Technical Guidelines for Evaluating Ground-Water-Recharge BMPs in New Jersey
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NJ Stormwater-BMP-Mounding Technical-Guidelines Workgroup
New Jersey Section, Ground-Water Committee
American Water Resources Association

# Summary

The NJ Stormwater-BMP-Mounding Technical Guidelines Workgroup ('workgroup') was convened by the ground-water committee of the New Jersey section of the American Water Resources Association. The workgroup was asked by the New Jersey Department of Environmental Protection (NJDEP) to develop guidelines for designing stormwater-recharge structures that would not adversely impact nearby structures. This is not intended to provide guidance on all aspects of designing and reviewing these best management practices (BMPs) but rather provide guidelines for determining if the transient ground-water mound they create might impact nearby structures

The workgroup was open to all ground-water professionals working in New Jersey with an interest in this subject. The workgroup meet in 2007 on 5/2, 5/23, 6/15, 7/12, 8/9, 9/6, 9/25, 10/29 and 11/27. Contributors to the workgroup's deliberations are listed at the end of this report.

The following is a recap of decisions and approaches. The overall conclusions are general philosophical statements based on basic hydrogeologic principals. They may act as guiding principals in deciding what approach is appropriate in any given situation. The developed tiers (1-5) are an analysis of maximum mounding height as compared to elevations of nearby structures. The tiers do not take into account other considerations that a successful recharge BMP must meet.

# Overall Conclusions

1) The tiers below are designed to address the maximum height of the transient ground-water mound that forms in the unsaturated zone below a stormwater recharge BMP.

2) The 'simple' methods below cannot provide an accurate estimate of the actual height or extent of ground-water mounding under a stormwater recharge BMP. Instead, they provide a series of criteria. If the criteria are met then the ground-water mound should not affect nearby structures.

3) A properly-calibrated three-dimensional ground-water model, using site-specific hydrologic parameters for the unsaturated and saturated zones, is needed to accurately estimate the height and extent of the transient ground-water mounding caused by a stormwater recharge BMP.

4) The Hantush methodology for estimating a steady-state or transient ground-water mound can be used in lieu of one of the 'simple' methods if the recharge rate used is the infiltration rate measured in the field at the site and the soils are uniform within the extent of the Hantush analysis. If a calculated <u>steady-state</u> ground-water mound does not impact nearby structures then the actual transient ground-water mound under the stormwater recharge BMP will not affect the structures. While this method will give a distance and a maximum elevation of the mound, the shape of the mound may not be accurate and will not predict impacts to adjacent areas sensitive to changes in groundwater elevation, such as nearby wetlands. However, this methodology will probably so vastly overestimate the mound that a design which fails this step cannot automatically be assumed to actually have an adverse impact under real-world operating conditions. The modeler must submit sufficient information to adequately demonstrate that the aquifer properties assumed in the model accurately reflect the properties of the aquifer at the site.

5) In cases where the amount of water recharged by the BMP to the water table after development significantly exceeds the amount of natural ground-water recharge before development then there is a potential for a permanent rise in the water table. Accurately calculating this rise is beyond the approaches described below.

# Tiers

The following Tiers discuss, in increasing complexity, some simple cases. In each tier the goal is to set limiting conditions such that the transient ground-water mounding from a stormwater recharge BMP that meets the conditions will not impact nearby structures.

The following assumptions apply to all the tiers described below:

A) These 'simple' guidelines apply to isolated BMPs. That is, the ground-water mound associated with each BMP does not interact with or affect mounds created by any other BMP.

B) Structures that are on the other side of a permanent hydrologic boundary, such as a perennial stream, do not have to be considered in this analysis.

