Chapter 10. LOW IMPACT

A number of "green" building initiatives have been developed to mitigate the effects of urban development on the health of people and the environment. Whether it is installing a green roof atop a city school, reducing a building's energy consumption by using natural lighting or driving on porous pavement in a neighborhood, these practices all represent green initiatives. Green initiatives use holistic planning to reduce the "footprint" of a site's impervious areas (buildings, parking lots, etc.).

Whether you are talking about the Smart Growth initiative, which encourages mixed land use to promote urban renewal and conservation, Leadership in Energy and Environmental Design (LEED) promoting energy efficiency and sustainability or Low-Impact Development (LID) which uses better site design techniques to maintain the natural hydrology of a site from its pre- to post-developed state, these initiatives all promote environmental sustainability and conservation. Designing sites to use less energy, be sustainable, and have a low-impact on the surrounding environment can have positive impacts on the health of both the public and the environment. These initiatives create healthier work and living environments, increase the health of our rivers lakes and streams, conserve natural resources, help reduce CO_2 emissions and help create a sustainable community. This chapter describes the design methodology of LID related to storm water management.

10.1 Low Impact Development (LID) Concepts

A site incorporating LID design generally produces a much smaller peak rate and volume of runoff than traditional storm water management methods. In a traditional design, the increased rate and volume of runoff is concentrated into pipes conveyed and detained in a single large structure at the "end-of-pipe". In an LID approach, storm water runoff is managed near the source ("source-controlled") in a number of small, landscape features. These features encourage infiltration and lengthen time of concentration as well as retaining flow to create a hydrologic landscape functionally equivalent to the pre-development conditions. These source treatment structures should ideally connect to natural drainage ways. The goal of LID is to combine this hydrologically functional site design with pollution prevention integrated management practices (IMPs) to reduce the impacts of development on the quality and quantity of runoff. The term IMP is used in place of BMP or best management practices as IMPS are integrated throughout the development providing source treatment as well as landscape amenities. Some examples of LID site planning considerations are listed below:

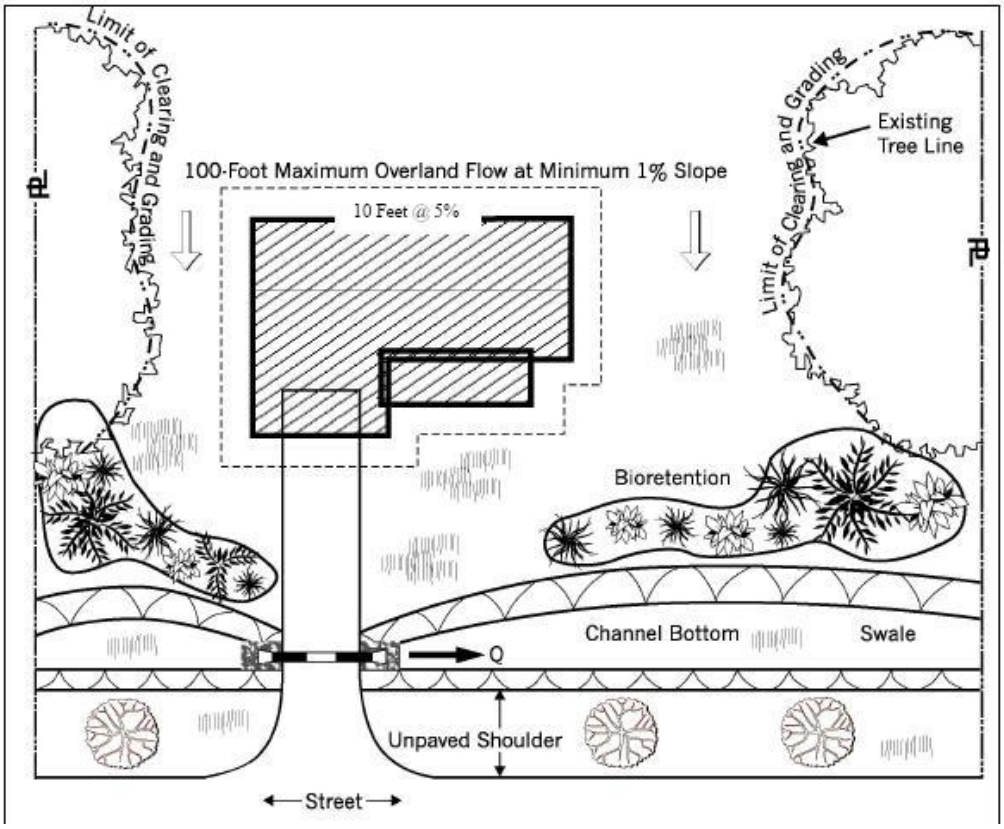
To assess the hydrologic functionality of a site, designers use the curve number (CN), time of concentration (Tc), and other factors. By maintaining the pre-development values of these metrics; a developed site will behave similarly to its pre-developed state; meeting storm water management requirements; as well as, preserving natural habitats and features, reducing thermal, flow and pollutant shocks to downstream environments, and utilizing runoff to supply groundwater recharge and landscaped areas. Figure 10-1 illustrates a layout of a single family residential lot using LID.

- Maintain natural drainage patterns
- Direct runoff to depressed areas for infiltration
- Preserve existing trees
- Reduce impervious areas
- Locate IMPs in soils with the highest permeability
- Disconnect impervious area from one another
- Limit clearing and grading as much as possible

- Locate impervious areas on less permeable soils
- Maintain the existing natural terrain and avoid construction of or in steep slope areas (>15%)
- Use “site fingerprinting” techniques to preserve tree canopy and natural vegetative buffers
- Re-vegetate cleared and graded areas
- Avoid concentrating flow into pipes or channels

10.1.1. Curve Number

The CN is used to determine the volume of runoff from a site. Developed LID sites try to maintain the same volume of runoff as their pre-developed condition, in essence maintaining the same curve number.



*Adopted from (MDDNR, 1999)

Figure 10-1: Layout of Residential Low-Impact Development Lot

Changes in land cover can increase the amount of runoff from a site by reducing infiltration. Therefore, reduction of land cover changes is the first step in limiting changes to the CN. There are a number of ways to reduce changes in land cover, including:

- Reduce the size of cleared area (i.e. preserve as much woodland as possible) and increase reforestation areas
- Locate cleared/graded areas outside permeable soils and vegetated areas
- Design roads, sidewalks, and parking areas to minimize land cover impacts
- Reduce or disconnect site imperviousness

10.1.1.1 Reduce Limits of Clearing and Grading

The limits of clearing and grading refer to the area of the site to which development is directed. This development area will include all impervious areas such as roads, sidewalks, rooftops, graded lawn areas and open drainage IMPs. To reduce the change in land cover and minimize hydrologic impact to the existing site, the development area should be located where impact on the pre development CN is less sensitive (e.g., on barren C and D type soils which will have less impact than developing forested A and B type soils). At a minimum, placing the development area outside of stream and lake buffer areas or increasing these buffer areas will lead to a reduction in land cover changes.

10.1.1.2 Site Fingerprinting

Site fingerprinting refers to a number of minimal disturbance techniques which can be used to further reduce the limits of clearing and grading. Site fingerprinting identifies the smallest possible site area that must be disturbed and clearly delineates this on the site. Techniques that can be used to minimize disturbance and preserve pre-development land cover (i.e. CN) include the following:

- Minimizing the size of construction easements, materials storage areas, and sighting stockpiles within the development envelope to the minimum needed to build the structures and move equipment. Significant compaction can be caused by construction traffic and is the leading cause of death or decline of mature trees in developed areas (Hinman, 2005)
- Careful sighting of lots and home layout, clearing and grading to avoid steep slopes, avoiding the removal of existing trees and excessive grading
- If steep slopes cannot be avoided, use of mitigation practices such as rainwater harvesting or dry wells should be implemented to attenuate the flow
- Roof rainwater harvesting is essential to LID in high density projects located on soils with low infiltration capacity.
- Minimize imperviousness by reducing paved surfaces on private areas. Examples are shared driveways, permeable pavements, or a driveway with just wheel strips.
- Design homes on crawl spaces or basements that conform to natural grades without creating a flattened pad for slab construction; thus saving clearing and grading costs.
- Flag the smallest site disturbance area possible to minimize soil compaction on site. Install construction fencing and tree protection areas where necessary to protect root structures along the limits of encroachment during the construction phase
- Re-vegetate cleared and graded areas to provide an effective way to decrease post-development CN. When minimal disturbance techniques are impossible or impractical, re-vegetation can be used to connect bioretention facilities to natural drainage ways, increase soil permeability, and mitigate land cover changes caused by development.

10.1.1.3 Preserve Permeable Soils and Vegetated Areas

Addition of impervious surfaces and compaction due to construction traffic over soils creates the greatest possible change in infiltration (e.g. CN) between pre- and post-development conditions. Therefore the preservation of existing soils should be promoted in all unpaved areas throughout the site. Areas with well drained soils are generally good sites for bioretention areas and help sustain groundwater recharge and

stream base flows.

Preservation of woodland areas can help reduce impacts on existing land cover. Woodland areas promote infiltration, distribute flow, reduce velocities, provide wildlife habitat, and help maintain stream bank and bed stability. Saving existing trees on a development site is a cost-effective and quality-enhancing practice. Expansion of vegetated areas adds to the benefits of preservation by further reducing CN changes. Trees and other native species should be kept in groups large enough to maintain soil moisture, sunlight, wind and other growth characteristics. Retaining mature trees of a single species is seldom successful (Hinman, 2005). For best results flag tree preservation area at least 3-ft outside of the existing edge of canopy.

10.1.1.4 Alternative Roadway Designs

Roadways, sidewalks, driveways, and parking areas are the greatest contributors to increasing CN and the size of the required detention/ retention structure. The increase in CN due to impervious areas and the associated land clearing increase both the amount and rate of runoff over pre-development conditions. LID designs minimize the effective imperviousness of roadways and parking areas by using minimal grading and clearing techniques, minimizing impervious areas, and using open drainage sections. The following features can be incorporated into a roadway design to minimize land cover impacts:

Narrow road sections: Small sections reduce impervious area and clearing and grading impacts. Reducing pavement widths from 26' to 20' reduces pavement area by 30%. A 40' cul-de-sac with an interior bioretention area of 20' in diameter decreases impervious area by 1300 ft^2 over a standard 40' cul-de-sac while still allowing adequate room for emergency vehicles to turn around. Other traffic calming techniques can also be used to minimize pavements while maintaining safety. Porous pavers may also be used where appropriate. Using queuing streets or pull-out parking in parking lots with porous pavers in peak overflow areas can reduce the size of parking lots.

Open Drainage Sections: Grassed swales and infiltration trenches can be used in place of curb and gutter where allowed to distribute and attenuate the flow as well as enhance water quality and result in reduction of drainage pipes and associated infrastructure.

Road Layouts: Local and collector streets with curves and alignment changes allow the roadway to fit into existing topography, minimizing earthwork and hydrologic impacts. Curvilinear road layouts must meet current AASHTO design requirements. Looped road layouts provide open areas in the center for bioretention as well as a visual break for houses facing the street. Minimizing frontage widths and providing green streets or open space pathways between homes for walking and biking will also reduce impervious areas.

Reduced Sidewalk Applications: Reducing sidewalk widths (44" ADA recommended minimum), using porous pavers, or only building sidewalks on one side of the street, where allowed, decrease site imperviousness.

10.1.1.4.1 Design of Roadways on Steep Slopes

LID designs generally avoid construction on steep slopes. However in mountainous or hilly areas, this situation can not be avoided especially in the case of roadway drainage. Roads on steep slopes most often consist of a series of switchbacks cut into the hillside. These roadways typically have no crown and drain towards the hillside into a ditch or open conveyance. In curves or other areas a pipe or culvert will convey the water from the ditch under the road and down the hillside. In order to provide adequate storm water treatment and lower the impact for these roadways, a number of practices have been developed or adapted from existing practice.

One such practice is the addition of a filtration area beneath the open ditch with an under-drain to provide separation and limited treatment for the WQV. Designed in a similar manner to a traditional infiltration trench, a steep slope trench must account for much faster velocities due to the increased slope (up to 15%). This may require the bottom of the trench to be rip-rap, concrete or another material with high erosion resistance. In order to provide infiltration with the use of concrete or rip-rap channel liners, the under-drain may have standpipes capped with grates every few hundred feet or as needed. Periodic outlet pipes should be installed to pass underneath the roadway to an outlet sufficiently protected from erosion. The object of the rock media is not to infiltrate water into the hillside soils as this can reduce the stability of the slope and increase the risk of landslides. The object is to provide filtration and detention while conveying the WQV to an appropriate outlet point.

On the down slope side of the roadway, practices such as relief drains can be used to capture and convey water to an appropriate outlet. These drains also intercept groundwater seepage in the slope increasing slope stability. Figure 10-2 shows a diagram of a relief drain.

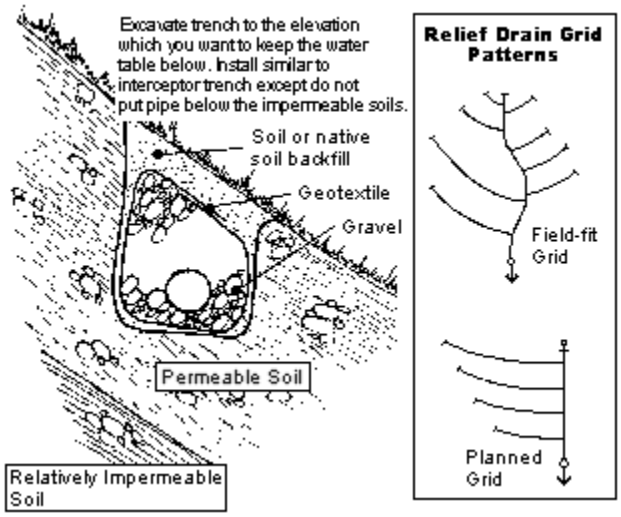


Figure 10-2: Relief Drain Washington dept. of ecology

Other down slope practices are staggered crescent benches which are staggered pockets to hold plantings, and chimney drains which are vertical drains through the hill which have an outlet at the toe of the slope. A number of geosynthetics are also available. If retaining walls are present weep gardens may also be appropriate.

