



A Guide to Low Impact Development

by

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**Course 189
4 PDH (4 Hours)**

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A Guide to Low Impact Development

Introduction:

This course presents an overview of low impact development techniques for site development. Low impact development refers to a suite of techniques that allow for the efficient development of a site while minimizing the detrimental stormwater impacts that generally accompany such development.

When you complete this course you should be familiar with the most common types of low impact development techniques and should know how to employ them.

The main reference used in this course is the New Jersey Department of Environmental Protection's Best Management Practices Manual. However, there are many different references that deal with the implementation of low impact development. In fact, very many state and county stormwater management regulations include significant discussions of low impact development.

What Are Low Impact Development Techniques?

It is well known that typical land development projects can have significant detrimental stormwater impacts including the following:

1. An increase in stormwater runoff rate and volume.
2. An increase in runoff velocity and a corresponding increase in the potential for erosion.
3. An increase in the pollutant load in the stormwater runoff.
4. A decrease in the quality of the flow in downstream water bodies.

Frequently engineers have attempted to mitigate these effects by collecting the runoff from the site and conveying it to a centralized facility where it is stored and treated prior to being sent downstream. This central facility is ordinarily a conventional detention basin, but it can also be a constructed stormwater wetland, an infiltration basin, or other stormwater management facility. While these measures can be very effective, the overall approach is to allow the detrimental impacts to occur on site and remediate them before allowing the runoff to travel downstream. Low impact development techniques use a different approach in that they attempt to reduce the impacts on the site, itself, by reducing the rate and volume of runoff and by eliminating (as much as possible) non-source pollution. These techniques do not respond to the stormwater cycle but rather interact with it in such a way that allows the engineer to design in accordance with the natural hydrologic processes.

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Low impact development incorporates both structural and non-structural measures. In a broad sense, non-structural measures generally minimize the hydrologic effects of the development and structural measures mitigate against those effects which could not be eliminated. Good low impact design gives priority to nonstructural measures. These include minimizing site disturbance, preserving sensitive environmental site features, reducing and disconnecting impervious surfaces, flattening proposed slopes, and maintaining natural drainage characteristics. Structural measures should be incorporated into the overall design in as natural a manner as possible.

Conventional development considers stormwater runoff as a problem that needs to be addressed. Conversely, low impact development promotes the idea of rainfall as a resource to be preserved and utilized. Some examples of how rainfall can be utilized are (i) it can be caught in rain barrels and used to irrigate lawns and gardens, (ii) it can be caught on rooftops and used for a non-potable water supply, and (iii) it can be directed into small, on-lot bioretention basins (sometimes known as rain gardens) and used for landscaping enhancement.

Sometimes it is assumed that a low impact development approach is only applicable to sites with a relatively small amount of impervious coverage. However, research has shown that it can be applied even to sites with a very high impervious percentage. The overall hydrologic effectiveness of a low impact development site is generally higher than a conventionally-designed site that makes use of a central treatment facility. Even in cases where a central collection and treatment facility is required, low impact developments spread throughout the site can still increase the overall effectiveness of the design.

Low impact development design generally makes use of a variety of small-scale features located throughout a development site. It is essential that the ownership and maintenance responsibility of the various practices be clearly delineated and understood by all parties. In the case of a residential subdivision some of the features may be owned by the individual lot owners, others may be the responsibility of a homeowners association, and some may be owned and maintained by the municipality. Finally, some or all of the features may need to be deed restricted or covered by legal easements in order to ensure their continued functioning in the long-term.

Low impact design principles have been adopted by many state, county, and local agencies. Schoharie County in New York State, for example, has prepared a “Low Impact Development Design Strategies” guide which discusses how these features can be implemented in that area. The New York State Department of Environmental Conservation (NYSDEC) defines low impact development as “...a strategy that seeks to implement development without adversely impacting the on-site hydrologic functions or, in the case of a retro-fit, returning the site as close to pre-development hydrologic conditions as possible. Low Impact Development designs capture and/or treat stormwater at its source by preserving and utilizing natural features, often using

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small-scale practices throughout a development site, reducing peak runoff by slowing down the flow of water, thereby allowing rainwater to soak into the ground or evaporate into the air. Other techniques involve the collection of rainwater for irrigation or future use, rather than quickly moving that water off site.”

It should be pointed out that there are a number of related terms that are often used interchangeably with low impact development. The NYSDEC Stormwater Management Design Manual defines “green infrastructure” slightly differently than the definition of low impact development given above. It defines green infrastructure, in part as “including a wide variety of practices at multiple scales to manage and treat stormwater, maintain and restore natural hydrology and ecology function by infiltration, evapotranspiration, capture and reuse of stormwater, and establishment of natural vegetative features”,

Another term used in New York State is “Better Site Design” (BSD) which can be thought of as a set of principles that aims to reduce the environmental impact of development projects. It can easily be seen, then, that all of these terms describe a similar suite of techniques which attempt to promote a similar set of goals.

This course addresses techniques that can be applied to specific development sites. However, many of the principles discussed in this course can also be implemented by municipalities and counties either through their master plans or through land development ordinances. Adopting these practices at a governmental level will promulgate these ideas region-wide. Widespread use of these techniques also raises the aesthetic values of an area because the various small-scale “green” areas tend to break up the overall congested landscape. Sometimes these areas can be used for passive recreation and they often act as refugia for migrant songbirds and other wildlife.

The photograph below shows a small rain garden within a residential development in the town of Kirkland, Washington. This photograph was taken from the municipality’s website, which contains a number of resources associated with low impact development. It shows how even a small low impact development feature can greatly enhance the visual quality of an area.

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Non-Structural Stormwater Management Strategies:

As indicated above, low impact development (LID) techniques can be divided into structural and non-structural measures and, of the two, non-structural measures should be given priority and should be used whenever possible. The NJDEP has requirements for stormwater management which are applicable to all major developments in the state. A major development is defined, by the NJDEP, as any project that disturbs more than 1 acre of land or calls for the installation of at least $\frac{1}{4}$ acre of new impervious surfaces.

The NJDEP requires the maximum practical use of the following nine non-structural strategies at all major developments:

1. Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss.
2. Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces.
3. Maximize the protection of natural drainage features and vegetation.
4. Minimize the decrease in the pre-construction “time of concentration.”
5. Minimize land disturbance including clearing and grading.
6. Minimize soil compaction.
7. Provide low maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers, and pesticides.

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8. Provide vegetated open-channel conveyance systems discharge into and through stable vegetated areas.
9. Provide preventative source controls.

These can be broken down into the following four broad categories:

1. Vegetation & Landscaping.
2. Minimizing Land Disturbance.
3. Impervious Area Management.
4. Time of Concentration Modifications.

Each of these is discussed in more detail below.

Before including any of these LID techniques into a land use project, the design engineer should consult with the applicable state or local reviewing agency to determine which practices will be acceptable. In some cases, these techniques may already be included in the development ordinance. In other cases, provisions in the ordinance may preclude the use of one or another of these techniques.

Vegetation & Landscaping:

The management of existing and proposed vegetation at a land development site can be one of the main nonstructural LID techniques. Preserving existing vegetation can significantly reduce the site's potential impact on downstream properties and waterways. Pervious vegetated areas reduce downstream runoff volumes and pollution loads by providing groundwater recharge, storage, and evapotranspiration. Three key non-structural low impact techniques include the preservation of natural areas, the use of native ground cover, and the establishment of vegetative filters and buffers. As explained below these features are all closely inter-related:

Preservation of Natural Areas: Wherever possible, the preservation of natural areas should be considered when designing a development site. The design engineer should analyze the site and determine which of the following environmentally sensitive areas are available for preservation:

1. Steeply sloped areas.
2. Forests.
3. Groundwater recharge areas.
4. Areas of high groundwater.
5. Freshwater wetlands (and any regulated transition areas associated with them).

These areas should be delineated on the site map and, where possible, the proposed improvements should avoid these areas. In order to fully preserve these areas, however, legal protection should be provided to them in the form of easements and/or deed restrictions. Some townships in New Jersey require that conservation easements be marked in the field with permanent markers declaring that the areas are set aside as conservation areas.

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Wherever possible, the amount of land set aside should be the maximum possible. In order to accomplish this it is often necessary to use creative design techniques. Cluster subdivisions, multi-story buildings, parking under buildings and underground stormwater detention storage are some ways that both the development potential and the preservation of natural areas of a site can be maximized.