C) The depth to the seasonal high water table is 2' or greater:

$$D_{SHWT} > 2$$

# Definition of Variables

$D_{NSi}$ = distance to nearby structure I from closest edge of the BMP
$D_{SHWT-BMP}$ = depth to the seasonal high water table below the bottom of the BMP
$D_{PB}$ = distance to closest property boundary from edge of BMP
$D_{SV}$ = height of the Saturated Volume
$D_{SHWT-NSi}$ = depth to seasonal high water table at nearby structure I
$D_{TV-BMP}$ = height of the triangle of water at the BMP
$D_{TV-NSi}$ = height of the triangle of water at nearby structure I
$D_{W}$ = depth of water in the BMP after the 'mounding-analysis storm'

$E_{NSi}$ = elevation of bottom of nearby structure I
$E_{BMP}$ = elevation of the bottom of the BMP
$E_{TV-BMP}$ = elevation of the top of the triangle of water at the BMP
$E_{TV-NSi}$ = elevation of the top of the triangle of water at nearby structure I
$E_{SV}$ = elevation of the top of Saturated Volume
$E_{W}$ = maximum elevation of the water surface in the BMP for the 'mounding-analysis storm'

SHWT = seasonal high water table

$V_{W}$ = volume of water generated by the 'mounding-analysis storm' that will be put into the BMP for recharging

$X_{BMP}$ = length dimension of the BMP
$X_{TV}$ = length of the triangle of water

$\theta_{FC-BMP}$ = field capacity under the BMP
$\theta_{FC-NSi}$ = field capacity under nearby structure I

Receiving Volume = the volume of unsaturated soil below the bottom of the BMP but above the seasonal high water table
Block of Soil = synonym for the Receiving Volume

Saturated Volume = the amount of the  receiving volume (or block of soil) below the bottom of the BMP that becomes saturated if entire volume of water in the BMP at the end of the mounding-analysis storm were to infiltrate vertically downward and remain in the unsaturated zone without any vertical leakage downward into the water table or any lateral dispersion in the unsaturated zone
Block of Water = synonym for the Saturated Volume

Triangle of Water = a triangle with same volume of water as the saturated volume (or block of water)

# TIER 1

Tier 1 is the most conservative case. The bottom elevations of all nearby structures are higher than the maximum elevation of water in the BMP for the mounding analysis storm. Or:

$$E_{NSi} > E_W$$

In figure 1 if Nearby Structure 1 were the only structure close to the BMP, then this would appear to be a Tier 1 case.