10.1.1.5 Reduction and Disconnection of Impervious Areas

Flows from impervious areas such as rooftops, parking lots and roadways are generally concentrated in downspouts or gutters increasing flow rates and velocities. If these areas are interconnected they can provide a path for runoff from a large area to quickly reach an outlet increasing peak rate. By reducing and disconnecting these areas from one another, the amount of direct runoff can be greatly reduced. Disconnecting impervious areas requires careful site planning. There must be adequate circulation so that pedestrians and vehicles do not use grassed areas and cause erosion. The following areas should be addressed when reducing and disconnecting impervious areas.

Minimize rooftop imperviousness: Rooftops contribute to site imperviousness and concentrate flow in downspouts. Smaller roof areas provided by multilevel homes can reduce the area. Directing downspouts to bioretention/infiltration areas, building green roofs, rainwater harvesting and other practices can mitigate the impacts of these impervious areas.

Disconnect impervious areas: Redirecting and dissipating concentrated flows onto vegetated surfaces can reduce the post-development CN.

- Direct roof drains to vegetated areas
- Direct flows from small swales to stabilized vegetated areas
- Break up flow direction from large paved surfaces
- Encourage sheet flow through vegetated areas

Carefully locate impervious areas: Place impervious areas so that they drain to natural features, vegetative buffers, or permeable zones/ soils. Other techniques include:

- Using shared driveways in residential areas
- Limiting residential driveway widths to 9-ft
- Minimizing building setbacks to reduce driveway lengths
- Efficient parking lot layouts. Avoid single loaded aisles, angled parking, and excessive spaces
- Plan efficient layouts to minimize road length, single loaded streets and double frontage lots.
- Use Porous or permeable pavers

10.1.1.6 Retention Storage

In an LID design after following careful site planning guidelines and implementing practices to minimize changes in CN there will most likely still be a need for additional retention storage to maintain the CN. This storage should be provided in source control IMPs. These IMPs are small scale and distributed strategically throughout the site close to the origin of the runoff that they treat. When the need arises additional detention basins may be required.

10.1.1.6.1 Residential

Residential lots must be laid out to distribute retention storage volume as much as possible throughout the site. It is important to allocate enough area to provide for needed storm water retention storage. In most cases, adequate space is available, but situations may arise on small lots (1/4-acre or less) where the storage requirements can not be accommodated while allowing for reasonable use of lawn and/or open space area. Retention storage in residential areas can be incorporated onto individual lots or common

areas. Due to maintenance concerns, locating IMPs in common areas dispersed throughout the site is recommended. However, guidelines for locating on-lot retention storage areas on residential LID sites include the following:

- Locate swales and bioretention IMPs (rain gardens) where they can provide a green space connection between existing wooded or natural areas;
- Bioretention practices must be located outside a road or utility right-of-way to avoid conflict with underground utilities;
- Infiltration or enhanced swales may be used in public right-of-way;
- Keep all LID storm water IMPs outside sensitive areas and respective buffers; and,
- Insure that the contributing drainage area to the site is stabilized prior to bioretention installation.

10.1.1.6.2 Commercial/Industrial

For commercial/ industrial LID sites, retention storage planning is focused on two areas, (1) perimeter buffer areas and (2) green areas located within parking lots. On site retention storage can be provided as interior bioretention, located within required landscape islands, or as cistern or rain barrel facilities. If the available green space in the parking area is insufficient, bioretention within the landscaped buffer area located on the perimeter of the site can be used. Existing minimum green space requirements plus the size of perimeter buffers and parking requirements will dictate the feasibility of providing all required storage within surface swales, terraces, or bioretention facilities.

10.1.1.6.3 Additional Methods

The following LID practices can be used for detention within residential or commercial/ industrial sites:

- Swales, check dams, and diversion structures
- Restricted drainage pipe and inlet entrances
- Wider swales and terraces
- Rain barrels, cisterns, dry wells
- Rooftop and Parking lot Storage
- Terraces designed for and used as detention
- Infiltration trenches
- Retention or Irrigation ponds
- Use 4:1 slopes for roadway swales outside of public right-of-way to minimize disturbance and preserve trees. Stabilizing these slopes with fiber mats and planting perennials, wild flowers or other dense ground cover or woody shrubs will enhance infiltration and increase time of concentration.
- Locate on-lot swales where they can provide green space connection to existing wooded or natural areas

In summary, a Site CN is very important in determining the amount of runoff that will be produced from a rain event. LID techniques help to reduce changes in CN caused by site development. Table 10-1

summarizes which LID techniques affect the factors governing the CN.

Table 10-1: LID Planning Techniques to Reduce the Post-Development LID CN

Suggested Options Affecting Curve Number	Reduce Length And Width of Roads and Driveways	Conserve Natural Resources Areas	Minimize Limits of Clearing and Grading	Preserve Permeable Soils	Preserve Natural Depressions	Use Transition Zones	Use Vegetated Swales	Provide For Bioretention
Land Cover Type		X	X			X	X	X
Percent of Imperviousness	X					X		
Hydrologic Soils Group		X		X				
Hydrologic Condition		X	X	X				
Disconnectivity of Impervious Area	X							
Storage and Infiltration					X			X

*Adopted from (MDDNR, 1999)

10.1.2. Time of Concentration

Time of concentration (Tc) describes the time it takes for runoff to flow from a site's most hydrologically remote point to the outlet. A sites time of concentration in conjunction with the CN determines the peak discharge rate for a storm event. The time of concentration is a function of flow velocity which in turn is affected by:

- Travel distance (flow path)
- Slope of the ground and/or water surface
- Ground surface roughness
- Channel shape and pattern

These factors can then be manipulated to modify the Tc of an LID site by modifying the following aspects of the flow:

- Maximize sheet flow
- Modify/ lengthen flow path
- Site and lot slopes
- Open swale IMP geometry

- Site and lot vegetation (roughness)

Sheet Flow: The site should be graded to maximize overland sheet flow distance and minimize the disturbance of woodlands along the Tc flow path. Where graded areas flow to natural drainage ways, velocities should not exceed 1-ft/sec to the extent practicable, as faster velocities may provide insufficient contact time for settlement of suspended solids. The installation of a stable, level spreader along the upland edge of the natural drainage way buffer, or flat grassy area about 30-ft wide upland of the buffer will allow the runoff to spread out.

Flow Path: Increasing the flow path or travel distance will increase the time of concentration and allow more time for infiltration reducing not only the peak flow but the total volume of runoff as well. In residential areas, rooftop and driveway runoff can be permanently infiltrated or stored within infiltration trenches, dry wells, or cisterns strategically located to capture the runoff prior to it reaching the lawn. Strategic lot grading can increase both the surface roughness and the travel length of the runoff lengthening the time of concentration along that particular flow path.

Site and Lot Slopes: Flatten lot slopes to approach a minimum of 1%. This will increase infiltration and travel time. While codes may require a positive drainage perimeter around the building, lot areas outside the pad should contain at least 1% positive slope. Also, soil compaction of original soils (not fill) in the lot should be avoided to maximize infiltration.

Open Swales: Open drainage conveyances are preferred in LID designs over conventional storm drainage structures. To alleviate flooding problems, vegetated or grassed open drainage IMPs should be provided as the primary means of conveying surface runoff between lots and along roadways. Swales can be made wider and flatter to decrease velocity and increase T_c. Infiltration and terraces can be used to reduce the quantity of the surface runoff as the need arises. The site should be graded as to minimize the quantity and velocity of surface runoff within the open drainage IMPs.

Site and Lot Vegetation: Revegetate and/ or plant areas to promote natural retention and increase travel time. Re-vegetating graded areas or preserving existing vegetation can reduce peak discharge by increasing surface roughness. Connecting vegetated buffer areas with existing vegetation or forest allows designers to avoid “paved areas” as the T_c flow path for the “shallow concentrated flow” part of the Tc calculation. The benefits of these practices minimize the need for bioretention facilities.

In summary, a site T_c is very important in determining the peak rate of runoff that will occur during a rain event. LID techniques help to reduce T_c. Table 2 summarizes which LID techniques affect the factors governing the T_c.

Table 10-2: LID Planning Techniques to Maintain Pre-development Tc

LID Objective	Disconnect Impervious Areas	Wider and Flatter Swales	Maintain Sheet Flow	Clusters of Trees and Shrubs in Flow Path	Provide Tree Conservation Zones	Minimize the Use of Storm Drain Pipes	Preserve Existing Topography	Provide for Bioretention
Minimize disturbance	X		X	X	X	X	X	
Flatten grades		X	X			X	X	X
Reduce height of slopes						X	X	
Increase flow path	X	X	X	X		X		
Increase roughness	X		X	X	X	X		X

*Adopted from (MDDNR, 1999)

10.2 LID Hydrologic Analysis

The goal of LID is to create a post-development landscape that has similar hydrologic functionality to the pre-developed site. This is done by maintaining the pre-development CN, Tc, as closely as possible and using a number of small scale retention structures near sources of increased runoff to make up the difference in runoff volume and peak rate between the pre- and post-developed conditions. The LID design approach focuses on the following hydrologic analysis and design components:

CN: Minimizing change in the post-development CN by reducing impervious areas, preserving trees, meadows and well drained areas to reduce storage requirements.

T_c: Maintaining the pre-development Tc to minimize the increase in peak runoff rate by lengthening flow paths and reducing the length of conveyance systems

Retention: Providing retention storage for volume, peak and water quality control, near the source of increased runoff.

Detention: Providing additional detention storage, if required, to maintain peak runoff control and prevent flooding.

Table 10-3 provides a summary of LID techniques that can be used to manipulate the above design and analysis components.

Table 10-3: LID Techniques for use with Design and Analysis Components

LID Hydrologic Design and Analysis Components	Flatten Slope	Increase Flow Path	Increase Sheet Flow	Increase Roughness	Minimize Disturbance	Flatten Slopes On Swales	Infiltration Swales	Vegetative Filter Strips	Constricted Pipes	Disconnected Impervious Areas	Reduce Curb And Gutter	Rain Barrels And Cisterns	Rooftop Storage	Bioretention	Revegetation	Vegetation Preservation
Lower Post-development CN					X		X	X		X	X			X	X	X
Increase Tc	X	X	X	X		X		X	X	X	X	X	X	X	X	X
Retention							X	X				X	X	X	X	X
Detention						X			X			X	X			

*Adopted from (MDDNR, 1999)

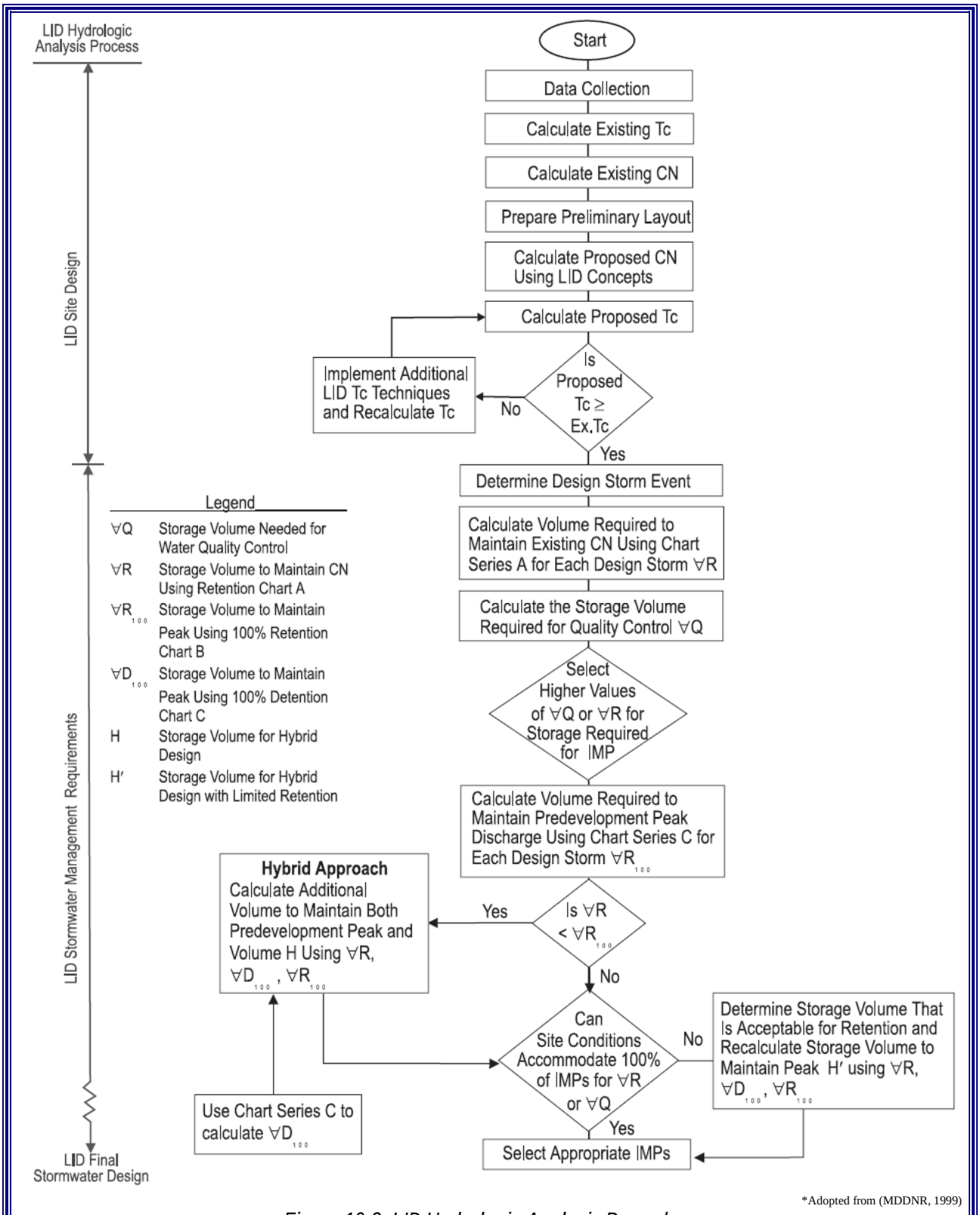
10.2.1 Process and Computations for LID Hydrologic Analysis

The LID hydrologic analysis procedure is used to determine the post-development CN, Tc, retention, detention and water quality requirements of the site (MDDNR, 1999). The analysis process is illustrated by the flow chart shown in Figure 10-3. The hydrologic evaluation steps are performed using an iterative process. Numerous site planning and management configurations may need to be evaluated to identify the optimum solutions. The concept of low-impact development is to emphasize the simple and cost-effective solutions. Use of hydrologic evaluations can assist in identifying these solutions prior to detailed design and construction costs.