Native Ground Cover: Lawns and other turf-grass areas generally produce significantly more runoff than more natural areas such as meadows, woods, or shrub lands. Therefore, the amount of lawn area on a site should be minimized when possible. This can be a significant LID feature because lawns can often form a very large part of a commercial or residential development. Instead of lawns, other vegetation (and particularly native plantings) can be used to landscape the site. There are many benefits to this type of landscaping.

For one thing native plants can provide a low maintenance alternative to lawns which often have to be mowed weekly during the growing season. In addition, native ground cover, shrubs, and trees can increase the amount of infiltration achieved. These plants can also provide better habitat for songbirds and other wildlife. Native plantings can often thrive without the use of pesticides which would otherwise wash downstream to the region's rivers. Finally, native landscaping can provide property screening, summer shade, and year round aesthetic benefits. Native vegetation cannot only be used on construction sites to offset the effects of development but they are also beneficial in enhancing the hydrologic condition of existing disturbed sites. Some areas that could be reclaimed include agricultural fields, abandoned quarries, and other sites that provide little hydrologic benefit in their present condition. In addition, forest remnants that have been taken over by invasive species can be replanted with native woody vegetation. Whenever native plantings are to be used to enhance the hydrologic characteristics of a property it is important to choose the correct variety of plantings. Factors to be considered in this regard include height, density, growth patterns, visual appearance, anticipated use of the planted area, and fertilizer, irrigation, and maintenance needs.

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The photograph below shows how even a small low-impact development feature (in this case a rain garden in an urban setting) can greatly enhance the aesthetics of an area. This feature also provides stormwater quality benefits.



Vegetative Filters and Buffers: Vegetative buffers can provide significant water quality and quantity benefits. Runoff flowing across a vegetated strip is slowed, filtered, and depending on the soil characteristics, may have a chance to recharge into the ground. When designing a vegetative filter strip, engineers should be sure to minimize the strip's slope and maximize its length in order to provide the most efficient runoff treatment. Generally vegetative slopes that are sloped at greater than 5-8% or are less than 25 to 30 feet long are of minimal use. A vegetated buffer can be provided by either preserving native vegetation or by planting new vegetation. Vegetative filters immediately downstream of roadways, parking lots, and other impervious areas can achieve pollutant removal, groundwater recharge, and a decrease in the

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runoff volume. If these filters are provided upstream of streams, ponds, or other riparian areas they can provide all of the benefits listed above and can also provide wildlife habitat and enhanced aesthetics.

Minimizing Land Disturbance:

Minimizing land disturbance is a LID technique that can generally be applied, in one way or another, at most land development sites. The most important phase of the project in this regard is the initial planning phase. When laying out a site for development the design engineer should keep in mind the many aspects that go into minimizing land disturbance. These include analyzing the terrain and ensuring that the development works with the topography rather than against it. By working with the terrain, the project's earthwork and tree clearing can be minimized. A major side benefit of this approach is that will generally reduce the construction costs as well by reducing the amount of earthwork required and minimizing the use of retaining walls.. In addition, all other pertinent site features should be worked into the design. Therefore, the engineer should identify wetlands, soil types, and other environmental constraints. Where possible, the development should be concentrated on areas of low permeability because this will minimize the resulting increase in runoff rates and volume. At the same time any existing depressions (including wetlands) or other storage areas present on the site should be preserved to achieve the same result.

Development in karst topography requires additional analysis and design provisions. Karst topography is a geologic formation underlain by soluble bedrock such as carbonite rock, often limestone. The New Jersey Geological Survey has the following recommendations for development within karst topography. Note that many of these recommendations are very similar to those for low impact development:

1. Do not concentrate flows.
2. Minimize grading.
3. Build within landscape (i.e. design around existing topographic features).
4. Do not alter natural drainage areas or patterns.
5. Minimize the amount of impervious coverage.
6. Avoid increased structural loads at the site to decrease the potential for ground failures.
7. Minimize changes to the existing soil profile. (i.e. minimize the amount of earthwork on the site).

Minimizing land disturbance is not confined to the initial planning phase but can also be accomplished during the construction and post-construction phases.

During construction a site's access roads, construction areas, and equipment and vehicle storage areas should be clearly delineated with fencing, or other barriers and strictly regulated.

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Construction can be phased to minimize the disturbance at any one time. Generally, the project's soil erosion and sediment control plan specifies these procedures.

After construction, there are several ways that the overall land disturbance can be minimized. Easements and deed restrictions can be placed on residential properties prohibiting the further disturbance of critical areas or placing limits on the size of homes or impervious surfaces. Enforcement of such provisions can sometimes be problematical, so it is important that any restrictions placed on a property be realistic, practical, easily definable, and easily enforced. Minimizing soil compaction is another way that the overall site disturbance can be minimized. This is generally done during the construction phase. However, at times soil compaction is unavoidable during construction and this must be remediated later.

Impervious Area Management:

An increase in impervious coverage is often associated with adverse hydraulic impacts. These can include an increase in the peak rate and volume of runoff as well as an increase in stream velocity and erosion. In addition, impervious areas can also accumulate non-point source pollutants that can significantly impact the water quality of receiving waters. All of these impacts can, in the long run, degrade the water quality of streams and can present a health hazard to humans. Therefore, the minimization of impervious surfaces is a vital feature in an LID approach.

Of course, the complete elimination of new impervious surfaces is generally not an option in land development, which often requires the conversion of vacant land (i.e. "green space") to residential or commercial use. This entails the construction of buildings and associated impervious parking, loading, and access features. However, this section will discuss some options to consider to minimize the effective total amount of impervious surfaces on a site. While the considerations discussed in this course can be beneficial on a specific property they are most effective when used on a municipal or regional basis. For this reason, as mentioned previously, these types of criteria are often incorporated into municipal and county master plans and development ordinances.

Reductions in the total amount of impervious surfaces (or, in the alternative, disconnecting impervious surfaces where possible) can have the following beneficial effects:

1. Reducing the peak rate and volume of stormwater runoff.
2. Increasing groundwater recharge.
3. Reducing the amount of pollutants that will be washed downstream.
4. Reducing the size and cost of storm sewer conveyance systems and stormwater treatment facilities.

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In addition, reducing the amount of impervious surfaces on a site, even slightly, often makes for a much more attractive design by allowing for landscaped areas that break up large expanses of pavement or concrete.

Some practical ways that impervious surfaces can be reduced or disconnected are discussed below.

Streets & Sidewalks:

Street widths are designed with safety and trafficability in mind. However, often streets are made unnecessarily wide, resulting in long strips of impervious blacktop that could be converted to green space. In New Jersey, the street width in residential developments is controlled state-wide by the Residential Site Improvement Standards (RSIS). In other states, municipal or county ordinances often require specific minimum street widths. The design engineer should ensure that the minimum street width is employed in all cases, subject to the applicable development regulations and in the interest of safety and traffic considerations.

Additional street features often lend themselves to porous materials. These include, but are not limited to, medians and islands. These areas can ordinarily be landscaped or vegetated. Not only will this reduce the amount of runoff generated but, as with many of the LID ideas, it can greatly increase the visual appeal of the landscape. Further, these areas can be designed to act as mini-storage units for stormwater. This can be done by incorporating an underground drywell below the feature or by grading and planting the area to function as a rain garden or bioretention system. Rain gardens not only reduce the overall rate of runoff, but they also promote groundwater recharge and remove a significant amount of the pollutant load from the runoff. Curbs are a part of the roadway system that are often (but not always) necessary for traffic and pedestrian safety. However, by their nature, curbs concentrate and channel stormwater runoff and reduce the time of concentration. Where it can be demonstrated that curbs are not required for safety purposes, the design engineer should consider eliminating them to allow for sheet flow off the roadway (as opposed to concentrated flow down the road). When curbs cannot be eliminated, holes can be provided at intervals within the curbline to break up the concentration of the flow. The area immediately downstream of these curb openings should be treated with riprap, gravel, or turf grass to prevent erosion.

Sidewalks are another component that can be modified by a low development approach. In many areas sidewalks are essential for pedestrian safety. Therefore, they should never be eliminated from a design for purely hydrologic reasons. However, sidewalks can be constructed of pervious materials (e.g. wood chips) in some areas and of semi-pervious materials (i.e. pavers, gravel, or porous pavement) in others.