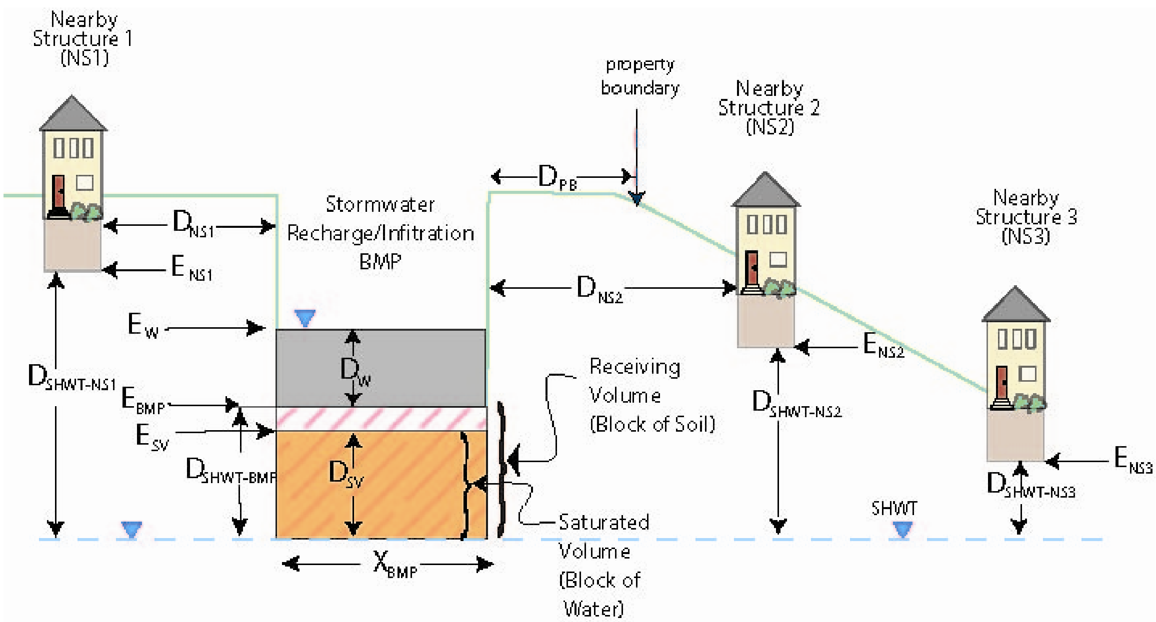


Figure 1. Parameters for tiers 1 and 2.

# TIER 2

This tier applies to the case where the bottom elevation of a nearby structure is lower than the maximum depth of water in the BMP during the mounding analysis storm, but above the elevation of the saturated volume. Tier 2 appears to apply to Nearby Structure 2 in figure 1:

$$E_W > E_{NSi} > E_{SV}$$

This tier applies to cases where the receiving volume (or block of soil) below the BMP can fully contain the saturated volume (or block of water) associated with the mounding-analysis storm and the bottom elevation of all nearby structures is above the top elevation of the saturated volume (or block of water). In order to be more conservative the following limiting assumptions are made:

- The water table is horizontal.
- There is no attenuation of the ground-water mound in the unsaturated zone.
- There is no vertical leakage downward into the water table.

The following steps should be followed to determine the top elevation of the saturated volume and check for compliance with Tier 2 criteria:

1. Define $\theta_{FC\text{-}BMP}$ as the field capacity of the soil under the BMP. Assume the field capacity of the unsaturated zone is 17% if the following conditions apply:

   a. The infiltration rate at the site is 1 in/hr or greater.
   b. The soils in the unsaturated zone are coarse grained and have a USDA classification of sand, loamy sand, or sandy.

   If conditions a and b are not both satisfied then the field capacity must be established by analysis of samples from the site.

2. The water in the BMP for the mounding-analysis storm must fit entirely into the receiving volume (or block of soil) below the BMP without any vertical leakage into the water table or attenuation in the unsaturated zone. Calculate the depth of the Saturated Volume (or block of water) as:

   $$D_{SV} = D_W / \theta_{FC\text{-}BMP}$$

   The top elevation of the saturated volume (block of water) must be less than the distance between the bottom of the basin and the seasonal high water table.

   $$D_{SV} < D_{SHWT\text{-}BMP}$$

3. The bottom elevation of all structures is above the elevation of the saturated volume:

   $$E_{NSi} > E_{SV}$$

## Tier 3

Tier 3 relaxes Tier 2 by allowing attenuation of the recharged volume in the unsaturated zone. This is modeled by assuming the saturated volume (or block of water) in the unsaturated zone is transformed into a triangle of water (fig. 2). By definition, the volume of this triangle of water is the same as the block of water. The top elevation of the triangle must then be lower than the bottom elevation of all nearby structures.

This tier applies to cases where the receiving volume below the BMP (or block of soil) can fully contain the saturated volume (or block of water) associated with the mounding-analysis storm. In order to be more conservative the following limiting assumptions are made:

- The water table is horizontal.
- There is no vertical leakage downward into the water table.

This tier does not require soil samples or measures of depth to seasonal high water table at nearby structures.

The following steps should be followed to determine the top elevation of the triangle of water and check for compliance with Tier 3 criteria:

1. Define $\theta_{FC\text{-}BMP}$ as the field capacity in the soil under the BMP. Assume the field capacity of the unsaturated zone is 17% if the following conditions apply:

   a. The infiltration rate at the site is 1 in/hr or greater.
   b. The soils in the unsaturated zone are coarse grained and have a USDA classification of sand, loamy sand, or sandy.