The basic information used to develop the LID site plan and used to determine CN and Tc for the pre-and post-development conditions is the same as that needed for traditional storm water management. A variety of models are available to simulate the rainfall-runoff processes for watersheds. The selection of the appropriate modeling technique will depend on the level of detail and rigor required for the application and the amount of data available for setup and testing of the model results.

10.2.2 Data Collection

The basic information used to develop the LID site plan and used to determine CN and Tc for the pre-and post-development conditions is the same as that needed for traditional storm water management. A variety of models are available to simulate the rainfall-runoff processes for watersheds. The selection of the appropriate modeling technique will depend on the level of detail and rigor required for the application and the amount of data available for setup and testing of the model results.



*Adopted from (MDDNR, 1999)

Figure 10-3: LID Hydrologic Analysis Procedure

10.2.3 Determining the LID Runoff Curve Number

The determination of CN requires careful evaluation of each land cover type within the site. By preserving natural vegetation and infiltration areas while minimizing and disconnecting impervious areas, the designer can minimize the need for retention IMPs and take full advantage of infiltration characteristics. The first step in determining the CN is to determine the percentage of each land use/cover on the site. The site should be analyzed in discrete unites to determine the CN. Curve numbers can be found in TR-55 (SCS, 1986). Because LID focuses on minimal disturbance and retaining areas with high storage and infiltration potential, overlying the site with SCS HSG boundaries can be used to develop the LID CN. Calculating the composite CN without considering disconnectivity of impervious areas is done using the following equation:

$$CN_c = \frac{CN_1 A_1 + CN_2 A_2 + \ldots + CN_n A_n}{A_1 + A_2 + \ldots + A_n}$$

Where, CN_c is the composite curve number, A_j is the area of each land cover type, and CN_j is the curve number for each land cover.

When the impervious areas are less than 30% of the total site area, the percentage of unconnected impervious areas within the watershed influences the calculation of the CN (SCS, 1986). Disconnected impervious areas are impervious areas without any direct connection to a drainage system or other impervious surface. Roof drains from homes directed to lawn areas where sheet flow occurs are an example of a disconnected impervious area. Disconnecting impervious areas from one another reduces the volume of runoff. The CN_c for sites with disconnected impervious areas less than 30% of the total site area is given by the following equation:

$$\mathrm{CN_c} = \mathrm{CN_p} + \left(\frac{\mathrm{P_{imp}}}{100}\right) \cdot \left(98 - \mathrm{CN_p}\right) \cdot \left(1 - 0.5\mathrm{R}\right)$$

Where, R is the ratio of unconnected impervious area to total impervious area, CN_p is the composite pervious CN, and P_{imp} is the percentage of impervious site area.

10.2.4 Determining Time of Concentration

The determination of T_c using LID is performed in the same manner as in conventional storm water management. In LID however, the pre-development Tc should be greater than or equal to the post-development T_c. The procedure for determining Tc can be found in section 5.3.2 of this manual.

10.2.5 Storm Water Management Requirements

In order to fulfill the objectives of an LID design, a post development site must store runoff in order to maintain the pre-development volume, pre-development peak runoff rate, and frequency and meet water quality requirements. Once the CN and Tc have been determined for the pre- and post-development conditions, storage requirements can be calculated. Of those requirements, the one which requires the largest volume to maintain will control the design. A series of design charts have been developed to estimate the surface area required to control the increase in runoff volume, rate and frequency. These design charts are based on an arbitrary depth of 6-inches for all storage structures, as this is the

recommended depth for LID bioretention basins. The charts also neglect any reduction in direct runoff from infiltration. The results of the design charts may be transformed to a depth other than 6-inches and to include the effects of infiltration by using the following equations, respectively:

$$\%\ \text{Site Area for BMP} = \frac{\%\ \text{Site Area for BMP at 6 inch depth} \cdot 6\,\text{inch}}{\text{alternative storage depth}}$$

$$\%\ \text{Site Area for BMP} = \frac{\text{Initial}\ \%\ \text{Site Area for BMP} \cdot (100 - x)}{100}$$

Where, x is the percentage of the storage volume infiltrated. The value of x should be minimal (< 10%).

In order to meet storm water management requirements, the appropriate IMPs or combinations of IMPs (treatment trains) must be selected to satisfy the surface area and volume requirements as calculated from the design charts. The design charts to be used to evaluate these requirements are:

- Chart Series A: Percentage of Site Area Required to Maintain the Pre-development Runoff Volume Using Retention Storage
- Chart Series B: Percentage of Site Area Required to Maintain the Pre-development Peak Runoff Rate Using 100% Retention
- Chart Series C: Percentage of Site Area Required to Maintain the Pre-development Peak Runoff Rate Using 100% Detention

The design charts are based on the following general conditions, and can be found in Appendix M:

- The land uses for the development are relatively homogeneous throughout the site
- The storm water management measures are evenly distributed across the development, to the greatest extent possible
- The percent of site area is based on 1-inch runoff increments. Use linear interpolation for determining intermediate values.

The procedure to determine the IMP requirements is outlined in the following steps. It should be noted that the practical and reasonable use of the site must be considered and IMPs must not restrict this use.

Step 1: **Determine storage volume required to maintain pre-development volume or CN using retention storage.** Use Chart Series A. The IMPs must not restrict the use of the site. The storage area, expressed as a percent of the entire site area, is for volume control only; additional storage may be required for water quality or peak rate control. The charts are incremented by inches of rainfall. Linear interpolation between charts may be necessary to capture the appropriate design storm.

Step 2: **Determine storage volume required for water quality control.** This volume is translated to a percent of the site area by assuming a storage depth of 6-inches. The volume requirement for storm water management water quality control is the first 1-inch of runoff from impervious areas. The surface area required for water quality volume control is shown in the following equation:

$$\%\ \text{Site Area for Water Quality BMP} = \frac{\text{Site Area} \cdot P_{imp} \cdot 1-\text{inch}}{\text{Site Area} \cdot \text{BMP Depth}}$$

<u>Step 3</u>: Determine storage volume required to maintain peak storm water runoff rate using 100 percent retention. The percentage of site area or amount of storage required to maintain the pre-development peak runoff rate is based on Chart Series B. This chart series is based on the relationship between storage volume, V_s/V_r, and discharge, Q_0/Q_i, to maintain the pre-development peak runoff rate. Where V_s is the volume of storage needed to maintain the pre-development peak runoff rate using 100% retention, V_r is the post development peak runoff volume, Q_0 is the peak outflow discharge rate, and Q_i is the peak inflow discharge rate.

<u>Step 4</u>: Determine whether additional detention storage is required to maintain the pre-development peak runoff rate. The percentage of the site required to maintain the pre-development volume using retention, as calculated in Step 1, may not be adequate to maintain both the pre-development volume and peak runoff rate. As CNs diverge between pre- and post-development conditions, the storage requirement to maintain the volume is greater than the storage required to maintain the peak runoff rate. As the CN converge or remain similar, the storage required to maintain the peak runoff rate is greater than that required to maintain the volume. If the percentage of the site required to maintain the pre-development runoff volume (Step 1) is less than the percentage of the site required to maintain the pre-development peak runoff rate using 100% retention (Step 3), then additional detention storage will be required.

The combination of retention and detention practices is defined as a hybrid IMP. The procedure for determining the percentage of site area required for the hybrid approach is given in Step 5. **Note: Steps 5 through 7 are only required if additional detention storage is needed (as determined by Step 4).**

<u>Step 5</u>: Determine storage required to maintain pre-development peak runoff rate using 100 percent detention. The percentage of site area required to maintain the pre-development peak runoff rate using 100% detention is given by Chart Series C. This chart series should only be used when hybrid design is necessary or where site limitations prevent the use of retention storage. Sites which may prevent the use of retention storage may have severely limited soils for infiltration or retention practices. The procedure to determine the site area is the same as that of Step 3.

Using Chart Series B and Chart Series C, the following assumptions apply:

- The T_c for the post-development condition is equal to the T_c for the pre-development condition.
- The depth of storage for the detention structure is 6-inches. For other depths use the following equation:

$$\%\ \text{Site Area for BMP} = \frac{\%\ \text{Site Area for BMP at 6 inch depth} \cdot 6\,\text{inch}}{\text{alternative storage depth}}$$

- The surface area, is for peak flow control

<u>Step 6</u>: Use hybrid facility design. When the percentage of site area for peak rate control exceeds that for volume control, a hybrid approach must be used. While retaining all of the volume will automatically control the peak rate, controlling the peak rate will not necessarily retain the entire excess volume. Therefore, a hybrid approach calculates the necessary site area to satisfy both criteria. To determine the hybrid area needed, the ratio of retention to total storage must be determined using the following equation:

$$x = \frac{50}{V_{R100} - V_{D100}} \cdot \left(- V_{D100} \cdot \sqrt{V_{D100}^2 + 4 \cdot \left(V_{R100} - V_{D100} \right) \cdot VR} \right)$$

This value can then be used to determine the additional amount of site area, above that required for volume control, needed to maintain the pre-development peak runoff rate with the following equation:

$$H = VR \cdot (100 - x)$$

Where VR is the large of the two area values in percent obtained from Step 1 (Chart A) and Step 2, V_{R100} is the value obtained from Chart B, in Step 3, V_{D100} is the value obtained from Chart C, Step 5, x is the ratio of retention storage to total storage, and H is the hybrid area expressed as a percentage of the total site area.

Step 7: Determine hybrid amount of IMP site area required to maintain peak runoff rate with partial volume attenuation (required when retention area is limited). This step should be used when a site conditions or physical constraints limit the amount of site area which can be used for retention practices but a hybrid approach is still needed. When this occurs, the amount, or percentage of area available for retention IMPs is less than the percent required to maintain the volume. A variation of the hybrid approach is used to maintain the peak runoff rate while attenuating as much of the increased runoff volume as possible based on input from the designer. The designer should determine the appropriate percentage of the site available for volume control (VR') by analyzing site constraints. This percentage is then put into the equations above in place of VR for determining the ratio of retention to total storage, "x", in place of VR. Note that VR' should at least equal the water quality volume from Step 2.