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In addition, the sidewalks can often be disconnected from the street or parking area impervious areas which will allow for some of the runoff that comes from the sidewalk to recharge before it reaches these larger areas. In addition, gravel sidewalks can be provided with underground storage areas which will reduce the overall runoff generated by these systems.

Parking & Driveway Areas:

In most commercial and multi-unit residential developments parking and driveway areas contribute greatly to the overall impervious coverage of the site. Twenty years ago many municipal ordinances required excessive amount of parking on-site to ensure that the site did not create a traffic hazard by requiring cars to be parked on the local road system. While this is a worthwhile goal, the result in many cases has been the construction of huge expanses of blacktop which are never occupied even close to capacity by vehicles. These impervious areas could have been reduced and the areas used as green space. Recently, more sophisticated approaches to parking are being used by some jurisdictions resulting in smaller parking lots being constructed.

There are a few different ways that the overall macadam parking area can be reduced. One of these is a concept called “Banked Parking”. An example of banked parking is presented below: Suppose a trucking company in New Jersey is constructing a 30,000 SF warehouse building and the local ordinance requires one parking space for every 500 SF of warehouse. This means that a total of 60 parking spaces would be required by ordinance. However, the developer knows from experience that the warehouse will only employ a maximum of 20 people and that visitors to the site will be infrequent. Therefore, the company can propose to construct 30 spaces (ample for its needs) and to “bank” the other 30 spaces. That is to say that the actual curbing and macadam will be installed for 30 spaces but that the remaining spaces will remain as green space. If, at some point in the future, the company or the municipality feel that there is not adequate parking on the site the remaining spaces can be installed. However, in many instances this will not be the case and the banked parking area will remain “green” in perpetuity. This is obviously a better solution than constructing an excessively large parking area that is never used to capacity.

Another concept is the idea of “shared parking”. This idea takes advantage of the fact that different uses require parking at different times of the day. For instance, a multi-story building may have professional offices on the ground floor and apartments on the upper floors. Both of these uses require parking. However, a certain number of the residents of the apartments would not be expected to be on the site when the offices are in use and some of the parking spaces can be “shared” by these uses.

For example, suppose the local parking ordinance requires that 100 parking spaces are required for the first floor offices and another 100 parking spaces are required for the apartments. Instead

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of constructing a 200 vehicle parking lot, it might make sense to construct a somewhat smaller lot (e.g. for 150 vehicles) realizing that there will not be 100% overlap in occupancy of the different uses. A full scale parking analysis should be done to determine the actual expected peak hour demands to properly size the lot.

Pervious Paving Materials:

Paved surfaces are generally considered to be impervious. They are ordinarily assigned a runoff coefficient approaching 1.0 (meaning that virtually all of the rainfall falling on these surfaces becomes surface runoff). This is true if the surface is macadam, concrete, or even hard-packed gravel. However, there are ways to make a pavement at least partially pervious. The “Massachusetts Low Impact Development Toolkit” is a publication of the Metropolitan Area Planning Council and much of the discussion below is taken from this document. The Toolkit lists the following three types of permeable paving.

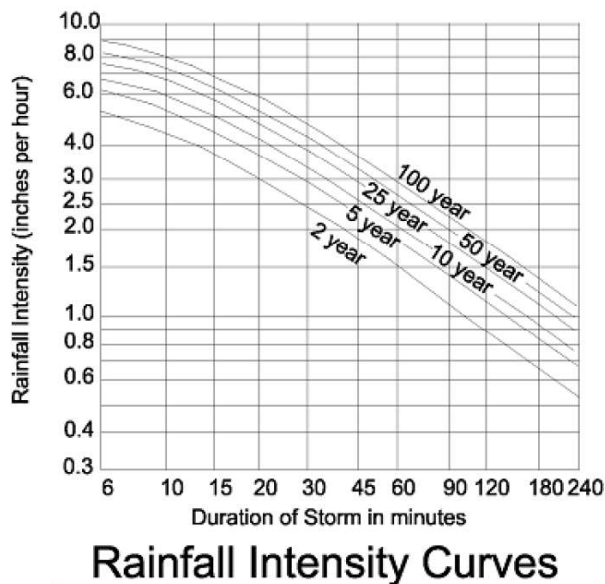
1. Porous asphalt and pervious concrete look very much like standard macadam and concrete surfaces. However, they are mixed with a very low content of fine sand and, consequently, have a void ratio of between 10% and 25%. Because of this, these materials have a very low runoff coefficient.
2. Paving stones are impermeable blocks made of brick, stone or concrete set on a sand or crushed stone base. Joints are filled with stone or sand to allow percolation of rainfall into the ground. Runoff coefficients for these units range from 0.1 to 0.7 depending on a variety of factors including rainfall intensity, joint width, materials used, and the base layer permeability. Open cell design and coarse bed material can often yield runoff coefficients of less than 0.3.
3. Grass pavers are a type of open cell unit paver in which the cells are filled with soil and planted with turf grass. These are sometimes called block pavers, turf pavers, or grid pavers. The pavers, which made of concrete or synthetic materials, distribute the weight of the traffic and prevent compaction of the underlying soil. The resulting runoff coefficients are in the range of 0.15 to 0.6. This is about the same range as a lawn.

Benefits of permeable pavement: The major benefit of permeable paving is that it reduces the rate and volume of runoff as explained above. A simple example will show just how significant this reduction can be:

Example: A one acre parking lot is being designed to support a new church building in Somerset County, New Jersey. An analysis of the parking required indicates that only one half of the area will be used on a regular basis and that the lot is only anticipated to be full on a few days of the

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year (such as Christmas and Easter). Therefore, the design engineer is considering constructing half of the parking area with grass pavers and designating this area as overflow parking. Based on published studies, the conventional paving will have a runoff coefficient of 0.99 whereas the grass pavers are assigned a coefficient of 0.4. The time of concentration (T_c) is assumed to be 10 minutes (which is generally a minimum assumption for T_c). Based on the rainfall chart shown below (which is taken from the Residential Site Improvement Standards in New Jersey), this translates to a 25 year storm of 6.6 inches per hour.



Using the Rational Method the peak rate of runoff is calculated below with (i) the entire area designed as conventional pavement and (ii) designing half of the parking lot with grass pavers. The Rational Method uses the following equation to calculate peak runoff:

$$Q = ciA$$

Where:

Q=The peak rate of runoff in cubic feet per second (CFS)

C=Runoff coefficient

I=Rainfall intensity in inches per hour

A=Drainage area in acres

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(i) Analyze entire area as conventional pavement: $Q = cIA = (0.99)(6.6)(1acre) = 6.5CFS$

(ii) Analyze one half the area as grass pavers: Calculate a weighted “c”

$$c = (0.99 + 0.4) / 2 = 0.695$$

$$Q = cIA = (0.695)(6.6)(1acre) = 4.6CFS$$

Note that there is a 29% decrease in the peak rate of runoff and there would be a comparable decrease in the overall runoff volume.

However, permeable pavers have additional benefits besides their obvious impact on runoff. Some of these are listed below:

- Grass pavers can improve the aesthetics of a site by providing an oasis of grass in an otherwise impermeable landscape.
- Porous paving can increase the effective developable area on a particular site because a portion of the stormwater management system is located below the pavement. This storage, as well as the infiltration provided can greatly reduce the size of a central stormwater management system required.

Limitations on the use of permeable pavement: Despite its many benefits, permeable pavement cannot be used in every situation and there are some cases where it can only be used after careful consideration of all of the environmental factors involved. Permeable pavement is often useful for fire lanes and other emergency access routes that only experience occasional traffic. The following limitations should be considered when using permeable pavement:

- Permeable paving can be prone to clogging from sand or other fine sediments that fill the voids or joints between the pavers. Therefore, it may not be advisable to use pavers in cold climates where frequent sanding is expected. Periodic maintenance is critical to offset the potential for clogging and the surface should be cleaned with a vacuum sweeper several times a year.
- In cold climates, there is the potential for frost action. Some design manuals recommend excavating the base course to below the frost level. However, this may not be required in very permeable soils. On the other hand, dead air and voids in the base course can provide insulation which brings the frost line closer to the surface. This situation should be analyzed on a case by case basis.

