AutoCAD Civil 3D 2010
Education Curriculum Instructor Guide
Unit 4: Environmental Design

Autodesk

Lesson 1

Sustainable Design

Overview

In this lesson, students learn about basic hydrology, stormwater concepts, and sustainable design as they relate to site engineering. In the fields of civil engineering and land development design, the term *sustainable design* refers to applying new methods to reduce the quantity of storm water, improve the quality of storm water, reduce erosion of soil, and infiltrate more storm water to recharge groundwater aquifers. Through the process of designing improvements to a parcel of land, a knowledgeable engineer can minimize the impact of changing the land cover by using sustainable design techniques.

Objectives

After completing this lesson, students will be able to:

- Describe the hydrologic cycle and perform basic surface runoff calculations.
- Describe the impact of land cover on surface water runoff.
- Describe important site considerations in sustainable design.
- Describe different types of strategies for sustainable design.
- Visualize the flow path for storm water runoff.
- Modify surface to alter the surface water flow direction.
- Create a rain garden.

Exercises

The following exercises are provided in a step-by-step format in this lesson:

1. Visualize Flow Patterns
2. Visualize Roadway Drainage
3. Create a Rain Garden

About the Hydrologic Cycle

The *hydrologic cycle* is the ongoing process in which water is evaporated from oceans, lakes, streams, and rivers and then redistributed to the surface of the earth in the form of precipitation. When precipitation, such as rain or snow, falls on the land surface, it encounters a number of different fates. A portion of the precipitation returns to the atmosphere as water vapor, or *evaporates*. Some of this water vapor is consumed by trees and other plant matter, and is eventually passed back to the atmosphere through their leaves in a process is called *transpiration*. Some precipitation *infiltrates* into the earth's soil and may be stored there as groundwater, or it may continue flowing through the soil until it reaches a stream or river. Finally, some precipitation becomes *surface runoff* and enters our streams, rivers, and lakes. Civil and environmental engineers study the behavior of surface runoff to learn more about floods, droughts, and water pollution. Humans can greatly impact surface runoff patterns by altering the way land is used. When studying surface runoff, the basic hydrologic unit is the *watershed*. A watershed is the total area of land that contributes surface runoff to a particular point of interest.

Surface Runoff Calculations

Surface runoff is usually measured in one of two ways. The first measure of surface runoff is *runoff volume*. To understand this method of measuring surface runoff, envision a circular swimming pool that is 4 feet (1.21 m) deep and has a radius of 10 feet (3.05 m). The total volume of water held in the pool is computed as:

$$V = \pi r^2 d = 1{,}257\,ft^3\left(35.36m^3\right)$$

The second measure of surface runoff is *volumetric flow rate*. The volumetric flow rate describes how much water flows past a certain point within a given period of time. Usually, civil engineers abbreviate volumetric flow rate as *Q* and express it in terms of cubic feet per second (cfs) or cubic meters per second (cms). If it takes 2 minutes for the pool to completely drain, you can determine the volumetric flow rate as follows:

$$Q = V/t = 1257\,ft^3 / 120\sec = 10.5cfs\left(0.29cms\right)$$

Impact of Land Cover

Civil engineers use many different techniques to model surface runoff and determine the volume and/or volumetric flow rate of the runoff. Many of these models determine surface runoff as a function of a *runoff coefficient*. Typically, the runoff coefficient is assumed to be the ratio of runoff volume to precipitation volume:

$$Runoff\ Coefficient = \frac{Runoff\ Volume}{Precipitation\ Volume}$$

The runoff coefficient is determined by examining the land cover characteristics of a watershed. Land cover that does not allow the infiltration of precipitation is called *impervious*, while *pervious* land does allow water to migrate through it. For example, an asphalt parking lot does not allow rain to infiltrate into the soil below the parking lot. Therefore, when a watershed is covered by asphalt, it is commonly called impervious. On the other hand, a grass lawn may allow a significant portion of precipitation to infiltrate into the earth's soil. Grass and other types of vegetative land cover are often called pervious. The conversion of land cover from pervious to impervious can create serious runoff problems.

