Chapter 10. LOW IMPACT DEVELOPMENT

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.

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 predevelopment 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 cannot 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** from Washington Dept. of Ecology shows a diagram of a relief drain.

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 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.

10.1.1.5.1 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.

10.1.1.5.2 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.

10.1.1.5.3 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 10-2 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.

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 5.2.3 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 J:

- 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:

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

Step 3: 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.

Step 4: 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).**

Step 5: 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

Step 6: 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:

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

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:

$$H = VR \cdot \left(\frac{100}{x} \right)$$

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.

<u>Step 7</u>: 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. 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:

- LID-01 Green Roofs
- LID-02 Rain Barrels, Cisterns, & Dry Wells
- LID-03 Pervious Pavement
- LID-04 Planter Box
- LID-05 Stormwater Alley
- LID-06 Driveways
- LID-07 Mountainous LID Steep Slope Sites
- LID-08 Vegetated Swales
- LID-09 Full Dispersion
- LID-10 Urban LID Applications
- LID-11 Stormwater Courtyards
- LID-12 Disconnect Impervious and Green Space Preservation

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.

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 10-4 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:	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
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: 2:1 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	3ft clearance above water table/ bedrock recommended	2 to 4 ft clearance above water table/ bedrock recommended	2ft clearance above water table/ bedrock recommended	2ft clearance above water table/ bedrock recommended	Generally not a constraint		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 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.

CHAPTER 10 REFERENCES:

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