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- Permeable paving should not be used in areas with slopes greater than about 5%, in high traffic areas or in areas subject to heavy axle loads. Therefore, it is not a viable option on major roadways, in trucking yards, or in mountainous areas.
- Permeable paving should not receive runoff from any other areas (and especially from any areas that are not fully stabilized) in order to minimize the potential for clogging the voids by siltation.
- Snow plows can catch the edge of grass pavers and some paving stones. Rollers can be attached to the bottom of the snowplow to prevent this.

Design parameters: The actual design of permeable pavement naturally depends on the type of permeable pavement used for a specific application. Design details for paver stones are included in the manufacturer's brochures. However, the following general considerations should be considered in the design:

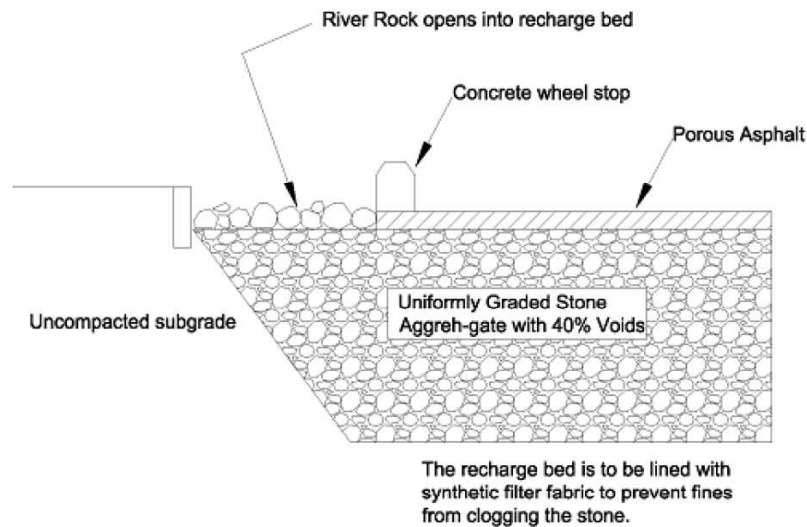
- For all permeable paving, the base course should be reservoir layer of 1"-2" clean, crushed stone. The depth of this layer should be determined based on the design storm considered and the depth of frost penetration.
- Permeable paving requires a single-size grading of base material in order to provide voids for runoff storage. The choice of materials is a compromise between stiffness, permeability, and storage capacity. The use of angular crushed rock with a high surface friction can prevent traffic compaction and rutting.
- The design may include a 2" thick filter course of ½" crushed stone applied over the base course. A synthetic fabric laid at the top of the filter course can help to prevent fines from entering into the base course and clogging the system.
- For grass pavers, deep-rooted grass species should be used whose roots can penetrate the reservoir base course. Irrigation may be required. It should be noted that grass pavers are not suitable for every day parking situations because the traffic will disturb the grass and prevent sunlight from reaching the vegetation. For this reason, grass pavers are more suited to

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occasional overflow parking areas or emergency vehicle access ways..

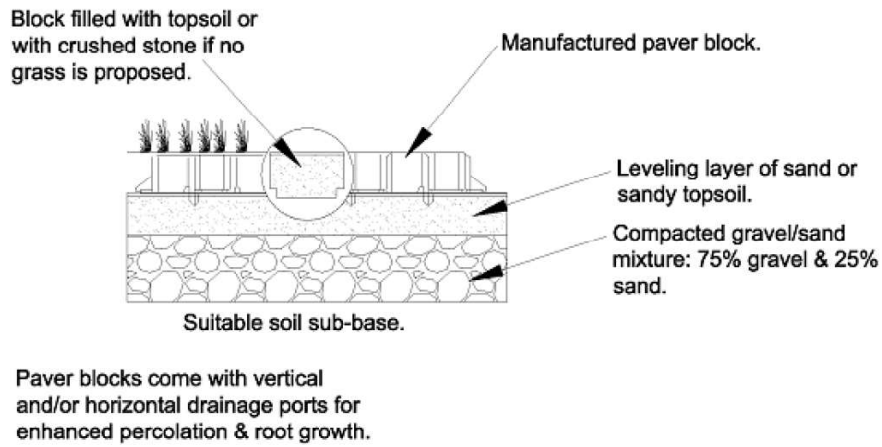
- As has been noted elsewhere, the introduction of sand and dirt onto the permeable paving will contribute to clogging the system and failure of the permeability. Therefore, the permeable paving should not be installed on a construction site until the entire area has been stabilized and erosion is no longer a consideration.

A few standard details for permeable pavement are shown below :



Porous Pavement with Subsurface Infiltration Detail

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Typical Grass Paver Schematic

Maintenance of permeable pavement: As was indicated above, routine maintenance of permeable pavement is absolutely essential to its long-term functionality. If the permeable pavement is not maintained on a regular basis it may continue to function as pavement but it will almost certainly lose its permeability. The following routine maintenance should be performed:

- Clean the surface using vacuum sweeping machines. As a general rule this should be done a minimum of three times per year, but this may need to be done more often if conditions warrant.
- Minimize the use of salt and sand during the winter months.
- Post signs identifying the area as porous pavement so that there is no question in the minds of maintenance personnel.
- Inspect the surface annually for deterioration.
- Keep landscaped areas adjacent to the permeable pavement well maintained to prevent erosion that could spill onto the pavers.
- Paving stones may need periodic maintenance including addition of joint material to replace original material that has been lost.
- The permeable pavement must never be resealed or repaved with an impermeable material.
- The permeable pavement should be monitored regularly to ensure that it drains properly after storm events.

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Cost considerations: As a general rule permeable paving is more expensive than more traditional pavement options both in terms of construction and in on-going maintenance costs. Estimates vary, based on a variety of factors including geographic region, but the installation of permeable paving may be as much as 50% greater than a more conventional option. Some sources indicate that the cost of the maintenance of permeable pavement may range from 1% to 2% of the installation cost annually. On the other hand, the use of permeable pavement can reduce the size of the central stormwater management facilities and can also reduce or eliminate the need for pipes and/or other stormwater conveyances. The design engineer should balance all of these factors when considering the use of permeable pavement on a particular site. The USEPA has a publication entitled “Reducing Stormwater Costs Through Low Impact Development (LID) Strategies and Practices”, which discusses many of the costs associated with these features, including the costs associated with permeable pavement. This document also presents several real-life case studies for review.

The photograph below shows the vegetation thriving in a grass paver parking lot.



Unconnected Impervious Areas:

If an impervious area is not directly connected to a site's drainage system it is considered an unconnected impervious area. Runoff generated by unconnected areas generally experiences at least a short stretch of sheet flow over pervious areas which allows for some infiltration and

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which reduces the quantity of runoff. It can also provide the opportunity for some level of filtration of the runoff, thereby enhancing the quality of the water downstream. Disconnecting impervious areas is generally easier to accomplish on site with a lower total percentage of impervious coverage but it can also be accomplished on sites with more impervious coverage. Unconnected impervious coverage can be either be above ground (e.g. rooftops) or at grade (e.g. parking lots).