An impervious land cover like asphalt may have a very high runoff coefficient, such as 0.9, while pervious land cover may have a very low runoff coefficient, such as 0.3. To see how land cover affects surface runoff, consider a rectangular watershed that is 100 feet long (30.48 m) and 60 feet wide (18.29 m). If 1 inch (2.54 cm) of rain falls on this watershed, determine the volume of runoff if the watershed is covered by asphalt (runoff coefficient of 0.9). Perform the same calculation if the watershed is covered by grass (runoff coefficient 0f 0.3). The volume of runoff is computed by multiplying the total volume of precipitation by the runoff coefficient.

Step 1. Determine the total volume of precipitation landing on the watershed:

$$V = Length * Width * Depth = 500\,ft^3\left(14.16m^3\right)$$

Step 2. Determine the volume of runoff for each land cover condition:

1. Asphalt has a runoff coefficient of 0.9; therefore, the volume of runoff from the watershed that is covered by asphalt is computed as:

$$0.9 * V = 450\,ft^3\left(12.74m^3\right)$$

2. Grass has a runoff coefficient of 0.3; therefore, the volume of runoff from the watershed that is covered by grass is computed as:

$$0.3 * V = 150\, ft^3 \left(4.25 m^3\right)$$

In this example, three times as much surface runoff volume occurs if the watershed is covered in asphalt versus grass.

In addition to generating a greater volume of runoff, runoff flows much faster on the asphalt than on the grass, which leads to a greater volumetric flow rate.

If it takes a total of 5 minutes for runoff to completely drain off the asphalt and 15 minutes for runoff to drain from the grass, compute the volumetric flow rate from each land cover condition.

1. Step 1. Convert the appropriate units:

   $$5 \min * \frac{60 \sec}{1 \min} = 300 \sec$$

   $$15 \min * \frac{60 \sec}{1 \min} = 900 \sec$$

2. Step 2. Compute the volumetric flow rate for each land cover condition:
   - For asphalt, the volumetric flow rate is:

     $$Q = V/t = 450\, ft^3 / 300 \sec = 1.5\, ft / \sec (0.46 m / \sec)$$

   - For grass, the volumetric flow rate is:

     $$Q = V/t = 150\, ft^3 / 900 \sec = 0.17\, ft^3 / \sec (0.05 m / \sec)$$

In this example, the volumetric flow rate from the asphalt is more than eight times greater than the flow rate from the grass.

Changing the type of land cover within a watershed has a tremendous impact on the runoff characteristics from the watershed. Often, this impact results in flooding capable of placing human life and property at risk. Civil engineers must design ways to minimize the negative effects altering land cover.

About Traditional Design

Historically, the most common design approach for handling increased surface runoff volume and flow due to increased impervious surface area has been to design a drainage system to route the runoff, detain it, then release it at a controlled rate. Routing runoff through inlets, culverts, storm sewers, and other conduits sends the storm water to a *detention pond*.

Detention ponds are earthen structures constructed either by damming a naturally-occurring drainage channel or by excavating existing soil. Detention ponds temporarily store surface runoff and release it at a volumetric flow rate that is comparable to the predevelopment conditions of the watershed. This results in protection of downstream properties from flooding and excessive erosion.

Detention Pond

To conceptualize how a detention pond functions, consider a bathtub that is full of water. If the bathtub were turned upside down, the water stored in it would spill out at a very high flow rate. This is analogous to the runoff conditions of a highly impervious watershed, where very little infiltration occurs and the surface flow velocity is very high. Now, consider the same bathtub, but instead of dumping the water out of it all at once, the drain in the bottom of the tub is opened, allowing the tub to drain over a period of 5 minutes. The same amount of water is emptied from the tub, but by using the drain the water exits the tub in a slower and more controlled manner. Detention ponds function the same way. Runoff from an urbanized watershed rushes into the pond very rapidly. But, the runoff is then stored in the pond and released at a slow, controlled rate through the pond's drain. Detention ponds are very effective at reducing the volumetric flow rate from a developed watershed. However, in recent years, a number of shortcomings have been identified with this approach to managing surface runoff.

