15	Post-D Impervious Area (or target Impervious Area)	Aimp	65,340	sq.ft	Avg BMP Recharge Efficiency		76.7%	Represents % Infiltration Recharged	OTHER NOTES					
16	Root Zone Water Capacity	RWC	3.94	in	%Rainfall became Runoff		78.3%	%	Pdesign is accurate only after BMP dimensions are updated to make rech volume= deficit volume. The portion					
17	RWC Modified to consider dEXC	DRWC	3.94	in	%Runoff Infiltrated		66.2%	%	of BMP infiltration prior to filling and the area occupied by BMP are ignored in these calculations. Results are					
18	Climatic Factor	C-factor	1.53	no units	%Runoff Recharged		50.8%	%	sensitive to dBMP; make sure dBMP selected is small enough for BMP to empty in less than 3 days. For land					
19	Average Annual P	Pavg	47.8	in	%Rainfall Recharged		39.7%	%	Segment Location of BMP if you select "impervious areas" RWC will be minimal but not zero as determined by					
20	Recharge Requirement over Imp. Area	dr	19.0	in					the soil type and a shallow root zone for this Land Cover allowing consideration of lateral flow and other losses.					
21	How to solve for different recharge volumes: By default the spreadsheet assigns the values of total deficit recharge volume "Vdef" and total proposed impervious area "Aimp" from the "Annual Recharge" sheet to "Vdef" and "Aimp" on this page. This allows solution for a single BMP to handle the entire recharge requirement assuming the runoff from entire impervious area is available to the BMP. To solve for a smaller BMP or a LID-IMP to recharge only part of the recharge requirement, set Vdef to your target value and Aimp to impervious area directly connected to your infiltration facility and then solve for ABMP or dBMP. To go back to the default configuration click the "Default Vdef & Aimp" button.													

- Figure 2 is a screen capture from a portion of the BMP Calculations worksheet. While most of the calculations in this worksheet are performed in a separate worksheet, the portion shown in Figure 2 can be studied to understand the worksheet usage. There are several sections and solve buttons in this part of the worksheet, as explained below.

NOTE: The three entries for Project Name, Description and Analysis Date are automatically copied from the Annual Recharge Sheet to the top of this sheet. The user can optionally input information regarding Groundwater Recharge BMP type.

Recharge BMP Input Parameters

- The user may start by inputting an initial value for the BMP surface area in square feet (variable ABMP) in Cell C5. In the NJGRS program, the variable ABMP is used in conjunction with the size of the recharge BMP's drainage area to determine the depth of stored runoff in the BMP resulting from a specific rain event. If a specific recharge BMP is being analyzed, ABMP will be based on the actual area of the BMP. If the spreadsheet is being used to determine the required recharge BMP dimensions, this value should be an initial estimate of the required surface area to satisfy the Post-Developed Recharge Deficit volume. This deficit volume (variable Vdef) is shown in Cell C14 and is either user-specified or, by default, taken from the Post-Development Annual Recharge Deficit computed on the Annual Recharge worksheet (Cell K24).
- Next, a value for the recharge BMP's effective storage depth (variable dBMP) must be specified in inches in Cell C6. In the NJGRS program, dBMP represents the maximum equivalent water depth that can be achieved in the BMP before overflow begins. Therefore, if the proposed recharge BMP will, for example, be a subsurface, vertical-walled chamber, dBMP will simply be the maximum achievable depth before the chamber is full and overflow occurs. However, if the proposed BMP will be filled with broken stone or other suitable material, dBMP will be the product of the BMP's actual or physical depth and the void ratio of the fill. For recharge BMPs that consist of a combination of filled and open areas (e.g., a perforated pipe within a stone filled trench) or for irregular, nonrectangular BMP shapes (e.g., a perforated elliptical pipe or an infiltration basin with sloping sides), dBMP can be computed by dividing the BMP's total storage volume by its surface area.
- Just like the BMP surface area variable ABMP, the dBMP value entered for effective storage depth can be either a given value for a specific recharge BMP or an initial guess for a BMP to be sized by the spreadsheet. If this second option is selected, the user should remember that the resultant dBMP computed by the program may or may not be its actual or physical depth, depending on whether the BMP uses broken stone or other media in which to store runoff.
- In addition to dBMP, the user must also provide two additional recharge BMP depths. In Cell C7, the variable dBMPu is the vertical distance from the vegetated ground surface to the maximum water level of the BMP. This value should be positive if the maximum level is below the ground surface and negative if above the vegetated ground surface. In Cell C8, the variable dEXC is the vertical distance from the vegetated ground surface to the bottom of the BMP. For example, if the top of a 36-inch deep stone-filled infiltration trench (void ratio = 0.33) is located 24 inches below ground level, dBMPu would be 24 inches and dEXC would be 60 inches (i.e., dBMPu plus the 36inch actual or physical depth of the trench). Remember, however, that since the trench is filled with gravel, the effective BMP depth (dBMP) would be 12 inches (i.e., 36 inches times 0.33). Using the dBMPu and dEXC variables,

virtually all types of recharge BMPs can be specified, including “above the surface,” “semi-buried,” and “completely buried” BMPs. See Figure 6-4 for additional examples of dBMPu and dEXC.