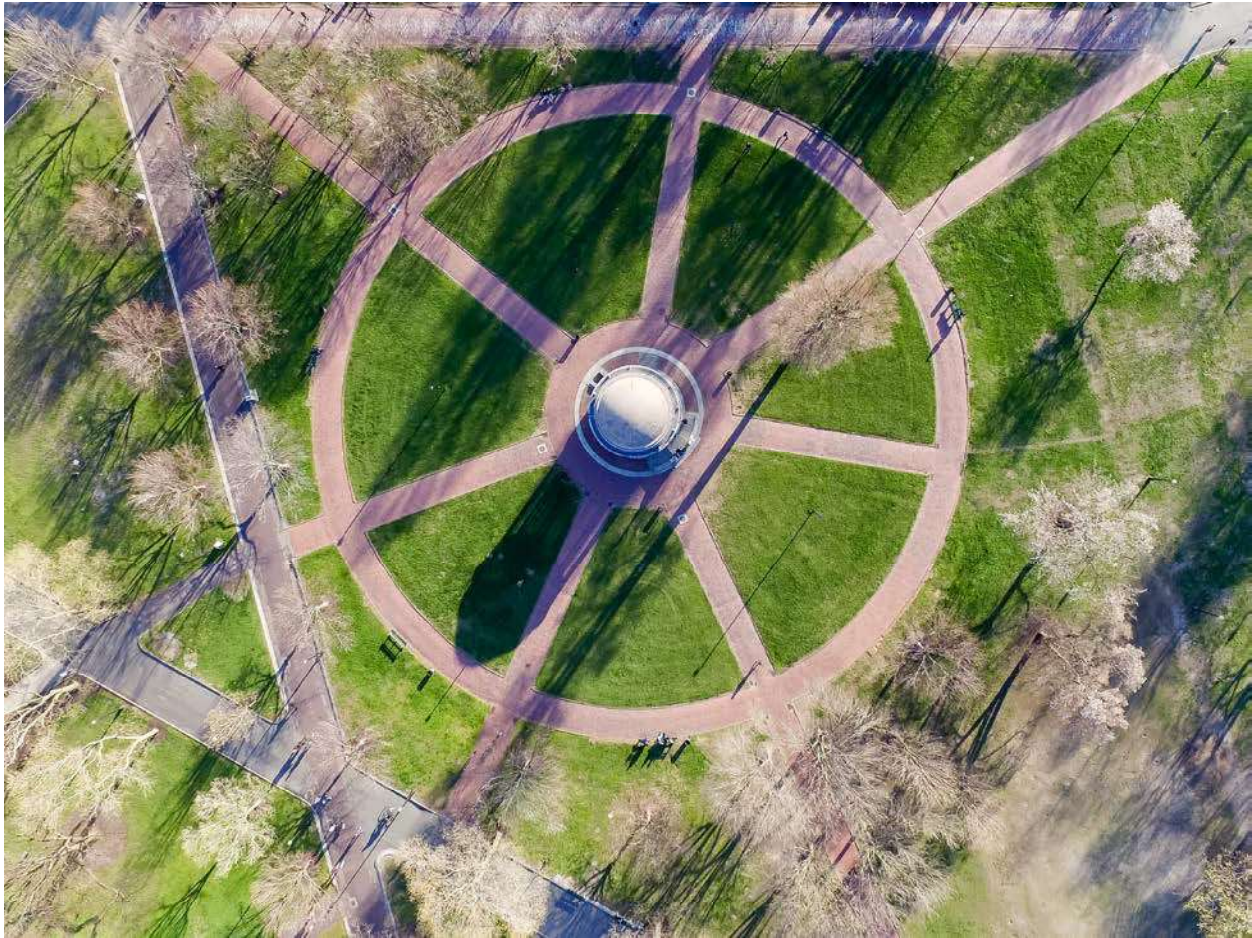
The NJDEP considers impervious areas unconnected under the following conditions:

1. All runoff from the unconnected impervious area must be sheet flow.
2. Upon entering the downstream pervious area, all runoff must remain as sheet flow.
3. In the case of roof leaders, runoff must enter the pervious areas from downspouts equipped with splash pads, level spreaders, or dispersion trenches that reduce flow velocity and induce sheet flow onto the downstream pervious area.
4. All discharges onto the downstream pervious surfaces must be stable and non-erosive.
5. The shape, slope, and vegetated cover in the downstream pervious area must be sufficient to maintain sheet flow throughout its length. Maximum slope of the downstream pervious area is 8 percent. (Note that this maximum slope should be reduced in easily erodible soils).
6. The maximum roof area that can be drained by a single downspout is 600 SF.

Obviously, some of the criteria listed above may need to be modified in other regions. Also, it should be noted that significant site features, such as karst topography or irregular topographic features, may alter the final design.

The photograph below shows how impervious surfaces (in this case walkways in the Boston Commons) can be “disconnected” by interspersing it with pervious areas. These areas can be used to infiltrate and treat the water, reducing the peak rate and enhancing the quality of the runoff travelling downstream.

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Vegetated Roofs:

An innovative way to significantly reduce the overall impervious coverage on a site is by the use of vegetated or “green” roofs. These systems have been used for several years in a number of European countries and they are gaining momentum in the United States. A vegetated roof consists of a lightweight vegetated planting bed that is installed on a new or existing roof. The plants and the bed material store rainfall that would otherwise contribute to the downstream runoff. The actual volume that will be stored depends on the size and porosity of the planting bed as well as the size, number, and type of plantings provided. The stored water is released from the roof via evapotranspiration.

There are a number of specialized commercial products that can be used to implement a green roof design. One common arrangement makes use of a 1” to 6” deep lightweight planting bed underlain by a geomembrane (an impervious synthetic underdrain system) that allows drainage of the roof surface. The actual plantings chosen should be selected based on the following criteria:

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1. The climate.
2. The expected frequency of access and maintenance to the roof.
3. The secondary use of the green roof. (i.e. will the roof be used simply as a stormwater management tool or will it function as a garden or for passive recreation?).

It is imperative, when designing a new or replacement green roof system, to provide adequate capacity and easy access to gutters, underdrains, downspouts, and other elements of the roof's drainage system. Clogging of the underdrain or other system components should be avoided by a combination of sound design and routine maintenance. In addition, overflows must be provided to address system malfunction, large rainstorms, clogging by snow or ice, or other potential problems. Naturally, in cold weather climates, green roofs will be most effective in the spring and summer months and will be less effective (if they function at all) during the fall and winter. In these areas, it may be necessary to bypass the normal roof drainage system during the coldest months to avoid ice build-ups.

Also in some areas (and, especially in arid climates) the roof vegetation may need to be irrigated periodically during the dry season to avoid losing the vegetation. Fertilizers and pesticides may need be applied as well, but these should be kept to a minimum.

Above all else the structural integrity of the roof must be kept in mind and the roof must be designed for any additional loading associated with the planting bed, plants, and stored runoff. It is also imperative that the green aspects of the roof do not interfere with other roof structures or appurtenances such as solar panels, HVAC equipment, etc.

The slope of the roof is also a consideration in this design. Most sloping roofs have a pitch of between 4:12 and 12:12 (vertical to horizontal). If sloping roofs are used as green roofs, erosion control measures will generally be required to keep the planting material in place. The underdrain systems discussed above are ordinarily only required on flat roofs, while more steeply sloping roofs will be able to drain by gravity.

The aerial view of the green roof of the city hall building in Chicago, Illinois, shows how a flat rooftop in an urban area can be converted to a garden oasis.

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The photograph shown below shows a sloping green roof on a hotel in British Columbia. Obviously, although this roof can provide stormwater benefits, it does not provide for any passive recreation.

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Time of Concentration Modifications.

The time of concentration (T_c) is defined as “the time for runoff to travel from the most hydraulically distant point of the watershed to the point of interest within the watershed”. Changes in land use generally result in changes in the T_c . Converting natural green spaces to impervious coverages will reduce the time of concentration and, consequently, increase the quantity and velocity of the runoff and lead to downstream erosion. In order to avoid these impacts, low impact development seeks to reduce or eliminate the reduction in the T_c associated with a particular development. The watershed parameters that affect T_c are the following:

1. Flow length.
2. Flow regime.
3. Surface runoff.
4. Channel shape.
5. Slope.

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During site design, it is possible to minimize this reduction in Tc by controlling the various factors that affect it.

Surface Roughness Change:

Rougher surfaces retard stormwater sheet flow more effectively than do smooth surfaces. Therefore, pavement will allow swifter runoff flow than a lawn, and a lawn will allow swifter flow than will dense, native vegetation. This, of course, affects more than just the time of concentration of the runoff. By slowing down the sheet flow a rougher surface allows for the attenuation of the peak flow and for the possibility of infiltration.

Therefore, whenever possible, a site design engineer should consider preserving native vegetation or replanting areas with native vegetation.

Slope Reduction:

Obviously, reducing the slope of an area will increase the resulting time of concentration. Therefore, shallow slopes should be encouraged on development sites. There are several ways to provide these on steeply sloping properties. One of these is by terracing and, if necessary, separating the different levels by retaining walls. Terraces can be used to redirect runoff to increase the length of the flow path and, consequently, the time of concentration.