   If conditions a and b are not both satisfied then the field capacity must be established by analysis of samples from the site.

2. The water in the BMP for the mounding-analysis storm must initially fit entirely into the receiving volume (or block of soil) below the BMP without any vertical leakage into the water table or attenuation in the unsaturated zone. Calculate the thickness of the Saturated Volume (block of water) as:

   $$D_{SV} = D_W / \theta_{FC\text{-}BMP}$$

   The top elevation of the block of water must be less than the depth to the seasonal high water table.

   $$D_{SV} < D_{SHWT\text{-}BMP}$$

3. Define $X_{BMP}$ as a characteristic length dimension for the BMP. Assume for each nearby structure that ground water flow is directly from the BMP towards that structure. $X_{BMP}$ is the width of the BMP in that direction. This value is then assumed to be the width of the saturated volume. In order to allow sufficient area for attenuation and transformation of the block of water into a triangle of water, the nearby structure must be at least twice the BMP's length dimension from the BMP:

$$D_{NS} > 2 * X_{BMP}$$

4. The saturated volume is assumed to attenuate in the direction of the nearby structure. However, in order to be conservative, it is assumed to attenuate only to the nearest property boundary between the BMP and the nearby structure, or to the nearby structure, which ever is closest. Define this distance as $X_{TV}$. In figure 2 the property boundary is closer than nearby structures. Thus for this case $X_{TV}$ would be set equal to $D_{PB}$.

5. The saturated volume attenuates to the triangle of water. The saturated volume has height $D_{SV}$ and length $X_{BMP}$ (per unit length of the BMP). The transformed volume has height $D_{TV\text{-}BMP}$ and length $X_{TV}$. In this analysis, only the parameter $D_{TV\text{-}BMP}$ has not yet been defined.

   Since the volumes of the block and triangle of water must be equal, the the block and triangle of water are related as:

$$D_{SV} * X_{BMP} = 0.5 * D_{TV\text{-}BMP} * X_{TV}$$

$$D_{TV\text{-}BMP} = 2 * D_{SV} * X_{BMP} / X_{TV}$$

6. At all nearby structures the triangle of water must fit in the unsaturated zone under the structure:

$$D_{TV\text{-}BMP} < D_{SHWT\text{-}NSi}$$

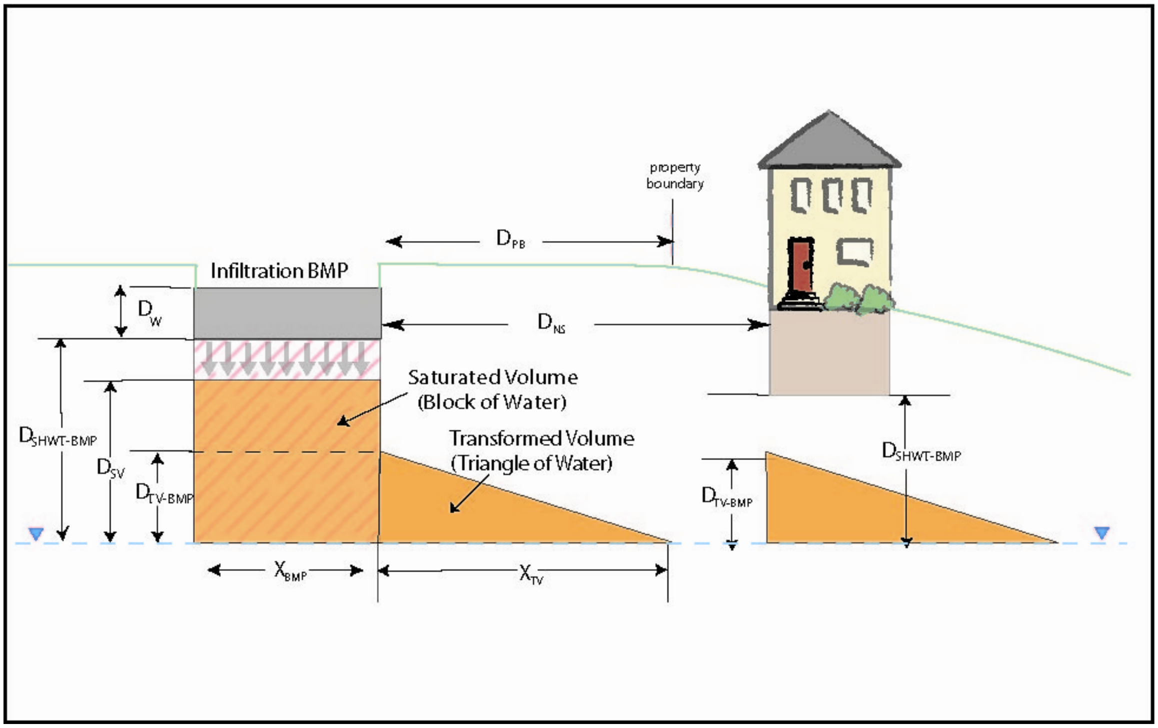


Figure 2. Geometry of transformed Triangle of Water, horizontal water table (tier 3)

# Tier 4

The Tier 4 analysis relaxes Tier 3 by assuming that the water table may slope away from the BMP (fig. 3). At nearby structures the depth to the seasonal high water table must be sufficient to ensure that any ground-water mound created by the BMP will not affect the structure. This tier requires both soil samples and measures of depth to seasonal high water table at nearby structures.

In order to be more conservative the following limiting assumption is made:

- There is no vertical leakage downward into the water table.

The following steps should be followed to determine the top elevation of the triangle of water at a nearby structure and check for compliance with Tier 4 criteria:

1. Define $\theta_{FC\text{-}BMP}$ as the field capacity in the soil under the BMP. Assume the field capacity of the unsaturated zone is 17% if the following conditions apply:

    c. The infiltration rate at the site is 1 in/hr or greater.
    d. The soils in the unsaturated zone are coarse grained and have a USDA classification of sand, loamy sand, or sandy.

    If conditions a and b are not both satisfied then the field capacity must be established by analysis of samples from the site.

2. The water in the BMP for the mounding-analysis storm must initially fit entirely into the receiving volume (or block of soil) below the BMP without any vertical leakage into the water table or attenuation in the unsaturated zone. Calculate the thickness of the Saturated Volume (or block of water) as:

    $$D_{SV} = D_W / \theta_{FC\text{-}BMP}$$

    The top elevation of the block of water must be less than the depth to the seasonal high water table.

    $$D_{SV} < D_{SHWT}$$

3. Define $X_{BMP}$ as a characteristic length dimension for the BMP. Assume for each nearby structure that ground water flow is directly from the BMP towards that structure. $X_{BMP}$ is the width of the BMP in that direction. This value is then assumed to be the width of the saturated volume. In order to allow sufficient area for attenuation and transformation of the block of water into a triangle of water, the nearby structure must be at least twice the BMP's length dimension from the BMP:

$D_{NSi} > 2 * X_{BMP}$

4. The saturated volume is assumed to attenuate in the direction of the nearby structure. However, in order to be conservative, it is assumed to attenuate only to the nearest property boundary between the BMP and the nearby structure, or to the nearby structure, which ever is closest. Define this distance as $X_{TV}$. In figure 3 the property boundary is closer than nearby structures. Thus for this case $X_{TV}$ would be set equal to $D_{PB}$.

5. The saturated volume attenuates to the triangle of water. The saturated volume has height $D_{SV}$ and length $X_{BMP}$ (per unit length of the BMP). The transformed volume has height $D_{TV}$ and length $X_{TV}$. In this analysis only the parameter $D_{TV}$ has not yet been defined.