- The next input cell on the BMP Calculations worksheet is the variable segBMP (Cell C9). This variable represents the post-developed site segment (as specified on the Annual Recharge worksheet) in which the proposed recharge BMP will be located. For example, if the recharge BMP is proposed to be built in Land Segment 3 in the Post-Developed Conditions table shown in Figure 1, then enter 3 for segBMP on the BMP Calculations worksheet.

NOTE: Input zero for segBMP if the location of the BMP is still undetermined or a series of identical BMPs will be distributed over multiple site segments.

- The last input cell on the BMP Calculations worksheet is the variable Aimp (Cell C15). Similar to the variable Vdef in Cell C14, Aimp is either user-specified or, by default, taken from the Total Impervious Area computed on the Annual Recharge worksheet (Cell M23).
- Once values and/or initial guesses are entered in the input cells, either of two solve buttons can be used to solve the design problem. These buttons are described below.



NOTE: Click this button to automatically evaluate the value of ABMP that provides Vdef given all other input values.



NOTE: Click this button to automatically evaluate the value of dBMP that provides Vdef given all other input values.

If the initial guess values you enter for ABMP or dBMP are drastically off from what is needed to satisfy Vdef (i.e., too small or too big, too shallow or too deep), the program may not be able to find the right answer. One can tell the answers are not acceptable because negative values or division by zero signs will show up. If this happens just change your ABMP and/or dBMP values to more realistic numbers and solve the problem again.

- It is important to remember that, by default, the spreadsheet takes the values computed on the Annual Recharge worksheet for the Post-Development Recharge Deficit Volume (Cell K24) and the Total Impervious Area (Cell M23) and specifies them as initial values on the BMP Calculations worksheet for the Post-Development Deficit Recharge (variable Vdef in Cell C14) and Post-Development Impervious Area (variable Aimp in Cell C15). This allows solution of the site’s total recharge deficit by a single groundwater recharge BMP that will receive runoff from the site’s entire impervious area. However, in many instances, the single groundwater recharge BMP will receive runoff from only a portion of the site’s impervious area (e.g., only roof runoff). In such cases, the user must specify the exact size of Aimp (impervious area to the BMP) in Cell C15. Failure to do this for such BMPs will result in an overestimation of the amount of runoff captured by the BMP and erroneous BMP dimensions and/or recharge amounts.
- At other sites, it may be necessary or desirable to utilize more than one groundwater recharge BMP to meet the site’s recharge requirements. In such cases, each BMP will not only receive runoff from a portion of the site’s impervious surface, but each will also seek to provide only a portion of the site’s total recharge deficit. In such cases, the user must specify both the exact Aimp and Vdef (Post-Development Deficit) for each BMP in Cells C14 and 15 of the BMP Calculations worksheet.

IMPORTANT: In such cases, the user must also use a separate NJGRS spreadsheet for each BMP. Using multiple copies of the BMP Calculations worksheet within a single spreadsheet can yield erroneous results.

NOTE: These procedures are also summarized in a note at the bottom of the BMP Calculations worksheet.

NOTE: Click the button to the right to retrieve the initial, default values of Vdef and Aimp from the Annual Recharge worksheet.

Default
Vdef & Aimp

- Similar to the Annual Recharge worksheet, the user-input cells in the BMP Calculations worksheet are tan colored. This includes the cells for Vdef and Aimp so that they can be altered from their default values by the user. As described above, these cells are initially assigned default values from the Annual Recharge worksheet so the user does not have to input values for certain sites and BMPs. All gray colored cells are used to show calculation results or internal validity checks and must not be changed by the user.

NOTE: Remember that the default configuration assumes that the runoff from the site's entire impervious area (set by specifying one or more land segments to "Impervious Areas" on the Annual Recharge worksheet) will drain to the BMP. If only a portion of this impervious area will do so, the correct impervious area must be specified for Aimp (Cell C15) on the BMP Recharge worksheet.