Vegetated Conveyance:

The use of vegetated conveyances such as swales and channels (instead of curbs and pipes) to convey runoff can significantly increase the contact area along the Tc flow path and, consequently, can increase the Tc. In addition, grade stabilization structures can be added along the flow path, further increasing the Tc. Vegetated conveyances, however, have the potential to provide additional benefits besides increasing the Tc. If designed properly they can provide opportunities for runoff treatment, runoff infiltration, and groundwater recharge. The design of a vegetated stormwater conveyance must take into account site specific features including slope, soil type, drainage area, and any additional site constraints (such as the presence of septic systems, existing utilities, etc.) The flow through the vegetated conveyance channel is calculated using the Mannings Equation:

$$Q = (1.486 / n) A R^{2/3} S^{1/2}, \text{ where}$$

Q is the total flow conveyed by the channel in cubic feet per second (CFS)

N is the roughness coefficient (see below)

A is the cross sectional area

R is the hydraulic radius (defined as the cross sectional area divided by the wetted perimeter)

S is the slope of the channel in ft/ft

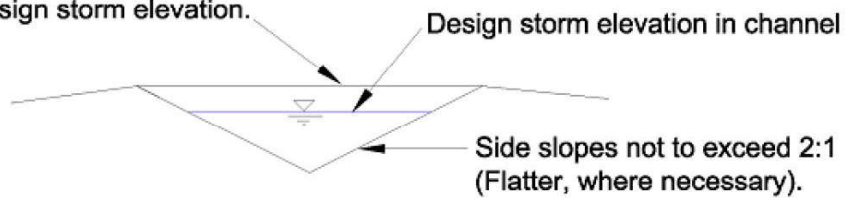
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A table of typical roughness coefficients for channels made up of different materials is presented below:

Material	Roughness Coefficient
concrete	0.013
earth	0.020
gravel	0.025
grass	0.030

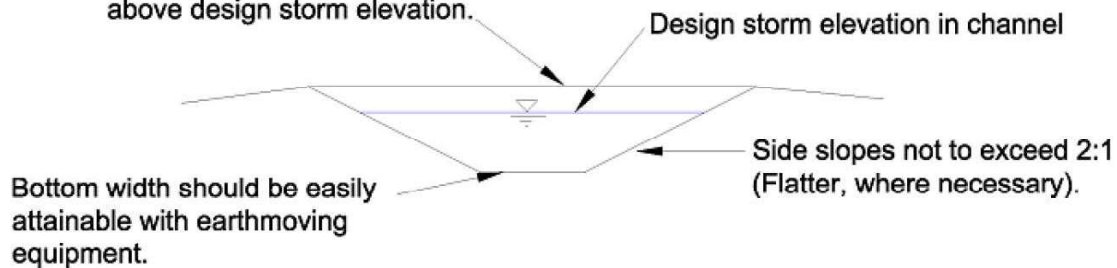
Some typical vegetated conveyance channel geometries are shown below.

Provide 6" (minimum) of freeboard above design storm elevation.



Triangular Channel Section

Provide 6" (minimum) of freeboard above design storm elevation.



Trapezoidal Channel Section

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The photograph below is taken from Association of Illinois Soil and Water Conservation District's "Illinois Urban Manual" and shows a well-maintained trapezoidal grassed channel that conveys runoff from a local road.

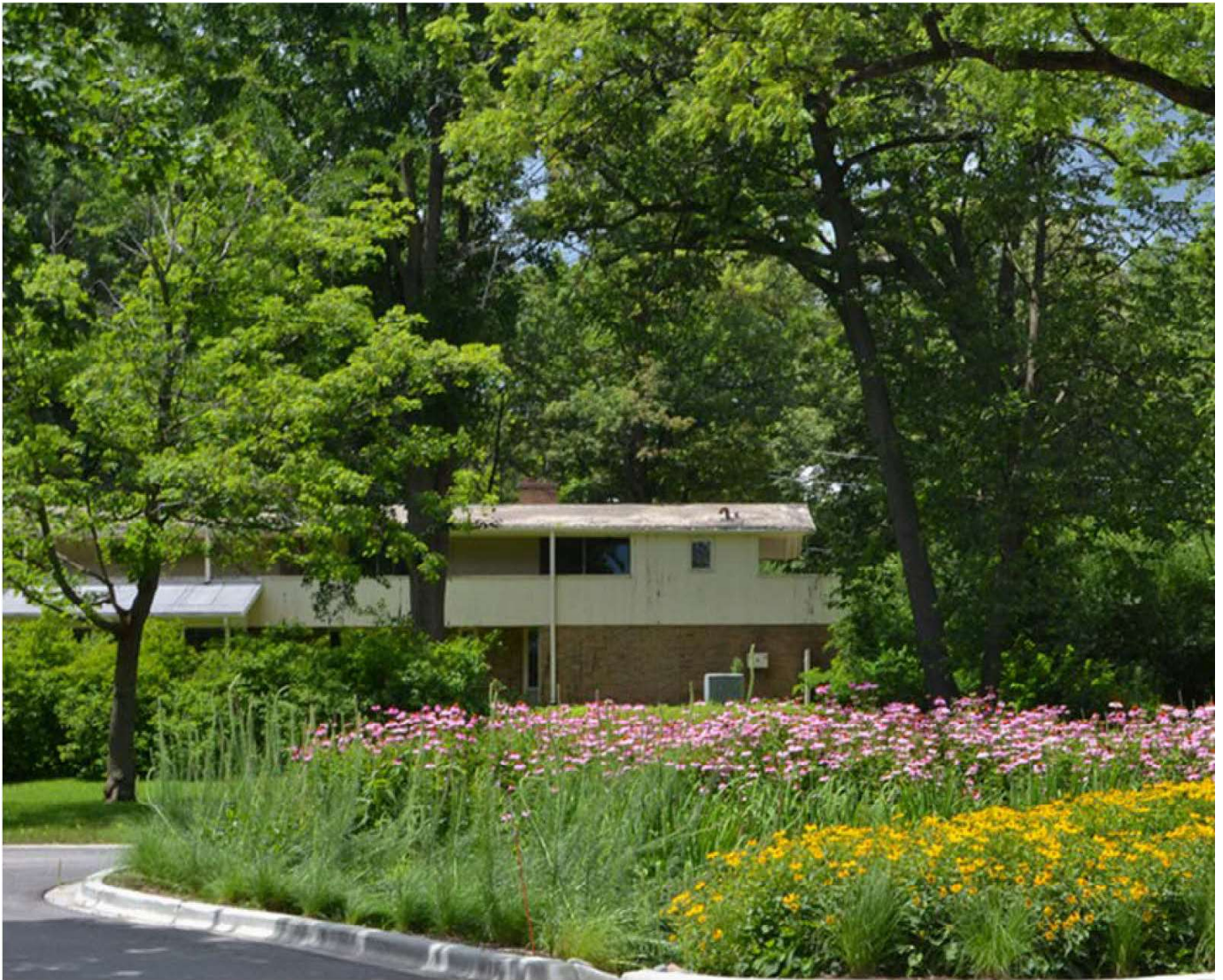


Structural Stormwater Management Measures:

On most development sites it is not possible to provide all of the necessary stormwater quality and quantity control by using only non-structural measures. Ordinarily, it will be necessary to use at least some structural measures. However, in the interest of LID, these structural measures should be incorporated into the overall design in as natural a manner as possible. One approach, for example, is to replace a large, central detention basin with several small bioretention systems or rain gardens placed in strategic locations where they can provide both stormwater benefits and enhance the aesthetics of the overall design.

The photograph below shows a small rain garden built into a residential development. Note that it not only provides stormwater benefits but also adds to the attractiveness of the neighborhood. This is in town of Hinsdale, Illinois.

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Another approach is to collect the runoff in a central location and discharge it into a constructed stormwater wetland instead of a conventional detention basin. Constructed wetlands have many environmental benefits in addition to providing stormwater control. The design of constructed wetlands is beyond the scope of this course, but they should be considered as a possible solution in any development plan. Site constraints (and especially the presence of sufficient water throughout the year) must be considered when deciding if a constructed wetland can be used.

Preventative Source Controls:

The most effective way to treat the quality of stormwater runoff is by preventing pollutants from entering the runoff in the first place. This can be accomplished by the use of preventative source

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controls. These are generally used on commercial and light industrial sites but they can often be used, on a more limited basis, on residential projects as well.

Preventative source controls can prevent the accumulation of trash and debris in drainage systems by providing trash receptacles or other facilities at appropriate locations throughout a site. Of course, regular trash pick-up and routine maintenance of the system is essential for the proper functioning of this design.