10.3 Low-Impact Development Integrated Management Practices (LID IMPs)

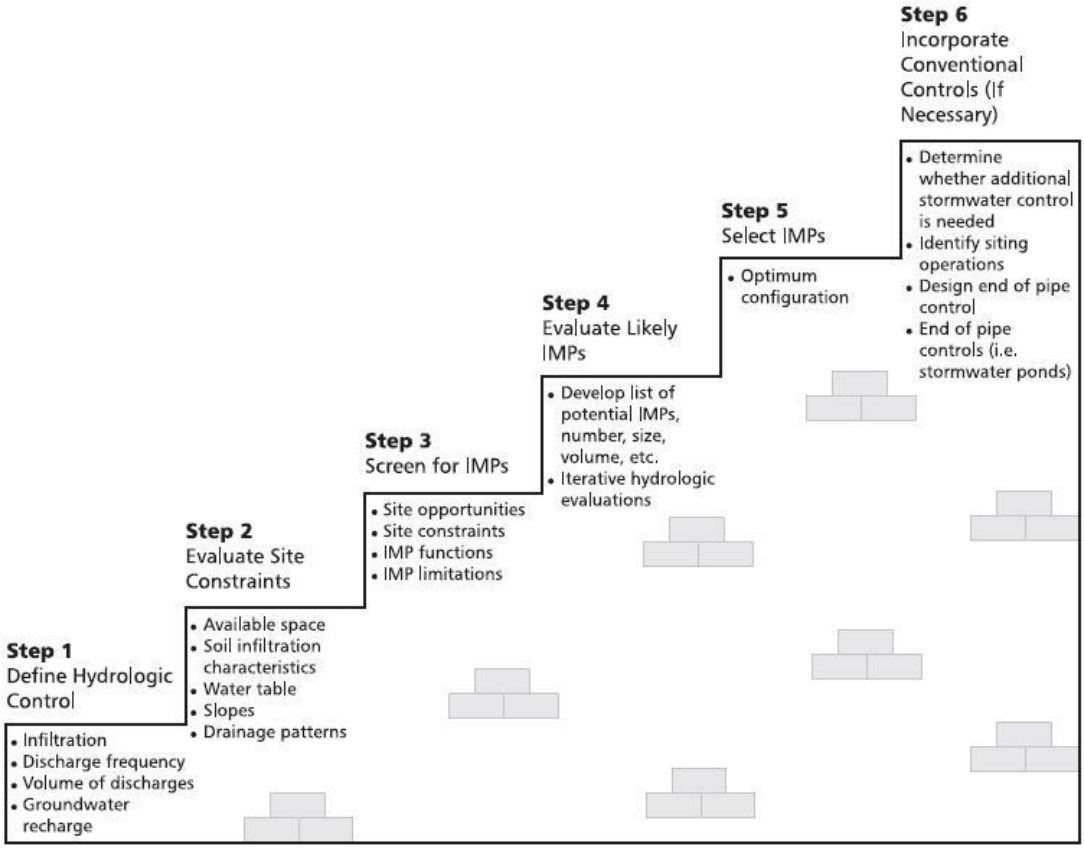
Low-impact development uses distributed source control techniques to achieve the desired post-development hydrologic conditions. The previous sections highlight how site planning and design techniques can be used to minimize hydrologic effects of development; as well as, asses the need for storage due to increases in runoff volume, or peak rate. LID IMPs are used to satisfy these storage volume requirements. These IMPs are the preferred for use with LID as they can maintain the pre-development runoff volume and be integrates into the site design. The design goal is to locate the IMPs at the source or lot, ideally on level ground within individual lots of the development or providing a green space connection to existing woodlands. Management practices that are suited to low-impact development include:

- Bioretention facilities
- Filter/buffer strips and other multifunctional landscape areas
- Grassed swales, bio-swales and wet swales
- Infiltration Trenches
- Rain barrels, Cisterns, and Dry Wells

10.3.1 LID IMP Selection Process

The selection and design process begins with the control goals identified in section 2. A set of simple

steps, shown in Figure 10-4 can help guide the designer through the selection process. These steps are iterative and may be repeated many times to optimize the design to the hydrologic control objectives and other design objectives. More than one design may meet all the constraints and design considerations and it is up to the developer/ designers judgment to decide which design is the most appropriate for their particular site and land use.



*Adopted from (MDDNR, 1999)

Figure 10- 4: Steps for Selection of LID IMPs

Step 1: Define Hydrologic Controls Required. The hydraulic controls required are those needed to maintain the pre-development runoff volume, peak runoff rate, and frequency. Because of the nature of LID, when the design parameters were quantified for the pre-development conditions, they define or quantify the hydrologic controls required for the developed site. These objectives were defined and addressed in the previous sections. Hydrologic functions such as infiltration, frequency and volume of discharges, and groundwater recharge become essential considerations when identifying and selecting IMPs.

Step 2: Evaluate Site Opportunities and Constraints. In this step, the site should be evaluated for opportunities and constraints. Opportunities are locations where physical conditions like available space, infiltration characteristics and slopes are amenable to IMP installations. These same conditions might also constrain the use of IMPs. Table 4 provides a summary of potential site constraints for various IMPs.

Table 10-4: Site Constraints of LID IMPs

	Bioretention	Dry Well	Filter/Buffer Strip	Swales: Grass, Infiltration, Wet	Rain Barrels	Cistern	Infiltration Trench
Space Required	Minimum surface area range: 50 to 200 ft^2 Minimum width: 5 to 10 ft Minimum length: 10 to 20 ft Minimum depth: 2 to 4 ft	Minimum surface area range: 8 to 20 ft^2 Minimum width: 2 to 4 ft Minimum length: 4 to 8 ft Minimum depth: 4 to 8 ft	Minimum length of 15 to 20 ft	Bottom width: 2 ft minimum, 6 ft maximum	Not a factor	Not a factor	Minimum surface area range: 8 to 20 ft^2 Minimum width: 2 to 4 ft Minimum length: 4 to 8 ft
Soils	Permeable soils with infiltration rates > 0.27 in/hr are recommended. Soil limitations can be overcome with use of underdrains	Permeable soils with infiltration rates > 0.27 in/hr are recommended	Permeable soils perform better, but soils not a limitation	Permeable soils provide better hydrologic performance. .Selection of type of swale, grassed, infiltration, or wet is influenced by soils	Not a factor	Not a factor	Permeable soils with infiltration rates > 0.52 in/hr are recommended
Slopes	Usually not a limitation, but a design consideration	Usually not a limitation, but a design consideration. Must locate down gradient of building and foundations	Usually not a limitation, but a design considerations	Swale side slopes: 3:1 or flatter Longitudinal slope: 1.0% minimum; 5% maximum based on permissible velocities	Usually not a limitation, but a design consideration for location of barrel outfall	Not a factor	Usually not a limitation, but a design consideration. Must locate down gradient of buildings and foundations
Water Table/ Bedrock	2 to 4 ft clearance above water table/ bedrock recommended	2 to 4 ft clearance above water table/ bedrock recommended	Generally not a constraint	Generally not a constraint	Generally not a constraint		2 to 4 ft clearance above water table/ bedrock recommended
Proximity to build foundations	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Not a factor		Minimum distance of 10 ft down gradient from buildings and foundations recommended
Max. Depth	2 to 4 ft depth depending on soil type	6 to 10 ft depth depending on soil type	Not applicable	Not applicable	Not applicable		6 to 10 ft depth depending on soil type
Maintenance	Low requirement, property owner can include in normal site landscape maintenance	Low requirement	Lower requirement, routine landscape maintenance	Low requirement, routine landscape maintenance	Low requirement		Moderate to high

*Adopted from (MDDNR, 1999)

<u>Step 3</u>: Screen for Candidate Practices. Based on the evaluation of site opportunities and constraints, a comparison with the available practices is made. IMPs that are inappropriate or infeasible for the specific site are excluded. The screening should consider the hydrologic functions, size, water quality contribution and other factors. Screening is not simply a matter of selecting from a menu of available IMPs but an integrated planning and design process.

<u>Step 4</u>: Evaluate Candidate IMPs in various configurations. After the candidate IMPs are identified, they are deployed as appropriate throughout the site and the hydrologic methods described previously are applied to determine if the mix of IMPs satisfies the hydrologic control objectives. Typically on the first attempt, the hydrologic control objectives are not met. Design iterations may be necessary, adjusting the number and size of IMPs until the hydrologic control and design objectives are optimized.

<u>Step 5</u>: Select Preferred Configuration and Design. The iterative design process typically identifies a number of potential configurations and mixes of IMPs. Design factors such as space requirements, aesthetics, cost and other factors can all be factored into the process to arrive at an optimum or preferred

configuration and mix of IMPs that provide the identified level of hydrologic control at a reasonable cost.

Step 6: Design Conventional Controls if Necessary. If for any reason the hydrologic control objectives cannot be achieved using LID IMPs, it may be necessary to add so conventional controls. Sometimes site constraint such as a high water table, low-permeability soils or intensive land uses such as commercial or industrial sites preclude the use of sufficient LID IMPs to satisfy the hydrologic design objectives. In this case it is recommended that LID IMPs be used to the extent possible and conventional controls, such as detention or retention practices (i.e. ponds), be used to satisfy the remaining objectives.

10.3.2 Design of LID Best Management Practices

10.3.2.1 Bioretention/Rain Garden Facilities

Bioretention facilities are detention structures that manage and treat storm water runoff in a shallow depression using a conditioned planting soil and plantings adapted to the climate to filter and infiltrate runoff into a prepared soil bed. These areas are designed to mimic natural forest ecosystems with a combination of soil filtration and plant uptake. Plantings may include trees, shrubs, grasses, and other herbaceous plants. Bioretention areas are applicable to small sites typically nor more that 1-2 acres. The contributing area should be well stabilized to prevent excessive debris and sediment from collecting in the bioretention area as this can effect filtration. As many of the native soils in Greenville County do not allow for adequate infiltration rates, bioretention cells are required to have an under-drain system placed beneath the planting mix. This under-drain connects to a storm water conveyance system or an outlet. In addition bioretention cells must have an overflow outlet in the case of large storms. Variations on this design included bio-swales which incorporate the same design features as a bioretention cell but are designed as part of the storm water conveyance system. Biodetention uses vegetative barriers across a slope to disperse, infiltrate, and treat storm water runoff. Key design considerations for bioretention cells can be found in chapter 9. However as LID applications of this IMP can vary considerably from a water quality application a brief discussion tailored to LID is included below.

Bioretention cells were first proposed in Prince George's County, Maryland and have become the principle tool in LID. The original concept was to treat storm water pollutants, but this practice may also be used as a source treatment retention structure. While bioretention cells have shown good performance in removing metals, suspended solids, and oil and grease pollutants, they perform poorly in the removal of nutrients, especially nitrogen. However, in areas where nitrogen is a pollutant of concern, bioretention can be adapted to provide some denitrification. Bioretention cells also called rain gardens are a landscape amenity, in addition to being a storm water quality and quantity control structure. This practice can be applied in a number of locations and settings including but not limited to:

- Individual lots for on-lot impervious surface treatment and infiltration
- Common areas to treat runoff from adjacent facilities such as apartment complexes, or commercial areas
- Within cul-de-sacs, parking lot islands, roadsides

Design considerations for bioretention cells include:
Soils: the soils underlying and surrounding a bioretention cell govern infiltration capacity, drainage time and storage capacity. These soils may consist of multiple layers with an optional surface layer being mulch underlain by a planting mix which in turn is underlain by a gravel filter layer containing an under-drain system.

Site Topography: For slopes greater than 10 %, sloped biodetention or weep garden designs should be used.

Depth-to-water table: A minimum of 3 ft of separation from the seasonal high water table to the bottom of the bioretention cell is required.

Expected pollutant loading: where nitrate is a concern, the under-drain should be elevated from the bottom of the facility to crease a fluctuating anaerobic/aerobic zone below the drain pipe to encourage the denitrification process. Phosphorous removal has been shown to increase with the depth of the cell. Oil and Grease removal occurs predominately in the mulch layer. Metals and sediments are predominately removed through filtration and sorption into the soil.

Plant Selection: appropriate plants should be used; preferably native species which can withstand anticipated seasonal drought periods as well as saturated conditions. Invasive species control may also be necessary. The type of plantings may also affect the size and depth of the cell.

Impacts of/ on surrounding activities: for applications near roadways, plant heights should be chosen while considering site distances and other safety concerns. Other human activity which may damage plantings, cause soil compaction or otherwise damage the aesthetics of the cell should be considered during design.

Ponding depth and surface water draw-down: Flow control needs will be determined by sighting concerns; however, a maximum drawdown time for surface ponding of 48-hours is required. (For example; a commercial application may desire a shorter drawdown time for aesthetics.)

Design components of a Bioretention cell include:
Pre-treatment: Pre-treatment of storm water runoff is required to reduce the incoming velocities, evenly spread the flow over the entire Bioretention area, and provide for removal of coarse sediments. For in-line bioretention cells, a gravel, landscape stone, or geotextile level spreader located along the upstream edge of the bioretention area followed by a gently sloping vegetated filter area along the upstream edge of the area is appropriate. Entrance velocities should not exceed 1 ft/sec. Off-line bioretention cells are placed next to a swale or curb with a common flow entrance and exit with the invert placed below the swale invert to provide the proper ponding depth. A diagram of an in-line bioretention cell adjacent to a parking lot is shown below in Figure 10-5.

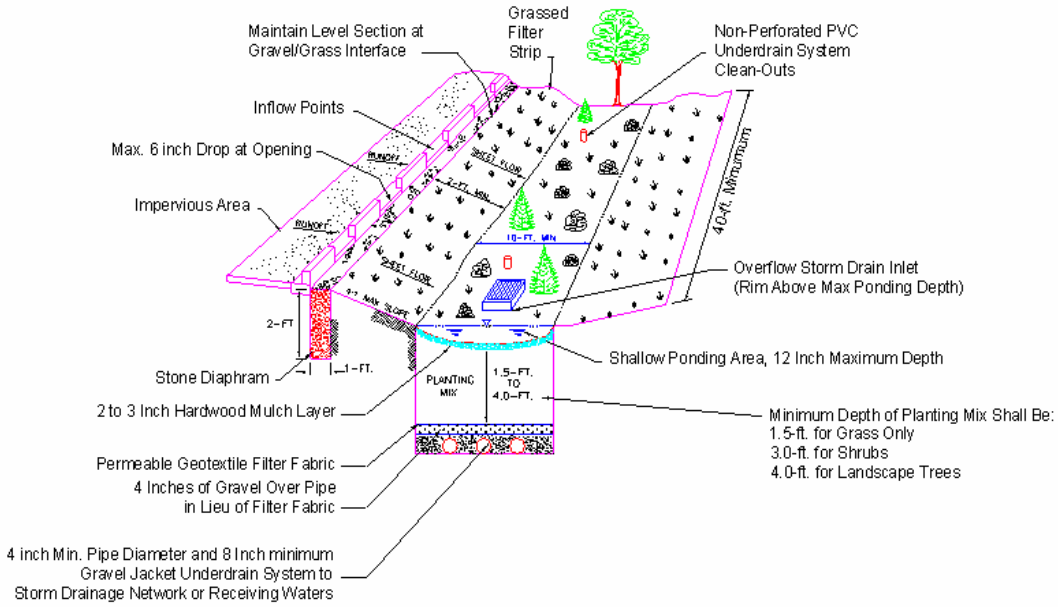


Figure 10-5: Diagram of In-Line Bioretention Cell

Other types of flow entrances include:

- Dispersed, low velocity flow across a landscape area
- Dispersed flows across pavement or gravel and past wheel stops for parking areas
- Curb cuts for roadside or parking lot areas; should include erosion protection material in channel entrance, and drop 2 to 3 inches (maximum 6 inches) from curb line to provide settling area (Figure 10-6).
- Pipe flow entrance; should include erosion protection and flow dispersion
- Catch basin; may be used to slowly release water to a bioretention area through a grate for filtering coarse material.