First, simply reducing the volumetric flow rate of surface runoff does very little to improve the quality of runoff. Often, as water flows across the earth's surface it becomes contaminated by pollutants such as sediment, oil and grease, phosphorus, nitrogen, metals, and various chemicals. The pollution of surface runoff tends to be even greater when the runoff flows across impervious land cover. While detention ponds are effective at managing the flow rate of surface runoff, the water released to downstream receiving channels is often significantly polluted.

Another shortcoming with the exclusive use of detention ponds as a runoff control strategy is the reduction of groundwater recharge. The water stored in the soil near the earth's surface is a vital source of drinking water for many people. As this water is drawn out of the earth by wells, it must be replaced or these water supplies will not be available for future use. When precipitation falls on a pervious watershed, a significant portion of the precipitation infiltrates the earth's soil. This infiltrated precipitation eventually enters the existing groundwater supply and replenishes underground aquifers. Many highly urbanized areas have noted decreases in their groundwater supplies over time as a result of lost recharge ability.

The continual pollution of surface water and the denial of groundwater recharge arising from land use conversion is an unsustainable condition; meaning that, in effect, nature's resources are being consumed at a rate faster than can be replenished. Theoretically, the long-term result of unsustainable development practices is an environment no longer capable of supporting human populations. Sustainable design strategies seek to minimize and mitigate the negative impacts of development. In recent years, civil engineers have begun to look beyond detention ponds to alternative surface runoff control strategies that are sustainable in nature.

About Sustainable Design

The implementation of sustainable land development, from a civil engineering perspective, occurs through the use of both design strategies and structural controls. Sustainable development strategies are innovative techniques applied during the design phase of a land development project to minimize the overall impact of the development on the environment. In effect, sustainable design strategies seek to prevent problems, such as surface water pollution and denial of groundwater recharge, before they arise. Sustainable design strategies are sometimes called *Low Impact Development Strategies*. Structural controls are physical elements that serve the function of mitigating the inevitable impacts of land use conversion on the environment. A detention pond is a type of structural control.

Strategies

Civil engineers use a variety of design strategies to minimize the impacts of urbanization. These include strategies such as footprinting, preserving natural hydrologic pathways, minimizing the area of new impervious areas, and disconnecting impervious to slow storm water runoff.

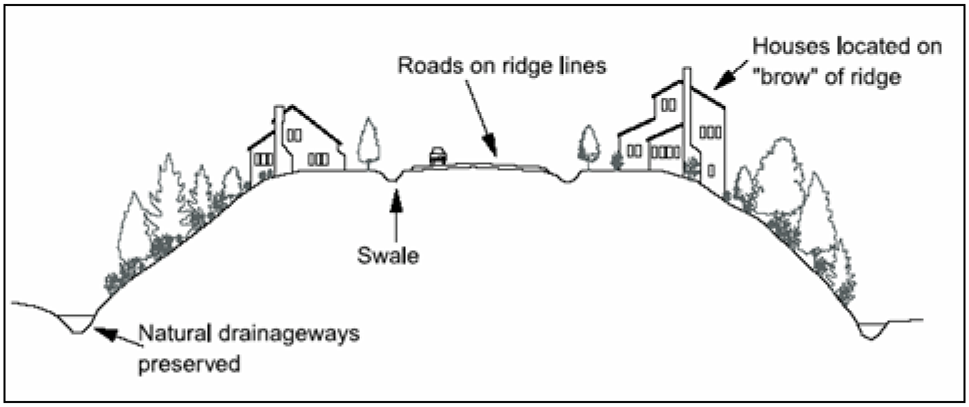
One sustainable design approach is called site *fingerprinting* or *footprinting*, an approach to site development where clearing of vegetation and disturbance of soil is carefully limited to a prescribed distance from proposed structures and improvements. This strategy contrasts the traditional development process of clearing a site of essentially all vegetation prior to construction of new homes and roadways. Site fingerprinting is most commonly employed on sites that possess existing vegetation in the form of tree cover. However, the term *existing vegetation* may also encompass any natural vegetative cover. Even *scrub* vegetation is capable of providing significant water quality benefits. The primary objective in applying this design strategy is to maximize the preservation of existing vegetation and soil. This approach to site development has the dual benefit of minimizing the effects of land disturbing activities (increased rate of storm water runoff, increased levels of pollutants), and also preserving natural areas of vegetation, thereby retaining all of the natural storm water management function.