   Since the volumes of the block and triangle of water must be equal, the block of water and triangle of water are related as:

   $$D_{SV} * X_{BMP} = 0.5 * D_{TV-BMP} * X_{TV}$$

   $$D_{TV-BMP} = 2 * D_{SV} * X_{BMP} / X_{TV}$$

6. The seasonal high water table must be measured at all nearby structures to be analyzed. At Nearby Structure I this is defined as $SHWT_{NSi}$

7. The field capacity must be established at nearby structures by means of soil sampling. At Nearby Structure I this is defined as $\theta_{FC-NSi}$.

8. Assume the triangle of water moves towards each nearby structure. To be conservative, assume the volume of water in the triangle does not change. Also assume that any change in field capacity is reflected by a change in the height of the triangle. Define $D_{TV-NSi}$ as the height of the triangle of water at each nearby structure. This is calculated by multiplying the triangle of water height's at the BMP by the ratio of the field capacity at the BMP divided by the field capacity at the structure:

   $$D_{TV-NSi} = D_{TV-BMP} * \theta_{FC-BMP} / \theta_{FC-NSi}$$

9. At all nearby structures the triangle of water must fit in the unsaturated zone under the structure:

   $$D_{TV-NSi} < D_{SHWT-NSi}$$

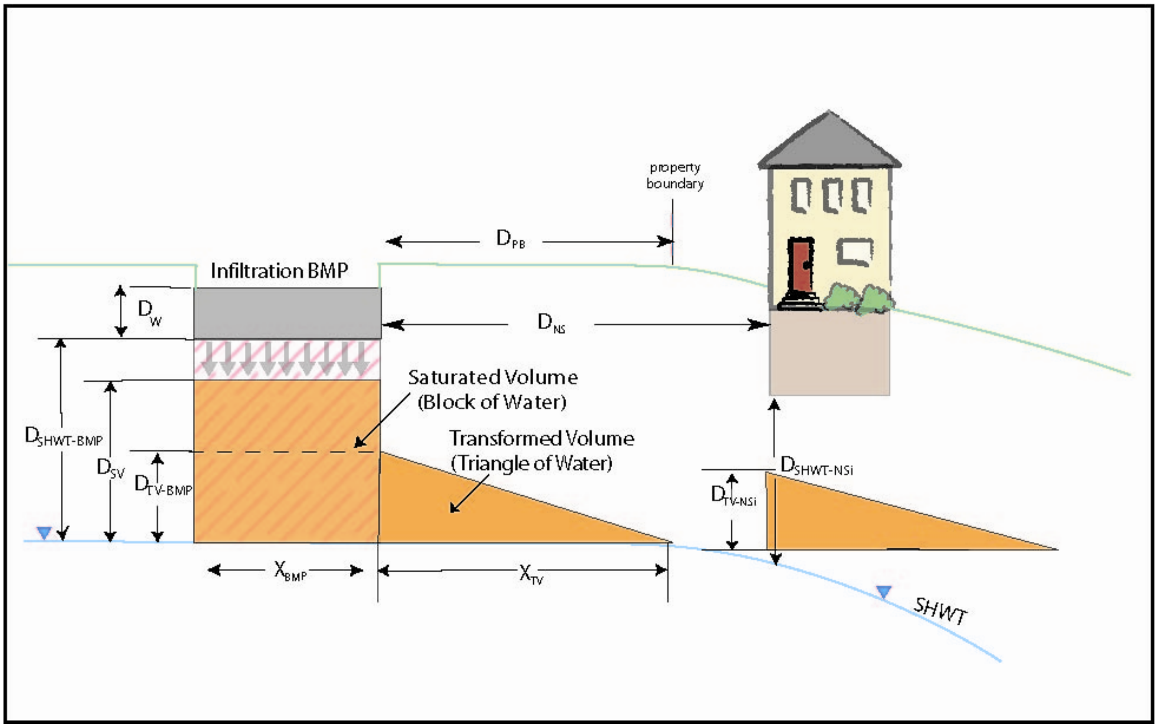


Figure 3. Geometry of transformed Triangle of Water, sloping water table (tier 4)

# TIER 5

Tier 5 is a modification of tier 2. In tier 2 the assumption was that the entire volume of water that was being recharged could fit into the unsaturated zone below the bmp. That is, the block of water is smaller than the block of soil (fig. 1). In some cases, however, the volume of water that is to be infiltrated is greater than can be contained in the unsaturated zone. Tier 5 relaxes this requirement by allowing the entire block of soil to become saturated with some water remaining in the BMP (fig. 4).