Figure 10-6: Bioretention Areas (Photo Credit Larry Coffman)

Ponding Area: Shallow depressed area where runoff ponds before infiltrating into the engineered planting soil mix. The maximum ponding depth should be set at 6- to 12-inches to allow the cell to drain within a reasonable time and prevent long periods of submergence of plantings. The surface area may be sized by using the LID hydrologic design criteria given above.

Engineered Planting Mix: The planting mix provides an area for infiltration and media for filtration as well as providing the plantings with nutrients and water. The soil mixture should have a significant amount of organic content to support plantings as well sufficient hydraulic conductivity and porosity to allow ponded water to draw down within 48 hrs after the storm event.

The drawdown time of a bioretention cell can be determined from Darcy's equation given in Section 9.8.1.4.6 of this manual

The engineered soils of a bioretention area can be divided into a number of zones; the mulch layer or zone, the detention/ filtration zone, the exfiltration zone, and optional retention/ denitrification zone as shown below in Figure10-7.

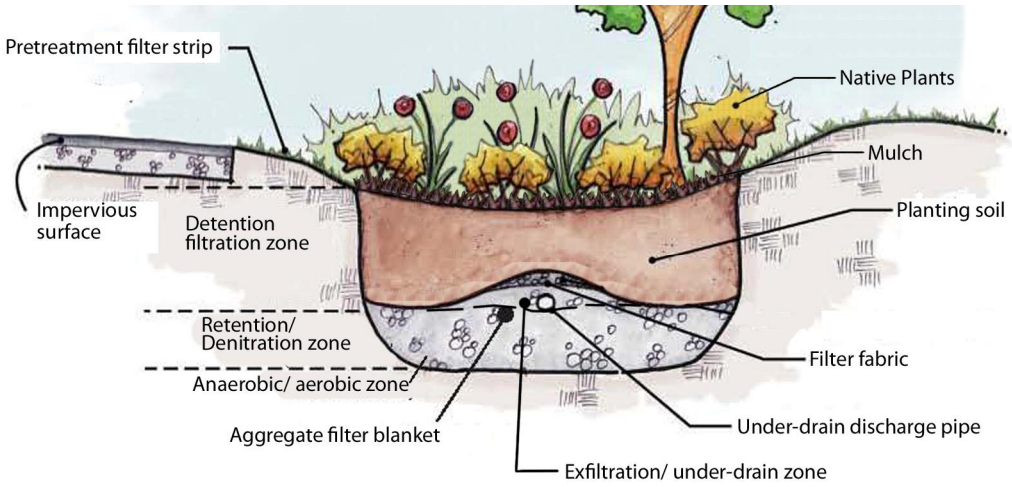


Figure 10-7: Diagram of Bioretention Cell

<u>The mulch layer</u> serves a number of purposes including trapping fine sediments, reducing erosion of the filter bed, regulates soil temperature and moisture, reduces weed establishment, and plays a role in pollutant removal. The application of mulch or other dense ground cover has been shown to attenuate heavy metals and absorb oil and grease. This layer can also be easily removed or added as part of a periodic maintenance procedure. The mulch layer should be a maximum of 2 to 3 inches thick. Shredded hardwood mulch is preferred as it resists flotation. The mulch should be free of weed seeds, soil, roots and other material that is not bole or branch wood or bark. Grass clippings should not be used as decomposing grass clippings are a source of nitrogen, pine and other bark is also discouraged as it inhibits plant establishment and usually floats.

<u>The detention/ filtration zone or soil layer</u> should have the conductivity and permeability as described In Section 9.8. The depth of the planting mix is usually based on storage volume which is equal to the Volume of the soil layer times the porosity of the soil. The minimum depth of the soil layer is given in section 9.8.

<u>The exfiltration or under-drain layer</u> is used to drain the soil layer as soils native to Greenville do not allow for adequate infiltration rates. The under-drain piping should be connected to a structural storm water

conveyance system or receiving natural water system and sized to handle the drawdown flow rate determined form Darcy's equation. The under drain may daylight to a dispersion area using an effective flow dispersion practice if applicable. Design criteria for under-drains are given in chapter 9 of this manual.

The retention or Denitrification zone should be below the under-drain and sized to hold the water quality volume. This layer is optional and geotextile is not required between this layer and the under-drain but should be provided between this layer and the underlying soil. This layer should consist of the same stone used in the under-drain layer. Adding a suitable carbon source (e.g., wood chips to the gravel layer will provide a nutrition source for anaerobic microbes and can enhance the denitrification process.

10.3.2.2 Filter/Buffer Strips and Other Multifunctional Landscape Areas

Filter/buffer strips are typically bands of close growing vegetation, usually grass, planted between pollutant source area and a downstream receiving water body. They can also be used as an outlet or pretreatment device for other storm water control practices. Key design considerations for filter strips, vegetated buffers, and level spreaders can be found in Chapter 9.

10.3.2.3 Grassed Swales, Bio-Swales, and Wet Swales

Traditionally, swale designs were simple drainage and grassed channels used to transport storm water away from roadways and rights of way. Today these IMPs can be designed to optimize their performance with respect to various hydrologic factors. Two types of grassed swales are generally used for this purpose – the dry swale, which provides both quantity (volume) and quality control by facilitating storm water infiltration and the wet swale, which uses residence time and natural growth to attenuate the peak discharge and provide water quality treatment before discharge to a downstream location. The wet swale typically has water tolerant vegetation permanently growing in the retained body of water. LID applications of these IMPs may require the use of engineered soil beds. Key design considerations for swales can be found in Chapter 9.

10.3.2.4 Infiltration Trenches

Infiltration trenches are excavated trenches that have been backfilled with stone or other porous materials to form a subsurface basin. Storm Water runoff is diverted into the trench and stored until it can be infiltrated into the soil, usually over a period of several days. This IMP has many practical configurations making it ideal for small urban drainage areas. They are most effective and have a longer life cycle when some form of pre-treatment, such as filter/buffer strips, is included in their design. Due to the low infiltration capacities of native Greenville county soils, engineered soils are usually required for this IMP. Key design considerations for infiltration trenches can be found in Chapter 9

10.3.2.5 Rain Barrels, Cisterns, and Dry Wells

These IMPs are generally used to retain a predetermined volume of rooftop runoff. Rain barrels applicable to residential and small commercial/industrial LID sites. Cisterns are usually larger and placed underground making them more applicable to commercial/ industrial LID sites as they can be placed under lots or other impervious surfaces. Dry wells function as infiltration systems to control runoff from building downspouts or as modified catch basins to catch direct surface runoff.

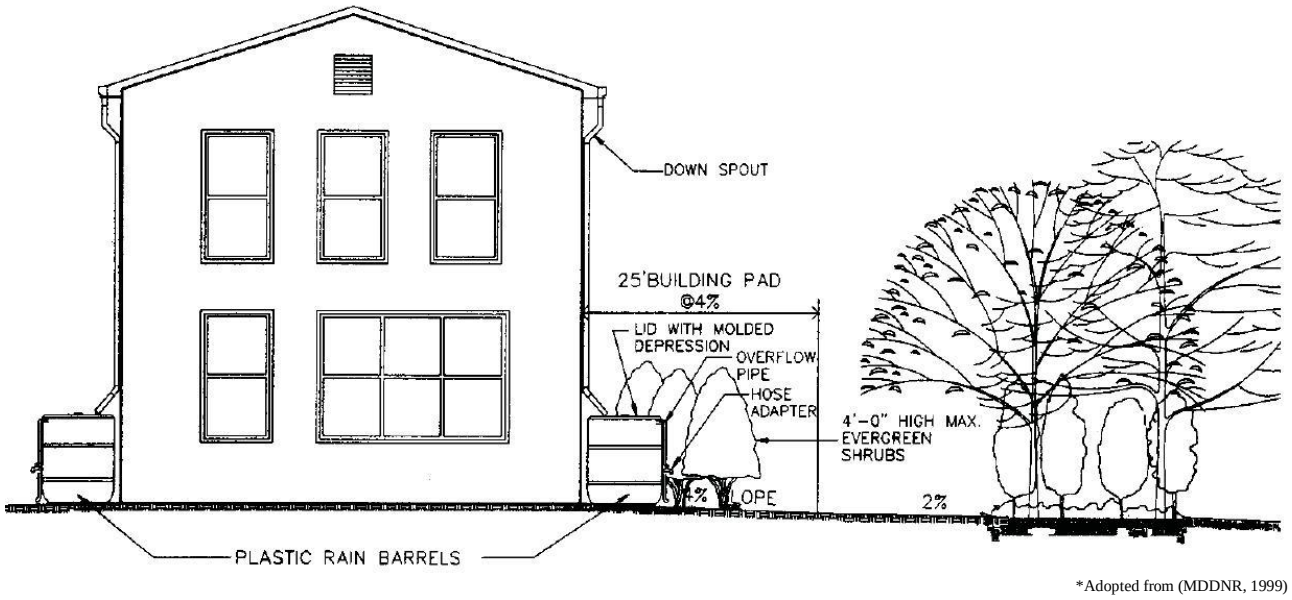
10.3.2.5.1 Rain Barrels

Rain barrels are low-cost, effective, and easily maintainable retention devices applicable to residential and commercial/ industrial LID sites. Rain barrels operate by retaining a predetermined volume of rooftop runoff; an overflow pipe provides some detention beyond the retention capacity of the rain barrel. A typical rain barrel is shown in Figure 10-8.

Rainwater from any type of roofing material can be directed to rain barrels. To be aesthetically acceptable, rain barrels can be incorporated into the lot's landscape plan or patio or decking design. Rain barrels placed at each corner of the front side of the house should be landscaped for visual screening. Gutters and downspouts are used to convey water from rooftops to rain barrels. Filtration screens should be used on gutters to prevent clogging of debris. Rain barrels should also be equipped with a drain spigot that has a garden hose threading, suitable for connection to a drip irrigation system. Connection fittings for interconnection with other rain barrels are also available. An overflow outlet must be provided to bypass runoff from large storm events. Rain barrels must be designed with removable, child-resistant covers and mosquito screening on water entry holes. The size of the rain barrel is a function of the rooftop surface area that drains to the barrel, as well as the inches of rainfall to be stored. For example, one 42-gallon barrel provides 0.5 inch of runoff storage for a rooftop area of approximately 133 ft^2. Figure 10-9 shows a typical residential rain barrel installation.

***Adopted from (MDDNR, 1999)**

Figure 10- 8: Typical Rain Barrel (MDDNR, 1999)



*Adopted from (MDDNR, 1999)

Figure 10-9: Typical Residential Application of Rain Barrels

10.3.2.5.2 Cisterns

Storm Water runoff cisterns are roof water management devices that provide retention storage volume in underground storage tanks. On-lot storage with later reuse of storm water also provides an opportunity for water conservation and the possibility of reducing water utility costs through rainwater harvesting. Figure 10-10 shows a typical cistern.

*TWDB 2005

Figure 10-10: Typical Cisterns

Cisterns are applicable to residential, commercial, and industrial LID sites. Due to the size of rooftops and the amount of imperviousness of the drainage area, increased runoff volume and peak discharge rates for commercial or industrial sites may require larger-capacity cisterns. Individual cisterns can be located

beneath each downspout, or storage volume can be provided in one large, common cistern. Pre-manufactured residential use cisterns come in sizes ranging from 100 to 1,400 gallons. Cisterns should be located for easy maintenance or replacement. These storage cisterns should be at least 50-ft away from animal stables, above ground applications of treated waste water and septic fields.

Cisterns should be equipped with an overflow which discharges into an appropriate area that is not a septic field and does not affect the foundation of any other structures. All vents should be covered with mosquito screening to discourage breeding of mosquitoes. Screens should also be used before and after the cistern to filter out leaves and other debris. Aboveground cisterns must be opaque, either on purchase or painted later to inhibit algae growth. Containers which were used to previously store toxic materials should not be used as cisterns. These components are shown below in Figure 10-11.