- The values shown in Figure 2 above are the final results obtained by solving for ABMP (with a constant dBMP of 5.2 inches) to satisfy the entire annual recharge deficit of 103,435 cubic feet (which is the default Vdef value from the Annual Recharge worksheet). The user can tell the results are correct by comparing the calculated Annual BMP Recharge Volume amount in Cell G14 (under the "System Performance Calculated Parameters" heading) with the Vdef amount in Cell C14. In addition, the user can see that the volume balance is shown to be "OK" (Cell J11) in the "Calculation Check Messages" section.

Parameters from Annual Recharge Worksheet

- This section of the BMP Calculations worksheet contains various parameters initially computed in and then transferred from the Annual Recharge worksheet. As noted above, the initial values for Vdef (Cell C14) and Aimp (Cell C15) are taken from the Post-Development Recharge Deficit Volume (Cell K24) and the Total Impervious Area (Cell M23) on the Annual Recharge worksheet. A complete description of when the user must specify other values for these parameters is presented above. The values for Root Zone Water Capacity (variable RWM in Cell C16) and RWC Modified to Consider dEXC (variable DRWC in Cell C17) are automatically adjusted to reflect the user's choice for the excavation depth (variable dEXC) of the BMP. The values for Climatic Factor (variable C-Factor in Cell C18) and Average Annual P (variable Pavg in Cell C19) are constant values for the municipality selected in Cell C3 of the Annual Recharge worksheet. It is important to note that if the user wishes to analyze a site in a different municipality, the user must go back to the Annual Recharge worksheet and change the municipality's name in order to obtain the correct C-Factor and Pavg values on the BMP Calculations worksheet. *WARNING: By changing the municipality, you also change the site's annual recharge deficit.*
- The final value shown in this section of the BMP Calculations worksheet is the Recharge Requirement over Impervious Area (variable dr in Cell C20). This value is the average depth of annual recharge in

inches over the impervious area (Aimp) specified (either by default or the user) in Cell C15. The value of dr is calculated by dividing Vdef by Aimp.

Root Zone Water Capacity Calculated Parameters

- This section of the BMP Calculations worksheet contains the calculated results for three root zone water capacity parameters. These values are needed for estimating the recharge efficiency of the groundwater recharge BMP under consideration. These parameters enable the NJGRS spreadsheet to estimate what portion of the infiltrated water from the BMP will travel downward below the root zone of the surrounding vegetation. As described above, this degree of water movement is the technical definition of groundwater recharge. The values of these three root zone water capacity parameters are automatically adjusted for the municipality and LULC segment in which the BMP is to be located. If the variable segBMP (Cell C9) is set to zero, weighted averages of these three parameters are utilized based on all the land segments specified on the Annual Recharge worksheet.

NOTE: See the Appendix to this guide for more information about these three root zone water capacity parameters.

BMP Calculated Size Parameters

- This section of the BMP Calculations worksheet contains values for two recharge BMP design parameters. The parameter Aratio (Cell G11) is computed by dividing the area (ABMP) of the BMP by the impervious area (Aimp) draining to it. The parameter VBMP (Cell G12) is the maximum storage volume in the BMP. It is computed by multiplying the BMP area (ABMP) by its effective depth (dBMP). These values can be checked by the user to help ensure that the ABMP, Aimp and dBMP values have been inputted and used correctly by the NJGRS spreadsheet.

System Performance Calculated Parameters

- This section of the BMP Calculations worksheet contains various calculated BMP performance values. Of these, the Annual BMP Recharge Volume value (Cell G14) is the most important, since it must match the Post-Development Deficit Recharge value (variable Vdef in Cell C14) for the BMP to completely satisfy the site's annual recharge deficit or target recharge volume (as described above).
- The next parameter, Average BMP Recharge Efficiency (Cell G15), specifies the percentage of infiltrated water that is recharged (i.e., travels below the root zone) over an average year. This efficiency depends on many factors, including the project location, land cover, soil types, BMP dimensions and depth of BMP. For the example shown in Figure 2 above, the recharge efficiency of the selected BMP is 76.7 percent.
- The remaining performance values in this section (Cells G16 to G19) are self-explanatory.