In order to be more conservative the following limiting assumptions are made:

- The water table is horizontal.
- There is no attenuation of the ground-water mound in the unsaturated zone.
- There is no vertical leakage downward into the water table.

The following steps should be followed to determine the top elevation of the saturated volume and check for compliance with Tier 5 criteria:

1. Define $\theta_{FC\text{-}BMP}$ as the field capacity of the soil under the BMP. Assume the field capacity of the unsaturated zone is 17% if the following conditions apply:

   a. The infiltration rate at the site is 1 in/hr or greater.
   b. The soils in the unsaturated zone are coarse grained and have a USDA classification of sand, loamy sand, or sandy.

   If conditions a and b are not both satisfied then the field capacity must be established by analysis of samples from the site.

2. The design storm fills the bmp to elevation $E_w$. As the unsaturated zone fills the water level in the BMP drops. Once the unsaturated zone is filled the water level in the BMP is defined as $E_{SV}$ and calculated as:

$$E_{SV} = E_w - (D_{SHWT\text{-}BMP} * \theta_{FC\text{-}BMP})$$

3. The bottom elevation of all structures must be above the top elevation of the block of water:

$$E_{NSi} > E_{SV}$$

In figure 4 it would appear that Nearby Structure 3 would fail the tier 5 requirements. It is important to note in this simple case there is no consideration of how long it will take the BMP to drain.

Tier 5 assumes the block of water is partially in the unsaturated zone and partially in the BMP. It is not easy to transform this block of water into a triangle of water. Because of these difficulties Tiers 3 and 4 cannot be expanded simply as Tier 2 was into Tier 5.

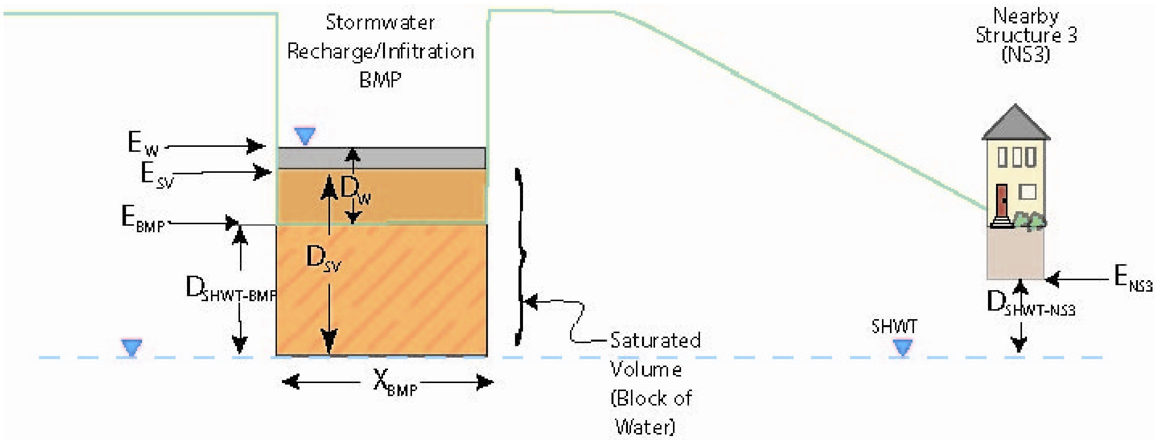


Figure 4. Geometry for Tier 5.

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