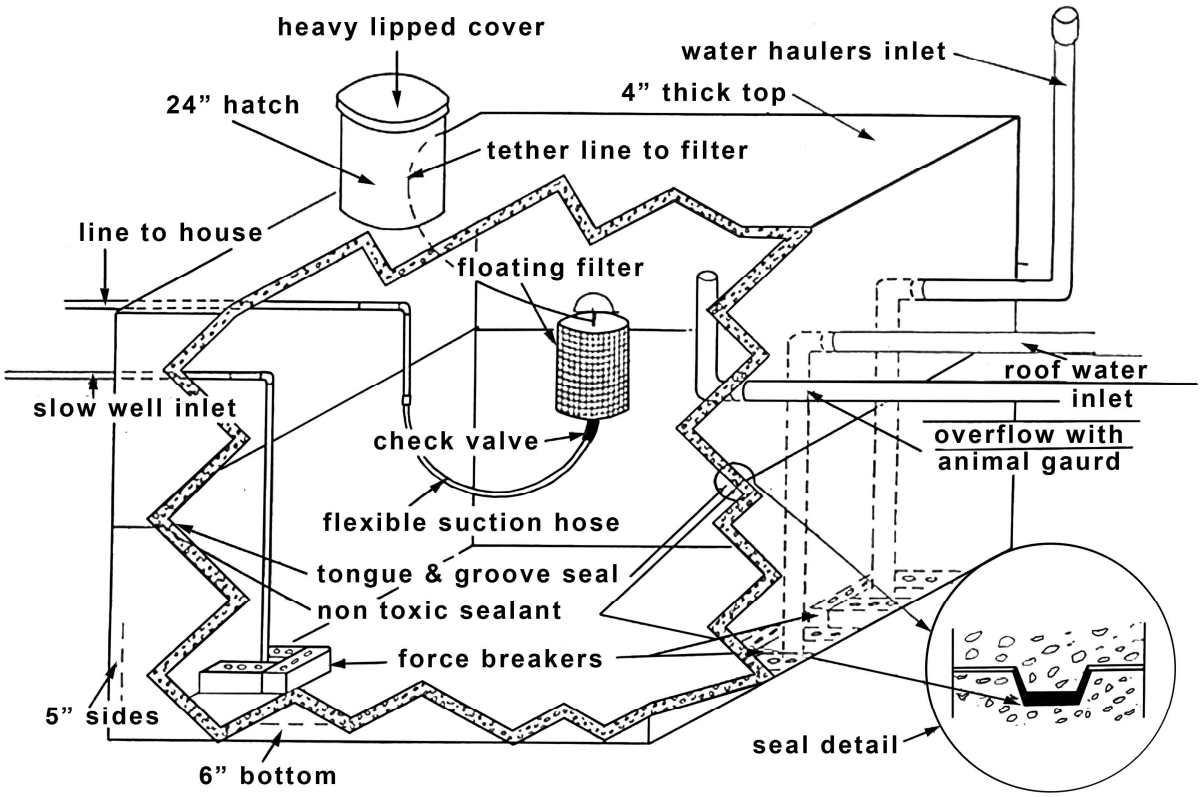


Figure 10- 11: Diagram of Cistern

The cistern should be sited as close to the supply and demand points as possible and sited as high as possible to facilitate gravity flow or ease pumping requirements. The highest level of the cistern should be at least 1-ft lower than the lowest downspout outlet to prevent surcharging of the gutter system. Water weighs just over 8 pounds per gallon, so even a relatively small 1,500-gallon tank will weigh 12,400 pounds. A leaning tank may collapse; therefore, tanks should be placed on a stable, level pad. If the bed consists of a stable substrate, a load of sand or pea gravel covering the bed may be sufficient preparation. In some areas, sand or pea gravel over well-compacted soil may be sufficient for a small tank. Otherwise, a concrete pad should be constructed. When the condition of the soil is unknown, enlisting the services of a geotechnical engineer may be in order to ensure the stability of the soil supporting the full cistern weight. Another consideration is protecting the pad from being undermined by either normal erosion or

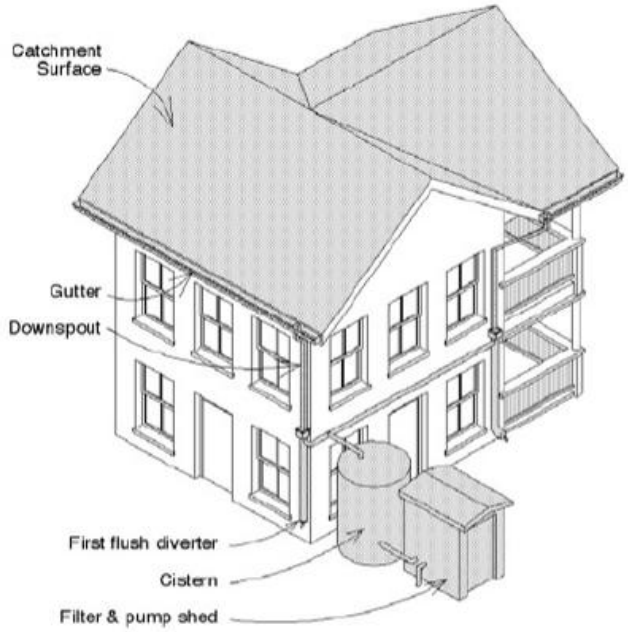
from the tank overflow. The tank should be positioned such that runoff from other parts of the property or from the tank overflow will not undermine the pad. The pad or bed should be checked after intense rainfall events. Underground systems should be anchored into the ground to guard against flotation if the soil becomes saturated and the tank is empty.

10.3.2.5.3 Rainwater Harvesting

Rainwater Harvesting is the collection and storage of rainwater for later use. With a minimum of treatment, stored rainwater can be used for irrigation, or as a source of grey water for flushing toilets. Collected rainwater is even preferred to regular drinking water as it contains zero hardness, and low sodium. This is a good practice for homes on steep slopes as it decreases the use magnitude of septic fields and infiltration which can decrease slope stability. This practice can also save money on utility bills. The basic components of a rainwater harvesting system are:

- Catchment surface (roof, patio)
- Conveyance system (gutters and downspouts)
- Storage (cistern or storage tank)
- Delivery system (gravity fed or pumped to end use)
- Treatment & Purification (leaf screens, filters, first flush bypass, etc.)

A diagram of a residential rainwater harvesting system is shown below in Figure 10-12.



*TWDB 2005

Figure 10- 12: Residential Rainwater Harvesting System

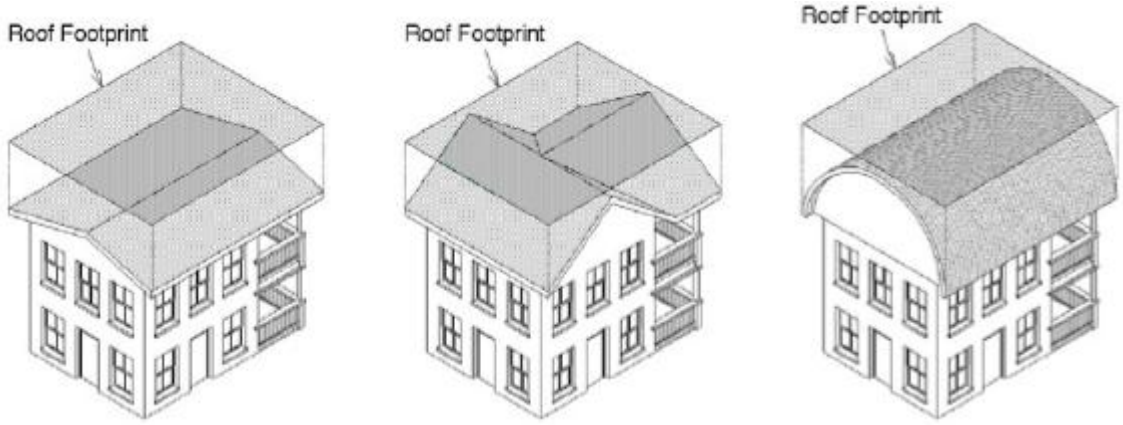
Catchment Surface: The roof of a house or building is the obvious first choice for a catchments surface. Some rainwater harvesters have even build “rain” barns to increase their roof area using the barns to park automobiles or for storage. Roof material and climatic conditions can affect the quality and amount of runoff collected. Typically the smoother the roofs surface the better. Table 10-5 lists the advantages and

disadvantages of common roofing types with respect to rainwater harvesting.

Table 10-5: Applicability of Common Roofing Materials to Rainwater Harvesting

Roofing Material	Use	Advantages/ Disadvantages
Metal	Irrigation/grey water	Smooth (few Losses); Copper flashings can discolor porcelain
Clay/ Concrete tile	Irrigation/ grey water	Porous causing loss; Must be sealed correctly against toxic leaching and bacterial growth
Composite or Asphalt shingle	Irrigation only	Inefficient flow causing loss; toxic leaching can occur
Wood shingle, tar and gravel	Irrigation only	Leaching of compounds
Slate	Irrigation/ grey water	Smooth (few Losses); Must be sealed with non-toxic sealant

Estimating the supply of rainfall is based on catchment area, rainfall amount and system efficiency. When calculating the catchment area, the projected area or roof footprint, not surface area, should be used. The footprint is calculated as the horizontal surface area covered by the collection surface regardless of the pitch of the roof (length times width of the roof from eave to leave and front to rear). Obviously if only one side of the structure is guttered, only the area drained by the gutters is used in the calculation. The roof footprint for a number of shapes is shown below in Figure 10-13.



*TWDB 2005

Figure 10- 13: Projected Roof Footprint (Effective Collection Area)

Conveyance System: The conveyance system generally refers to the gutters and downspouts. Special attention must be paid to the sizing and maintenance of gutters and downspouts to minimize overrun and loss of capacity due to debris. Gutters should be installed with slope towards the downspout; also the outside face of the gutter should be lower than the inside face to encourage drainage away from the building wall. Debris filters should be installed in the gutters, downspouts, or entrance to the cistern.

Storage: Harvested rainwater is stored in cisterns. The cistern is generally the most expensive component of a rainwater harvesting system. Additional guidelines can be found in Section 3.2.5.2.

The sizing of cisterns is determined by the supply of rainwater, demand, aesthetics, personal preference and budget. A number of methods are used for sizing cisterns. One simple way is by quarterly demand. Calculate the demand for water over the three month period of highest use. While demand give the amount of water you want, supply is governed by the amount of rain actually that falls. Therefore, the tank should be sized such that the supply of rainwater should meet or exceed the demand and in turn, the demand should not be unreasonable based on the rainfall history of the area. Also due to gutter losses, first flush and other losses, most rainfall collection systems are assumed to be between 75 to 90% efficient.

The volume of water harvested can be estimated from the following equation.

$$V = P \cdot CA \cdot Eff \cdot 0.62 gal/in/ft^2$$

Where V is the volume of rainfall harvested in gallons, P is the rainfall depth in inches (average annual, monthly, quarterly, etc.), CA is the catchment area in square feet, and Eff is the system efficiency expressed as a decimal (0.75 to 0.90).

Delivery System: The delivery system will either be gravity fed or pumped. If the cistern is high enough, a gravity system can be used, however with underground systems this is usually not the case. An operating pressure 20- to 30-psi is generally required for irrigation. Water gains 1-psi for every 2.31-ft of vertical height so to generate 30-psi, the tank would need to be located 70-ft above the outlet. As that degree of separation is impractical, systems are generally pumped using a bladder tank or on demand pump.

Bladder tanks are similar to systems used by well owners. Water is pumped into a pressurized tank which provides a limited volume of pressurized water for instant use. The tank is refilled by the pump as needed with a one way check valve between the pump and tank to keep the tank pressurized. The pumps are generally ¾ to 1-hP pumps and the typical bladder tank holds 5 to 10-gallons. The new on-demand pumps eliminate the need for a pressure tank. These pumps combine a pump, motor, controller, check valve, and pressure tank function all in one unit. They are self-priming and are built with a check valve incorporated into the suction port. As pumps push water rather than pull it, they should be sited as close to the cistern or storage tank as possible.

Treatment and Purification: The level of treatment needed for harvested rainwater is based upon its intended use. Limited treatment (filtration) is needed for irrigation applications; a higher treatment level including disinfection can be performed in addition to filtration to make the water potable. No federal or state standards exist currently for harvested rainwater quality, although state standards may be developed in the future. The latest list of drinking water requirements can be found on the United States Environmental Protection Agency's website. For those intending to harvest rainwater for potable use, the microbiological contaminants E. coli, Cryptosporidium, Giardia lamblia, total coliforms, legionella, fecal coliforms, and viruses, are probably of greatest concern, and rainwater should be tested to ensure that none of them are found. County health department and city building code staff should also be consulted concerning safe, sanitary operations and construction of potable rainwater harvesting systems.

Gross filtration is needed to screen out large contaminates like leaves and other debris. A number of filters are available including:

- Leaf Screens: a wire mesh screen placed above the entrance of the downspouts to strain out

leaves and other debris

- Leaf guards: ¼" wire screen in a wire frame that fits along the length of the gutter. These are usually only necessary in areas with tree overhang.
- Downspout funnel: A PVC or Galvanized Steel box fitted with a brass screen installed in the downspout above the highest level of the storage tank. Allows for easy cleanout and maintenance.
- Strainer Basket: a spherical mesh basket place in the entrance of the downspout to strain out debris.
- Filter Sock: a nylon sock that fits inside the downspout to catch leaves and other debris.
- Charcoal Filter: A charcoal filter at the bottom of the downspout. Shown below in Figure 10-14.

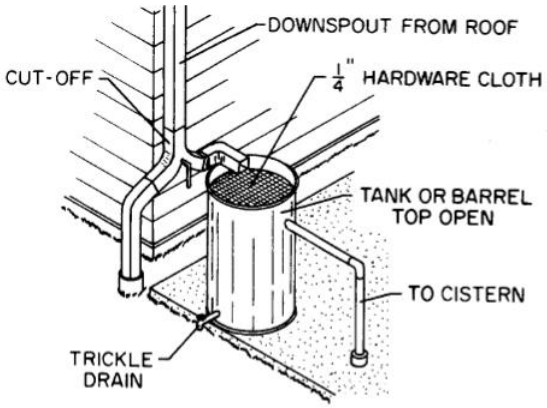
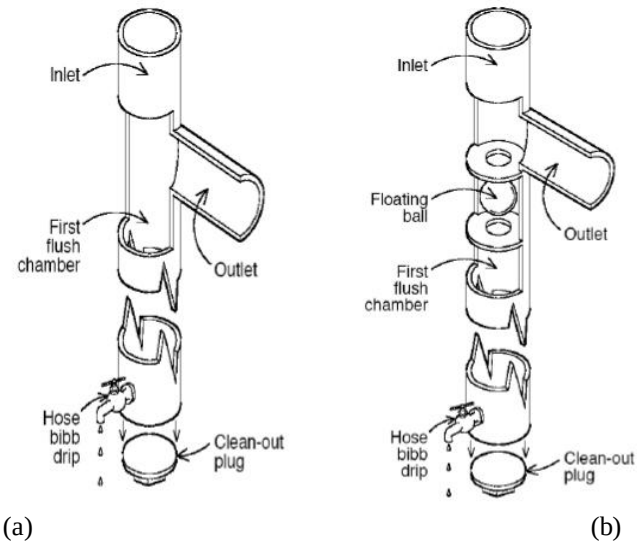


Figure 10-14: Charcoal Filter

These filters must be cleaned regularly (monthly and after each rainfall event) to prevent clogging, the formation of bacteria, and products of leaf decay. Depending upon the amount and type of tree litter and dust accumulation, the homeowner may have to experiment to find the method that works best.