The NJDEP has an extensive checklist for low impact development and this checklist includes the following design parameters under preventative source controls. Many of the items on the list are not applicable to single family dwelling developments but are more applicable to multi-family residential developments and commercial developments.

1. The number and spacing of trash receptacles.
2. The number and spacing of pet waste stations.
3. The number of inlets, trash racks, and other devices that prevent discharge of large trash and debris.
4. The anticipated frequency of street sweeping and litter collection.

Stormwater as a Resource:

Obviously, the idea of treating stormwater as a resource is not a new one. For thousands of years people have been collecting rainwater and using it drinking, for irrigating their crops, watering their livestock, and for myriad other purposes. In this way, some LID ideas can be thought of not as new approaches, but as going back to a more simple way of interacting with nature.

Rainwater can be collected in a variety of ways and used for a variety of purposes. On a small scale, rain barrels can be used to collect runoff from a housetop and then used to water the garden during dry periods. The same principle can be used on a larger scale by farmers by catching runoff from barns or greenhouses and storing it for later use for irrigation. Some modern greenhouses are equipped with a system that catches roof runoff, uses it to water plants within the greenhouse, catches any overflow from this watering operation, and stores the excess for use in a later watering.

Rainwater caught from a rooftop can also be used as a non-potable water supply in residential and commercial buildings. However, this type of system can be expensive because it requires additional filtration and also an additional set of pipes within the building to carry the non-potable water. Local regulations also generally require that this water is dyed so that there is no possibility of a resident mistaking it for potable water.

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The photograph below shows a rain barrel connected to the downspout of a house roof leader. The stored water can be used to water the garden or lawn when necessary. This is a typical rain barrel installation.



Additional Considerations:

Most of the information contained in this course is applicable to a design engineer laying out a site for development. However, as stated previously, these same ideas can be applied to local, county, and state regulations to ensure that low impact development techniques be incorporated region-wide. When evaluating specific low impact development ideas for inclusion into regulations, a governmental agency should consider the following:

1. Permitting the use of certain low impact development techniques to manage runoff from low-intensity, high-frequency storms (which generally flush the majority of pollutants downstream) but prohibiting their consideration when addressing erosion and flood control issues. For instance, small on-lot rain gardens may provide significant benefit in treating runoff water quality storms but they will typically be overwhelmed during major storm events and will not attenuate the peak flood rate exiting a site.
2. Requiring deed restrictions or adopting ordinances that prohibit the alteration or elimination of on-lot low impact practices approved for use at a land development site. It is imperative that such restrictions or ordinances clearly define the right of the municipality (or county) to restore such practices and the means by which the restoration will be accomplished and financed.

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3. Requiring deed restrictions or adopting ordinances that require land owners to properly maintain any structural or non-structural low impact practices on their properties.
4. Requiring signage of low impact techniques (in the field), where appropriate. For example, areas set aside as conservation easements should be monumented with signs that delineate their boundary and describe their function.
5. Published literature should be made available to property owners (and other interested parties) explaining the function and maintenance of various low impact techniques. The state of New Jersey has provided this type of information targeting such activities as proper septic system operation, lawn fertilization, and others and has found them to be successful. These publications can sometimes be promulgated in conjunction with the local cooperative extension service.

Design Example:

Much of the information contained in this course has been qualitative in nature. However, the low impact development results can be quantified using standard hydrologic analyses. This analysis is similar to a previous example but will use the SCS Method for computing runoff. This methodology is described in great detail in the USDA publication TR-55 “Urban Hydrology for Small Watersheds”. A very brief overview of the SCS Method is provided below.

The SCS Method uses a runoff coefficient (CN) which is somewhat analogous to the “c” value in the Rational Method. However, there is a linear relationship between c and the direct runoff in the Rational Method, while the relationship between the CN value and the direct runoff is strongly non-linear.

The SCS runoff equation is:

$$Q = (P - 0.2S)^2 / (P + 0.8S)$$

Where;

Q = runoff (inches)

P = rainfall (inches)

S = potential maximum retention after runoff begins (inches)

The value of S ranges between 10 and 100 and is related to the curve number, CN, as follows:

$$S = (1000 / CN) - 10$$

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The value of CN is based on a series of charts contained within TR-55 and is related to both land use and the hydrologic properties of the underlying soil. A portion of the table of CN values included in TR-55 is reprinted below:

Cover Type & Hydrologic Condition	CN Hydrologic Soil Group A	CN Hydrologic Soil Group B	CN Hydrologic Soil Group C	CN Hydrologic Soil Group D
Open Space (lawns, parks, golf courses, cemeteries, etc.): Good condition*	39	61	74	80
Paved parking lots, roofs, driveways etc .	98	98	98	98
Streets & roads:				
Paved, curbed & storm sewer (excluding right of way)	98	98	98	98
Paved, open ditches (including right of way)	83	89	92	93
Gravel (including right of way)	76	85	89	91
Woods (Good condition)**	30	55	70	77

*>75% grass cover

**Woods are protected from grazing, and litter & brush adequately cover the soil.

After the CN value is calculated, the peak discharge (q_p) can be calculated using the following equation:

$$q_p = q_u A_m Q F_p$$

Where:

A_m = the drainage area in square miles

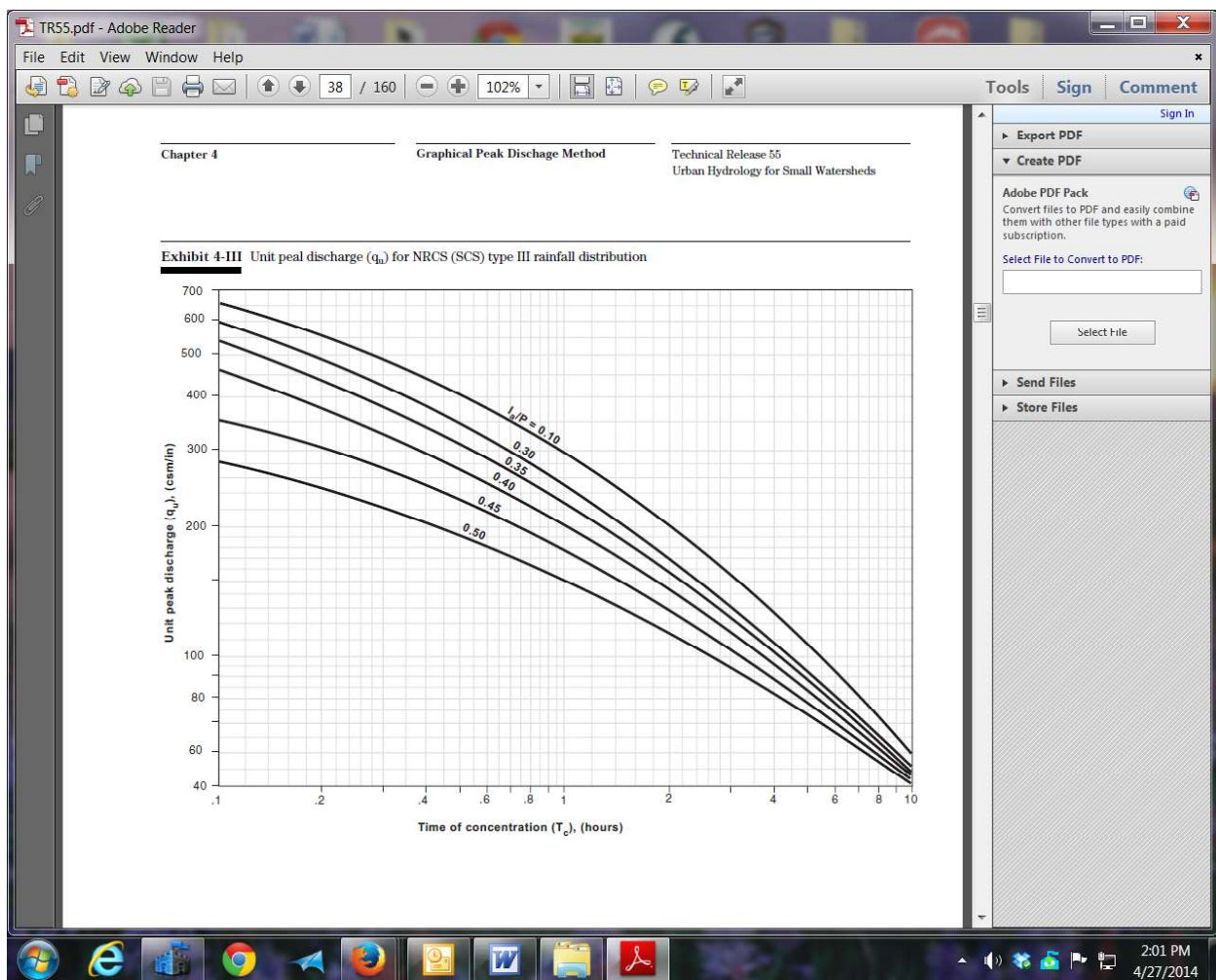
Q = the direct runoff in inches, calculated as explained above

F_p = the pond or swamp adjustment factor. In this example below it is assumed that there are no ponds or swamps. Therefore, a pond factor of 1.0 is used.