Recharge Design Parameters

- Inches of Runoff to Capture (variable Qdesign in Cell K5) is the first value in this section of the BMP Calculations worksheet. This value is the minimum depth of runoff over the BMP's contributory impervious drainage area that must be captured and directed to the BMP to allow it to meet the site's groundwater recharge deficit. Similarly, Inches of Rainfall to Capture (variable Pdesign in Cell K6) specifies the minimum depth of rainfall over the BMP's impervious area that must be similarly controlled by the BMP to meet the site's recharge deficit. This value is also the maximum event rainfall the BMP can store without overflowing and, therefore, is the design rainfall for the BMP as described above.
- The next parameter in this section, Recharge Provided Average over Impervious Area (Cell K7) is the total annual depth of groundwater recharge provided by the BMP. For a site's recharge deficit to be met, this value must equal the Recharge Requirement over Impervious Area (variable dr in Cell C20). Runoff Captured Average over Impervious Area (Cell K8) is the last parameter in this section. It is the total annual depth of runoff over the BMP's impervious contributory drainage area that infiltrates into the ground. As such, it does not contain that part of the impervious area runoff to the BMP that overflows from the BMP during rainfall events greater than the BMP's design rainfall (Pdesign).

Calculation Check Messages

- This section the BMP Calculations worksheet provides three important messages to check the validity of the computed results. The Volume Balance message (Cell J11) is a check of the Annual BMP Recharge Volume in Cell G14 against the Post-Development Deficit Recharge (variable Vdef in Cell C14). If these values are equal, the problem is solved successfully and the message in this section should read "OK." However, if the BMP's annual recharge volume does not equal Vdef, the message instructs the user to continue to solve the problem. This may also occur if the user changes any of the BMP design parameters and forgets to solve the problem by clicking on any of the two solve buttons described above.
- The dBMP Check message (Cell J12) checks the validity of the value inputted for the dBMP, the BMP's effective depth in Cell C6. If this value is greater than the difference between the depths to the BMP's upper and lower surfaces (variables dBMPu and dEXC in Cells C7 and C8, a warning message is issued telling the user to adjust dBMP. dEXC Check (Cell J13) is the third message. It checks the validity of dEXC to make sure it is larger than dBMPu. If it is not, a message will appear instructing the user to make dEXC larger than dBMPu.
- Below these messages is a report on the location of the BMP as specified by the user in Cell C9 (variable segBMP). If the user has entered a valid segment number for segBMP, the message will read "OK." If the user enters a zero for segBMP, the message will read "Location is selected as distributed or undetermined." However, if the user enters a land segment number that was not previously defined in the Annual Recharge worksheet under Post-Developed Conditions, the message will say "Land Segment Number Selected for BMP is not Defined." The user should then make appropriate corrections to segBMP.

Other Notes

- This section of the BMP Calculations worksheet contains notes regarding the assumptions and limitations of the calculations in this worksheet. In the current version of the spreadsheet, these notes refer to the following aspects of spreadsheet use:
 1. The variable Pdesign (Cell K6) is accurate only after the BMP's annual recharge volume (Cell G14) is equal to the site's recharge deficit (variable Vdef in Cell C14). In addition, Pdesign is computed from the results of the BMP's performance. It is not used to compute that performance.
 2. A recharge BMP results are sensitive to its effective depth (dBMP in Cell C6). The user must ensure that the selected dBMP is small enough for the BMP to empty in less than 72 hours.
 3. If a BMP is located within an impervious Post-Development land segment, the Root Zone Water Capacity (variable RWC in Cell C16) at the BMP will be minimal, but not zero. This allows consideration for lateral flow and other losses at the BMP.

APPENDIX: BASIC EQUATIONS AND VARIABLES USED IN RECHARGE EFFICIENCY PARAMETERS CALCULATIONS

Basic Equations for Soil Water Capacity

A. Equation from GSR-32:

$$RWC = \text{Root Depth} \times AWC \quad (1)$$

where:

RWC = Root Zone Water Capacity, in
AWC = Available Water Capacity, in/ft

B. New Equation:

$$ERWC = 1 - (0.5 \times C \text{ Factor}) \times RWC \quad (2)$$

where:

ERWC = Empty Root Zone Water Capacity under natural recharge, in
C-Factor = Climate Factor, a ratio of precipitation to potential evapotranspiration

and the range of values in NJ are as follows:

Variable	Range of Values, in NJ
RWC	0.3 or 14.35
Gravel, Dirt	1.18 – 1.83
Impervious Areas	0.02 or 5.88

Infiltration and Artificial Recharge under BMP or LID-IMP

$$\frac{\text{Total Average Annual Recharge Deficit}}{= \sum_{i=1}^n \text{Minimum} \left(\frac{Q_i}{A_{ratio}}, d_{BMP} \right)} \quad (3)$$

where:

Q_i = Depth of runoff produced by storm i , in

A_{ratio} = Ratio of surface area of the BMP (ABMP) to the impervious surface area served by the BMP, (A_{imp})

n = total number of runoff producing precipitation events in an average year

d_{BMP} = the BMP effective depth, e.g., the maximum equivalent water depth that can be achieved in the BMP before overflow begins, in inches