As the first flush of runoff generally carries a large amount of dust that has accumulated since the last rainfall, first flush diverters should be used to divert the initial runoff from the tank. The recommended diversion volume of first flush waters ranges from one to two gallons for each 100 square feet of collection area. If using a roof for a collection area that drains into gutters, calculate the amount of rainfall area that will be drained into every gutter feeding the system. Remember to calculate the horizontal equivalent of the "roof footprint" when calculating the catchment area. The simplest first flush diverter is a 6- or 8-inch PVC standpipe of a length sufficient to hold the rooftop first flush volume. The first flush diverter should be equipped with a hose bib and a cleanout. Some diverters are equipped with floating ball valves to close the diverter when the first flush volume has been collected. A diagram of a simple first flush diverter is shown below in Figure 10-15.



*TWDB 2005

Figure 10-15: First Flush Diverter (a) open (b) with ball valve

As gross filtration does not filter out suspended sediments collected from the catchments surface and not all are carried the first flush, in tank filtration should be used to keep the remaining sediments out of the pump and delivery system. A cistern float filter allows the pump to draw water from the storage tank from between 10 and 16 inches below the surface. Water at this level is cleaner and fresher than water closer to the bottom of the tank. The device has a 60-micron filter. An external suction pump, connected via a flexible hose. An example of a float filter is shown below in Figure 10-16.

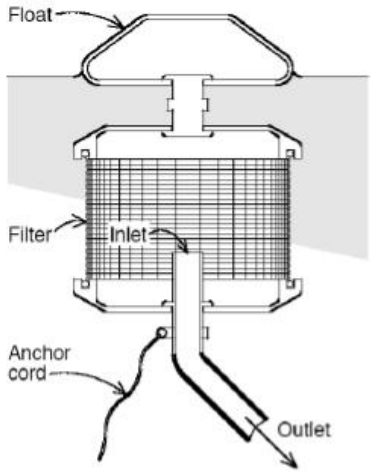
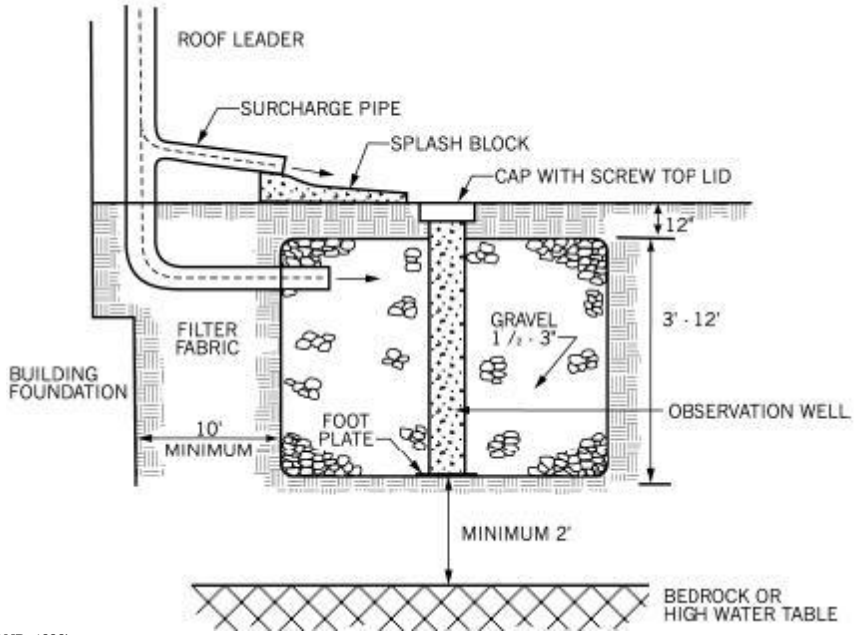


Figure 10-16: Float Filter

Higher levels of treatment require, chlorination, Ozone, UV or reverse osmosis/ nano-filtration disinfection methods. Unless these systems should meet federal state and local drinking water standards they should not be ingested but used only for irrigation and other non-potable uses. Rainwater harvesting systems require regular maintenance to keep them operating efficiently and correctly and free of mosquitoes and microbiological contaminates.

10.3.2.5.4 Dry Wells

A dry well consists of a small excavated pit backfilled with aggregate, usually pea gravel or stone. Dry wells function as infiltration systems used to control runoff from building rooftops. Another special application of dry wells is modified catch basins, where inflow is a form of direct surface runoff. Figure 10-17 shows a typical detail of a dry well. Dry wells provide the majority of treatment by processes related to soil infiltration, including adsorption, trapping, filtering, and bacterial degradation.



*Adopted from (MDDNR, 1999)

Figure 10-17: Typical Detail of a Dry Well

A summary of design considerations for Dry wells can be found in Table 10-6. The capacity of a dry well can be determined using the equation below.

Table 10-6: Summary of Dry Well Design Considerations

Design Storm	Water Quality Volume from the 2-yr 24-hr storm
Soil Permeability	>0.26 – 0.5 in/hr
Storage time	Empty within 3 days
Backfill	Clean aggregate > 11/2, < 3", surrounded by engineering filter fabric
Runoff Filtering	Screens should be placed on top of roof leaders, grease, oil floatable organic materials and settleable solids should be removed prior to entering well.
Outflow structures	Overland flow path of surface runoff exceeding the capacity of the well must be identified and evaluated. An overflow system leading to a stabilized channel or watercourse including measures to provide non-erosive flow conditions must be provided
Observation well	Must be provided, 4-inch PVC or foot place constructed flush with ground surface, cap with lock
Depth of Well	3 to 12 ft
Hydrologic design	Eq ( ); Bottom of well must be a minimum of 2-ft above the seasonal high water table.
Water Quality	Same as infiltration trench
Maintenance	Periodic monitoring –quarterly at first and annually thereafter.

*Adopted from (MDDNR, 1999)

$$R = \frac{A}{12}\left(nd + kT/12\right)$$

Where R is the depth of rainfall (in), A is the surface area of the practice (ft^2), n is the porosity of the stone fill, d is the depth of the well (ft), k is the percolation rate of the soil (in/hr), and T is the time to fill the well (hrs).

10.3.2.6 Permeable Pavers

Permeable pavers are paving surfaces designed to be pervious with some infiltration capacity. These pavements are designed to accommodate pedestrian, bicycle, and vehicular traffic while treating, infiltrating and storing storm water runoff. Permeable pavers can be divided into a number of general categories including:

Cast in place Concrete or asphalt pavement: These pavements are similar to standard pavements but contain fewer fine materials and may contain special admixtures or binders resulting in a pervious surface.

Aggregate or plastic pavers: these include modular blocks of plastic, concrete or other material which have wide joints or openings that can be filled with soil, gravel, or grass. This may also include cast in place concrete grids with openings that can be filled with permeable materials.

Plastic or metal grid systems: these systems com in rolls and are covered with soil and grass or gravel. The grid sections interlock and are held in place with stakes or pins.

Typical applications of pervious pavements include parking lots, sidewalks, pedestrian and bicycle paths, patios, walkways, and driveways on individual lots, emergency access roads and facility maintenance roads. Pervious pavements have also been used in residential areas for vehicle traffic. Permeable pavements are generally not used on highways or high traffic roads, due to the newness of the technology, except in specific test cases. These systems have been designed to function as infiltration facilities with underlying aggregate storage with low underlying soil infiltration rates (as low as 0.1 in/hr) (Hinman,

2005). Applications of porous pavement also meet requirements of acceptable surfaces for disabled persons. While most porous pavers are rougher than conventional paving, when properly installed there is less than a ¼-inch of abrupt height change presenting a relatively smooth and firm surface. When using porous pavers however, they may settle from vehicle use therefore it is a good idea to use conventional pavers for disabled parking spaces. Also conventional concrete pavers should be used at curb ramps approaching traffic areas as the scoring of the pervious concrete may be confused with truncated dome inserts which alert the blind to approaching traffic areas.

10.3.2.6.1 Sighting Parameters

The design of pervious pavements will depend on the application and location. Locations where pervious pavements are not recommended are:

- Construction and landscaping material yards or where excessive sediment is deposited on the surface
- Steep erosion prone areas with upslope erosive areas which may clog the pavement surface

<u>Slope limitations are:</u>
5% for permeable asphalt,
6% for permeable concrete,
10% for aggregate pavers and
6% for plastic/ metal grid systems
(primarily for traction control).

- Storm Water Hotspots, locations where concentrated pollutant spills are possible such as gas stations, and industrial chemical storage sites.
- Areas where maintenance is unlikely to be performed at appropriate intervals (residential and major roadways)
- Residential driveways where there are not clear, enforceable guidelines, education and back up systems as part of the storm water management plan.
- Where heavy regular applications of sand are used for maintaining traction during winter.
- Also areas with high seasonal groundwater or other conditions which create prolonged saturated conditions at or near the ground surface and within the pavement sections. Fill soils can become unstable when saturated.
- Locations where the estimated long term infiltration rate is less than 0.1 inch/hr.

10.3.2.6.2 Application Guidelines

<u>Conventional Pavers</u>: The guidelines provided below should be followed for successful application of pervious pavements.

<u>Design and Installation Specifications</u>: Proper site preparation is essential to successful operation of these systems. This includes correct installation of aggregate base and wearing course gradations, separation layer, and under-drain design. Installation specifications should also be followed, for example the use of excessive frequencies using a vibrating plate compactor during concrete installation will seal the void spaces in permeable cast-in-place concrete.

Qualified Contractors: Porous pavements are specialty applications and should be installed by contractors who have been trained and have experience with the type of pavement being used. If the installation contractor does not have adequate experience they should retain a qualified consultant to monitor the production, handling and placement of the porous pavement.

Sediment and Erosion Control: The introduction of sediment and runoff from surrounding unpaved areas should be avoided where possible to prevent clogging of the pavement pore spaces. When this is unavoidable, pre-treatment practices must be used to allow for filtering or settling of sediments before the runoff reaches the porous pavement. Filter fabric should also be used between the underlying soil and the base course of the pavement to prevent fines from migrating up into the base. During construction, muddy vehicles should not be allowed to drive on the base material or surface. This is especially true of fine soils such as those found in Greenville County. Under-drains are also required in these applications where the long-term infiltration rate of the underlying soil is less than 0.1 inch/hr. These precautions will enhance the operation and extend the operational life of the pavement.

10.3.2.6.3 Estimating Infiltration Capacity

In order to insure adequate infiltration, it is important to estimate the long-term infiltration rate of the soil underlying a pervious pavement application. For small installations (patios, walkways, and driveways on individual lots) no infiltration field tests are necessary. However a soil grain size, texture analysis or soil pit excavation and infiltration tests may be prudent if highly variable soil conditions or seasonal high water tables are suspected. For large installations (sidewalks, alleys, parking lots, and roadways) that include storage volume using base material below the surrounding land one of the following methods should be used to estimate the infiltration capacity of the underlying soil.

Method 1: USDA Soil Textural Classification (Rawls survey) every 200 feet of road or every 5000 ft^2

Method 2: ASTM D422 Gradation Testing at Full Scale Infiltration Facilities every 200 ft of road or 5000 ft^2.

Method 3: Use small-scale infiltrometer tests every 200 feet of road or every 5,000 ft^2. These tests include the USEPA falling head or double ring infiltrometer tests (ASTM 3385-88). As these tests may not adequately measure variability of conditions in the test area they should be taken at several locations within the area of interest.

10.3.2.6.4 Design, Installation and Testing

The design components of a permeable paving system are described below.

The Wearing Course or Surface Layer provides strength for the designed traffic loads while maintaining adequate infiltration capacity for storm water runoff. This course may be cast-in place concrete, asphalt, concrete and plastic pavers and plastic or metal grid systems. These courses generally have very high initial infiltration rates. Various clogging rates have been observed and should be planned for in the system design. While this layer allow for the infiltration of storm flows and provides some water quality benefits, the wearing course should not be allowed to become saturated from excessive water volume stored in the aggregate base layer. For backup infiltration capacity, an unpaved stone edge hydraulically connected to the aggregate base or an overflow outlet should be installed.

1. Permeable Hot-Mix Asphalt

   a. The top course is typically 2 to 4 inches thick. Permeable asphalt has similar strength and flow properties as conventional asphalt. Total void space should be approximately 16%. The content of the asphalt cement should be 5.5 to 6.0 percent by weight dry aggregate. An elastomeric polymer can be added to reduce drain down. Also hydrated lime may be added at a rate of 1.0% by weight of the total dry aggregate to mixes using granite stone to prevent separation.

   b. The asphalt system should be installed toward the end of construction activities to minimize sediment problems. Erosion and introduction of sediment should be strictly controlled during and after construction. Test panels are recommended to determine asphalt cement grade and content compatibility with aggregate. In order to prevent rising water in the underlying aggregate base to saturate the pavement, a positive overflow should be installed.