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q_u = the unit peak discharge from the chart below in csm/in. This chart is taken from a screen shot of an online version of TR-55 and makes use of two parameters: the time of concentration and the initial abstraction. Initial abstraction includes all losses of the rainfall before runoff begins, including water retained in surface depressions, water intercepted by vegetation, evaporation and infiltration. Through various studies the initial abstraction has been found to be approximated by the following equation:

$$I_a = 0.2S$$



Statement of the problem: The project is a 4 acre wooded site in Morris County, NJ that will be developed into an office building and associated parking. The project will be analyzed two

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ways; first using a conventional design and then using low impact techniques as explained below. Under existing conditions, the area is wooded with significant forest litter and brush and is underlain by soils with a hydrologic soil group of "C". Therefore, (based on the table above, the CN value under existing conditions is 70). The 24 hour, 100 year rainfall in Morris County (based on published sources) is 8.3 inches. Because of the relatively short reach lengths involved a minimum time of concentration of 10 minutes is assumed.

Under existing conditions, calculate: $S = (1000 / CN) - 10 = 1000 / 70 - 10 = 4.2857$

$$I_a = 0.2S = 0.2 \times 4.2857 = 0.857$$

$$Q = (P - 0.2S)^2 / (P + 0.8S) = (8.3 - 0.2 \times 4.2857)^2 / (8.3 + 0.8 \times 4.2857) = 4.723"$$

In order to determine the unit peak discharge we need to calculate the value of I_a/P and recall that the time of concentration is 10 minutes (0.16 hrs).

The value of I_a/P is $(0.857/8.3) = 0.103$ (Use 0.1 to read the chart above).

Using these two values, the graph yields a unit peak discharge of 600.

Therefore, the peak rate of runoff is calculated as:

$$q_p = 600(4 / 640)(4.723")(1.0) = 17.7CFS$$

Conventional Design: A ½ building footprint with 2 ½ acres of parking are proposed. The remaining 1 acre will be converted to a lawn (including a detention basin with grass cover).

The composite CN value is calculated below:

Land Use	Area (Acres)	Soil Type	CN	CN X Area
Parking lot	2.5	C	98	245.0
Building rooftop	0.5	C	98	49.0
Lawn	1.0	C	74	74.0
Total	4.0	---	---	368.0

The weighted CN is calculated as $368.0/4.0 = 92$

$$S = (1000 / 92) - 10 = 0.8696$$

$$Q = (P - 0.2S)^2 / (P + 0.8S) = (8.3 - 0.2 \times 0.8696)^2 / (8.3 + 0.8 \times 0.8696) = 7.34"$$

$$I_a = 0.2S = 0.2 \times 0.8696 = 0.1739$$

The value of I_a/P is $(0.179/8.3) = 0.02$ (Use the minimum graph of 0.1 to read the chart above).

Therefore, the value of Q is 600, as above.

Therefore, the peak rate of runoff is calculated as:

$$q_p = 600(4 / 640)(7.34")(1.0) = 27.5CFS$$

This means that there is a 55% increase in the peak rate of runoff. Detention facilities would have to be designed to store this increase.

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Low Impact Design: A variety of low impact developments will be employed. The same ½ acre building footprint is proposed. However, based on the anticipated parking demand the design engineer has decided to “bank” ½ acre of parking (i.e. leaving it as lawn) and to use grass pavers for an additional ½ acre of the parking area which is only expected to be used a few times per year. Finally, some of the detention storage is being provided in pipes below the parking lot which will allow for the preservation of ½ acre of the woods.

The composite CN value is calculated below:

Land Use	Area (Acres)	Soil Type	CN	CN X Area
Macadam Parking lot	1.5	C	98	147.0
Grass Parking Lot	0.5	C	74	37.0
Building Rooftop	0.5	C	98	49.0
Lawn (Including “banked” parking)	1.0	C	74	74.0
Woods	0.5	C	70	35.0
Total	4.0	-----	-----	342.0

The weighted CN is calculated as $342.0/4.0 = 85.5$ (Use CN=86)

$$S = (1000/86) - 10 = 1.628$$

$$Q = (P - 0.2S)^2 / (P + 0.8S) = (8.3 - 0.2 \times 1.628)^2 / (8.3 + 0.8 \times 1.628) = 6.62"$$

$$Ia = 0.2S = 0.2 \times 1.628 = 0.326$$

The value of Ia/P is $(0.326/8.3) = 0.04$ (Use the minimum graph of 0.1 to read the chart above).

Therefore, the value of Q is 600, as above.

Therefore, the peak rate of runoff is calculated as:

$$q_p = 600(4/640)(6.62")(1.0) = 24.8CFS$$

This means that there is now only a 40% increase in the peak rate of runoff. While this is still large enough that it would require detention facilities, these facilities would be smaller than required with the conventional design.

A comparison of the scenarios presented above indicates that the low impact design reduces the peak rate of runoff exiting the site by about 10% over a conventional design. Note that a more sophisticated design could have accounted for the following parameters which were ignored in this example:

1. Increase in time of concentration caused by retaining some woodland, by providing less pavement and by disconnecting the impervious surfaces.
2. Providing storage under the banked paving which could reduce the overall volume of runoff.

Accounting for either of these parameters would result in an even greater decrease in the proposed peak rate of runoff.

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Final Thoughts:

As shown throughout this course low impact development techniques can be used in an almost unlimited number of ways and can be adapted to almost any situation. The 2013 Low Impact Development Symposium, held in Saint Paul, Minnesota is a good example of this. The diversity of oral presentations and posters presented at this symposium is truly remarkable. The following list is taken from this symposium and doesn't begin to address the wide variety of topics presented or the range of geographic areas covered:

1. Low Impact Development in Shenzhen City, China.
2. Implementation of a Rainwater Harvesting and Infiltration Facilities in the San Francisco Bay Area.
3. A two year comparison of Stormwater Retention by Experimental Greenroofs Planted in Different Sedum Species.
4. Rain Gardens and Car Wash Runoff: Perfect Together?
5. Evaluating Residential Disconnected Downspouts as Stormwater Control Measures.
6. Increasing the Runoff Reduction Benefit of a Planter by Installing Gravel Columns.
7. Is "Zero" Runoff Realistic in Urban Areas.
8. The Stockholm Solution – Ten Years of Experience of Urban Tree Planning and Management Combined with Local Stormwater Management.
9. Stormwater Management as an Amenity at the Mississippi Watershed Management Organization Community Facility.
10. Peat-Based Sorption Media: A New Approach for Removing Heavy Metals from Stormwater.

As was indicated above, this list barely scratches the surface of the wide diversity of low impact development techniques that were presented at the symposium. However, even this short list gives an idea of the nearly limitless possibilities of low impact development techniques. They can be simple or complex, standard or innovative, inexpensive or costly. What they all have in common is a goal to working with the hydrologic cycle and to remove, as far as possible, the negative hydrologic effects of land development.

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Two final photographs will attempt to show the range of low impact development procedures that can be used in different regions.

The photograph below shows a small detention and filtration system that is an attractive addition to an urban downtown area.



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The photograph below shows a constructed a view of Teardrop Park in New York City. The designers have decided to go with this option which includes a variety of native plantings and provides significant aesthetic benefits and also wildlife habitat.



As has been pointed out several times in this course, though, these are only two of the many options that can be used to implement low impact design. The engineer is constrained by the

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site, the climate, and many other factors, but there are almost limitless different ways to implement these useful procedures.