Find Average Empty RWC under Infiltration Facility

A. Modification to account for the buried depth of the facility

We know that

$$d_{BMPb} = d_{EXC} - \text{Maximum} (0, d_{BMPu})$$

We can define the following relationship:

$$DWRC = AWC \times \text{Maximum} \{0, \text{Root Depth} - [0.5 \times d_{BMPb} - (d_{EXC} - d_{BMPb})]\}$$

which can be simplified to

$$DWRC = AWC \times \text{Maximum} \{0, \text{Root Depth} - [d_{EXC} + (0.5 \times d_{BMPb})]\} \quad (4)$$

where:

$DWRC$ = Root zone water capacity under BMP modified for the buried portion of the BMP and calculated over all land segments, in inches

B. Define the empty portion of EDRWC

$$EDWRC = DWRC \times [1 - (0.5 \times C \text{ Factor})] \quad (5)$$

where:

$EDWRC$ = empty portion of DRWC, in inches

C. Account for the effect of moisture supplied by infiltration facility in reduction of empty portion of root zone

$$RE_{avg} = (1/n) \quad (6)$$

where:

RE_{avg} = $DWRC$ modified to account for infiltration under the BMP, inch

The average empty root zone water capacity under the BMP “ $RERWC$,” calculated for the average rootzone water capacity of all land segments, is calculated as follows:

$$RERWC = (n/365) \times RE_{avg} + \{EDWRC \times [(365 - n)/n]\} \quad (7)$$

The total infiltration depth under a BMP during an average year “ $RBMP$,” measured in inches, is calculated as follows:

$$RBMP = \sum_{i=1}^n \text{Maximum} (0, \text{Infiltration depth in BMP} - RERWC) \text{ during event "i"} \quad (8)$$

The BMP Recharge Efficiency is calculated as follows:

$$= RBMP / \{\sum_{i=1}^n \text{Infiltration depth in BMP during event "i"}\} \quad (9)$$

In equations (8) and (9), results are very sensitive to C-Factor. As C-Factor increases, natural recharge increases and recharge deficit due to development increases. The NJGRS equations imply that if a development is constructed in an area of high natural recharge, the recharge efficiency of a BMP at the site would also be high. Therefore, the size of required recharge BMP should not be unduly large in areas with a large C-Factor.

The above parameters are calculated in the spreadsheet for each land segment as well as for the entire area (area weighted average) under Post-Developed Conditions. If the user specifies the location of the recharge BMP, the relevant parameters of the same land segment will be used. If the user does not specify the location, the average soil and loss factors based on all of the post-developed land segments specified on the Annual Groundwater recharge worksheet will be used.

References

- American Society of Civil Engineers. 2001. Standard Guidelines for Artificial Recharge of Ground Water – EWRI/ASCE 34-01. Reston, Virginia.
- Bouwer, H. 2002. Artificial Recharge of Groundwater: Hydrogeology and Engineering. *Hydrogeology Journal* (2002) 10:121-142.
- deVries, J.J. and Simmers, I. 2002. Groundwater Recharge: An Overview of Processes and Challenges. *Hydrogeology Journal* (2002) 10:5-17.
- Lerner, D.N. 2002. Identifying and Quantifying Urban Recharge: A Review. *Hydrogeology Journal* (2002) 10:143-152.
- Linsley, R.K. Jr., Kohler, M.A. and Paulhus, J.L.H. 1975. *Hydrology for Engineers*. McGraw-Hill. New York.
- Maryland Department of the Environment. 2000. 2000 Maryland Stormwater Design Manual – Volume I – Stormwater Management Criteria. Water Management Administration. Baltimore, MD.
- Scanlon, B.R., Healy, R.W. and Cook, P.G. 2002. Choosing Appropriate Techniques for Quantifying Groundwater Recharge. *Hydrogeology Journal* (2002) 10:18-39.
- Sophocleous, M. 2002. Interactions Between Groundwater and Surface Water: The State of the Science. *Hydrogeology Journal* (2002) 10:52-67.
- USDA Natural Resources Conservation Service. National Engineering Handbook, Part 630, Hydrology.
- USDA Natural Resources Conservation Service. June 1986. Technical Release 55 – Urban Hydrology for Small Watersheds.
- Viessman, W. Jr., Knapp, J.W., Lewis, G. L. and Harbaugh, T.E. 1977. *Introduction to Hydrology – Second Edition*. Harper & Row. New York.
- Zomorodi, K. 2002. Development of Groundwater Recharge and LID Computational Techniques for New Jersey. Dewberry & Davis, LLC. Fairfax, Virginia.