2. Portland Cement permeable concrete

   a. Typically 4 to 12 inches thick depending upon design loads. Permeable concrete is approximately 70 to 80 percent of the unit weight of conventional concrete and uses Portland cement type I or II conforming to ASTM C 150 or Type IP or IS conforming to ASTM C 595. The void space should be 15 to 21% according to ASTM C 138 with a water cement ratio of 0.27-0.35, and an aggregate to cement ratio of 4:1 to 4.5:1. Admixtures including water reducing/retarding admixture (ASTM C 494 Type D) and hydration stabilizer (ASTM C 494 Type B), and fiber mesh may be used. Potable water should be used. Permeable concrete is similar to conventional concrete without the fine aggregate (sand component). A number of aggregate specification are used including:

      i. 3/8 inch No. 16 washed crushed or round (ASTM C 33)

      ii. 2/8 inch No. 50 washed crushed or round (ASTM D 448)

      iii. 5/8 inch washed crushed or round.

While the 3/8 inch is generally smoother, the 5/8 provides a slightly stronger surface.

   b. The cement mix should be used within 1 hour after water is introduced and within 90 minutes if an admixture is used and the temperature of the mix does not exceed 90° Fahrenheit. Base aggregate should be wetted to improve the working time of the cement. A mechanical or manual screed can be used to level concrete at ½ inch above a form. The surface should be covered with a 6-mil plastic and a static drum roller used for final compaction (roller should provide approx. 10 psi vertical force). Cement should be covered with plastic within 20 minutes and remain covered for a minimum curing time of 7 days with no truck traffic for 10 days. High frequency vibrators can seal the surface of the concrete and should not be used. Placement widths should not exceed 15 feet unless the contractor can demonstrate competence to install greater widths. Shrinkage associated with drying is less than for conventional concrete. A conservative design can include control joints at 60-ft spacing cut to ¼ of the pavement thickness.

   c. The following tests should be conducted to ensure proper performance

      i. The contractor should place and cure two test panels covering a minimum of 225 ft^2 at the required thickness to demonstrate that specified unit weights and permeability can be achieved on site. The test panels should have two cores taken from each panel in accordance with ASTM C 42 at least 7 days after placement.

      ii. Untrimmed cores measured for thickness (ASTM C 42)

1. Within ¼ inch of specified thickness

iii. Cores then trimmed and measured for unit weight (ASTM C 140)

1. within 5 lbs/ft^3 of design specification

iv. Void Structure should be tested (ASTM C 138)

1. provide infiltration rate greater than underlying soil

If the test panel meets the requirements, the panel can be left in place as part of the completed installation. The material should be collected and sampled once per day to measure unit weight per ASTM C 172 and C 29.

3. Aggregate or Plastic Pavers

a. Design specifications for these systems are generally provided by the manufacturer. These systems should provide adequate infiltration and load bearing capacity for the application. Directing surface flows to these systems from adjacent areas is not recommended without pretreatment.

b. Pavers should be installed immediately after base preparation to minimize introduction of sediment and displacement of base material. Do not compact pavers within 3 feet of an unrestrained edge. Cast-in-Place or pre-cast concrete are preferred material for edge constraints. Plastic edge confinement secured with spikes is not recommended. Sand should not be placed in paver openings or used as a leveling course as it will clog. An ASTM No. 8 stone is recommended to fill openings for light vehicle loads, while ASTM No. 89 stone is recommended for heavy vehicle loads. Sweep in stone, compact and sweep away excess material.

4. Plastic or Metal Grid Systems

a. Design specifications for these systems are generally provided by the manufacturer. These systems should provide adequate infiltration and load bearing capacity for the application. Directing surface flows to these systems from adjacent areas is not recommended without pretreatment.

b. Grids should be installed immediately after base preparation to minimize introduction of sediment and to reduce the displacement of base materials. The grids should be placed with the attached filter fabric on the bottom where present and interlock the male/female connectors along unit edges. Anchors should be installed at an average of 6 pins per square meter or according to manufacturer's specification. Higher speed transition areas and turning areas will require additional anchors (double pin application. Aggregate fill should be back dumped to a minimum depth of 6 inches so that delivery vehicle exists over aggregate. Avoid sharp turnings when installing aggregate. Spread fill gravel using power brooms, flat bottom shovels, wide asphalt rakes or other appropriate equipment. A stiff bristle broom can be used for finishing. Aggregate may be compacted if necessary to a level no less than the top of the grid or no more than 0.25 inches above the tope of the grid. Edge constraints should be placed along edges that may have heavy vehicle loads or tight turning radii (cast-in-place concrete is preferred). The top course aggregate should be clean, washed angular stone with granite hardness. A suggested gradation is given below in Table 10-7 (Hinman, 2005).

Table 10-7: Top Course Aggregate Gradation

U.S. Standard Sieve	Percent Passing
4	100
8	80
16	50
30	30
50	15
100	5

The Aggregate Base or Storage Bed provides a stable base for the paver, a highly permeable layer for the infiltration of storm water into the underlying soil or under-drain system, and a temporary reservoir for storage of water prior to exfiltration through the underlying soil or under-drain system. In concrete and asphalt systems this layer is typically composed of a larger aggregate with a smaller stone (leveling or choker course) between the wearing course and the larger stone base course. The choker course is needed to reduce rutting from construction traffic and to more evenly distribute the loading to the base material. Designs with partial or no exfiltration require under-drains. All installations are required to have an observation well installed at the furthest down slope area.

1. Permeable Hot-Mix Asphalt

    a. The minimum depth for structural support of this layer is 6 inches. The maximum depth is determined by the below grade storage volume. Aggregate base depths of 18 to 36 inches are common depending on storage needs. The coarse aggregate layer should be 2.5 to 0.5 inch uniformly graded crushed (angular) thoroughly washed stone (AASHTO No. 3). The choker course should be 1 to 2 inches in depth and consist of 1.5 inch to 0.0937 inch (No. 8 sieve) uniformly graded crushed washed stone for final grading of the base course. In applications with larger slopes, underground baffles may be used to make more efficient use of the storage layer. If baffles are used with an under-drain system, positive drainage to the under-drain must be provided along the baffles.

    b. Before installing the storage bed, the surrounding area should be stabilized to prevent runoff and sediment from entering the storage bed. A non-woven filter fabric should be installed on the subsoil according to the manufacturer's specifications. Where the installation is adjacent to conventional paving surfaces, filter fabric should be wrapped up the sides to the top of the base aggregate. Overlap adjacent strips of fabric at least 24 inches and secure 4 ft outside of the storage bed. Install the aggregate in maximum 8-inch lifts and lightly compact each lift. Install a 1 to 2-inch choker course evenly over the surface of the coarse aggregate layer. Filter fabric should be folded over between placements of the base and asphalt courses to protect installations from sediment inputs to be trimmed when the site is fully stabilized.

2. Portland Cement permeable concrete

    a. The design requirements for Permeable concrete are similar to those for asphalt given above.

However, a choker course is not required for concrete installation but may be used.

b. The installation of the permeable concrete aggregate base is the same as for asphalt installations as given above in 1b.

3. Aggregate or Plastic Pavers
   a. The minimum thickness for the aggregate base for aggregate or plastic pavers depends on anticipated loadings, soil type and storm water storage requirements. The Interlocking Concrete Paver Institute or the manufacturer's provided guidelines for base thickness should be followed when available. Typical depths range from 6 to 22 inches though larger depths may be used if greater storage capacity is desired. The minimum base depth for pedestrian and bicycle applications is 6 inches. An ASTM No. 57 crushed aggregate or similar is recommended for the coarse layer while ASTM No. 8 of 3 inches is recommended for the choker course.
   b. The surrounding area should be stabilized prior to installation of the aggregate base. If the base course is being used for retention, the storage bed should be excavated level to maximize infiltration across the entire area. If an under-drain is used, the bed should be sloped to provide positive drainage at the desired rate for the under-drain. A non-woven filter fabric should be installed along the bottom and sides of the excavation according to the manufacturer's specifications. Where the installation is adjacent to conventional practices, the fabric should be raped up the sides to the top of the base aggregate. Install the No. 57 aggregate in 4 to 6 inch lifts compacting with at least 4 passes of a 10-ton steel drum roller. Initial passes can be with vibration but the final two should be static. Install the choker course in a similar manner. Both courses should be moist to facilitate compaction.
   c. Appropriate density and stability are developed when no visible movement is observed in the open-graded base after compaction. Also the surface variation of the choker should be within ± ½ inch over 10 feet.
4. Plastic or Metal Grid Systems
   a. The minimum thickness of this layer depends on anticipated loadings, underlying soil type and storage requirements. A typical minimum depth for driveways, alleys and parking lots is 4 to 6 inches. Increased depths can be used to increase storage capacity. The base aggregate should be made up of a sandy gravel material typical for road base construction. A typical gradation is given below in Table _ (Hinman, 2005).

Table 10-8: Base Course Aggregate Gradation

U.S. Standard Sieve	Percent Passing
3/4	100
3/8	85
4	60
8	15
40	30
200	<3

The surrounding area should be stabilized prior to installation. If the base course is being used for retention, the storage bed should be excavated level to maximize infiltration across the entire area. If an under-drain is used, the bed should be sloped to provide positive drainage at the desired rate for the under-drain. A non-woven filter fabric should be installed along the bottom and sides of the excavation according to the manufacturer's specifications. Overlap adjacent strips at least 24 inches and secure fabric 4 feet outside of the storage bed. The aggregate should be installed in 6 inch lifts and compacted to 95% modified proctor.

The Subgrade conditions should be analyzed by a qualified engineer for load bearing given the anticipated soil moisture conditions. A separation between the base course and the seasonal high water table of three feet must be observed.

1. Permeable Hot-Mix Asphalt
   a. After grading, the existing subgrade should not be compacted or subjected to excessive construction traffic. Immediately before base aggregate placement remove any accumulation of fine material from erosion with light equipment and scarify the soil to a minimum depth of 6 inches. The estimated long-term infiltration rate may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have under-drains to prevent prolonged saturated conditions at or near the ground surface within the pavement section.
2. Portland Cement Permeable Concrete
   a. After grading, the existing subgrade should not be compacted or subjected to excessive construction traffic. Immediately before base aggregate placement remove any accumulation of fine material from erosion with light equipment and scarify the soil to a minimum depth of 6 inches. The estimated long-term infiltration rate may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have under-drains to prevent prolonged saturated conditions at or near the ground surface within the pavement section.
3. Aggregate or Plastic Pavers
   a. Under-drains are required for soils where the estimated long-term infiltration rate is less than 0.5 in/hour. The draw-down time for the base should not exceed 24-hours. For vehicle traffic areas, grade and compact the subgrade to 95 percent modified proctor density (ASTM D 1557). For pedestrian areas, compact to 95 percent standard proctor density (ASTM D698). The majority of soils in Greenville County will not retain useful infiltration rates when compacted and will require the use of an under-drain.
4. Plastic or Metal Grid Systems
   a. After grading, the existing subgrade should not be compacted or subjected to excessive construction traffic. Immediately before base aggregate placement remove any accumulation of fine material from erosion with light equipment. Under-drains are required for soils where the estimated long-term infiltration rate is less than 0.5 in/hour. The draw-down time for the base should not exceed 24-hours.

Some applications may have water quality layers between the filter fabric and subgrade. These layers should only be used when the underlying soil has high infiltration capacity (Type A and B soils with a drawdown time of < 24 hours).

10.3.2.6.5 Maintenance

Maintenance of permeable paving surfaces is essential to their continued operation. Erosion and introduction of sediment from surrounding land uses should be strictly controlled after construction. Permeable paving surfaces should be cleaned annually to semi-annually. Utility cuts should be backfilled with the same aggregate base used under the pavement to allow continued conveyance of storm water.

The following maintenance guidelines are suggested for each type of paving system.

1. Permeable Asphalt and Concrete
   a. Clean surface using suction and sweeping, or high-pressure wash and suction (sweeping alone in ineffective) (Hinman, 2005). Hand held pressure washers are effective for cleaning void spaces and are appropriate for smaller areas. Smaller utility cuts can be repaired with conventional pavers is desired.
2. Portland Cement permeable concrete
   a. Same as asphalt
3. Aggregate or Plastic Pavers
   a. Washing should not be used only suction and sweeping should be used when debris are dry. Pavers can be removed individually and replaced during utility work. Broken pavers should be replaced to prevent structural instability.
4. Plastic or Metal Grid Systems
   a. Remove and replace top course aggregate if clogged or contaminated using vacuum trucks or other techniques. Remove and replace broken grid segments where three or more adjacent grid cells are broken or damaged. Replenish the top course aggregate as needed.

10.3.3 Other Environmentally Sensitive IMPs

Low-Impact Development is a relatively new concept. It is anticipated that over the next few years many additional best management practices and improvements to the LID approach will be introduced as local agencies and designers begin to experiment with the use of the practice.

One such example of an additional developing practice is rooftop greening. This technique consists of the use of pre-cultivated vegetation mats. This practice has the following benefits:

- Improve air quality (up to 85% of dust particles can be filtered out of the air)
- Cooler temperatures and higher humidity through natural evaporation
- 30-100% of annual rainfall can be stored, relieving storm drains

Innovative technologies are encouraged and shall be evaluated on a case by case basis providing there is sufficient documentation as to the effectiveness and reliability of the proposed structure. To justify the efficiency of innovated practice, the owner may be required to monitor the hydrologic and water quality function of the practice. If satisfactory results are obtained, the practice may be used and no other monitoring studies shall be required. If the control is not sufficient, other on-site and/or downstream controls shall be designed to satisfy the hydrologic and water quality requirements.

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