The disturbance of native vegetation and soil can be further minimized by locating proposed structures and roadways along existing contours and ridgelines. Site earthwork and clearing can be minimized by orienting the major axis of proposed buildings parallel to a site's existing contours, and staggering multiple floor levels to adjust to grade changes.

Similar to the first strategy, focused on preserving existing soil and vegetation, another sustainable design strategy attempts to preserve a site's existing hydrology. The traditional approach to development has been to quickly and efficiently drain a developed site using collection techniques such as curb and gutter and storm sewer pipe networks. By contrast, a sustainable design approach seeks to mimic a site's predeveloped hydrology as closely as possible. This hydrologically functional landscape contributes to the establishment of the site footprint by attempting to preserve streams and stream buffers, wetlands, high permeability soils, and woodlands. Additionally, natural drainage paths are retained to preserve, as closely as possible, a site's predevelopment time of concentration. A watershed's time of concentration is the time that it takes the most hydraulically remote portion of a watershed to contribute runoff to the watershed's outflow point. Methods of preserving predevelopment times of concentration are as follows:

- Maximization of overland (nonchanneled) surface flow.
- Designing such that site grading preserves or, if possible, lengthens predevelopment runoff paths.
- Lengthening and flattening site slopes to the extent that there is no conflict with the paramount goal of minimizing grading and clearing of vegetation.
- Maximizing the use of open swale systems.

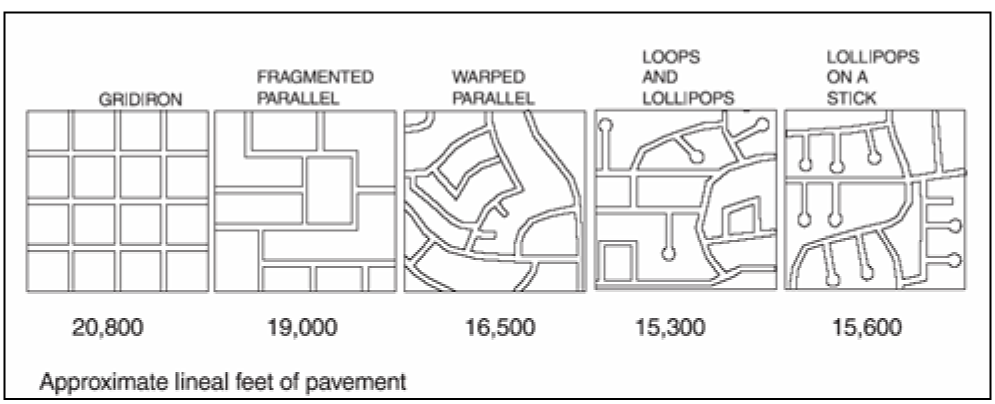
The following illustration shows the principles of site fingerprinting and preservation of natural drainage paths.



Minimization of Earthwork By Situating Road Along Existing Ridge Line
(Prince George's County, Maryland, June 1999)

Another focal point of sustainable design is to minimize the amount of impervious area on a developed site. Perhaps the simplest way that this is accomplished is through the use of reduced roadway widths. A typical primary road section consists of two 18' drive lanes, with curb and gutter present on each side. Imperviousness is often further increased by the installation of sidewalk sections on each side of a roadway. In locations where traffic volumes permit, a rural residential roadway section can be used in place of the primary road section. Reduction of drive aisle widths from 18 to 12 feet results in a 33 percent reduction in impervious area. Furthermore, with the attempted preservation of natural runoff patterns, curb and gutter might not be required.

In addition to reducing the width of proposed roadways, attention to their layout orientation can greatly reduce the total amount of impervious area arising from a development project. The following illustration presents various subdivision road configurations and their respective pavement lengths.



Comparison of Pavement Lengths by Roadway Layout
(Prince George's County, Maryland, June 1999)

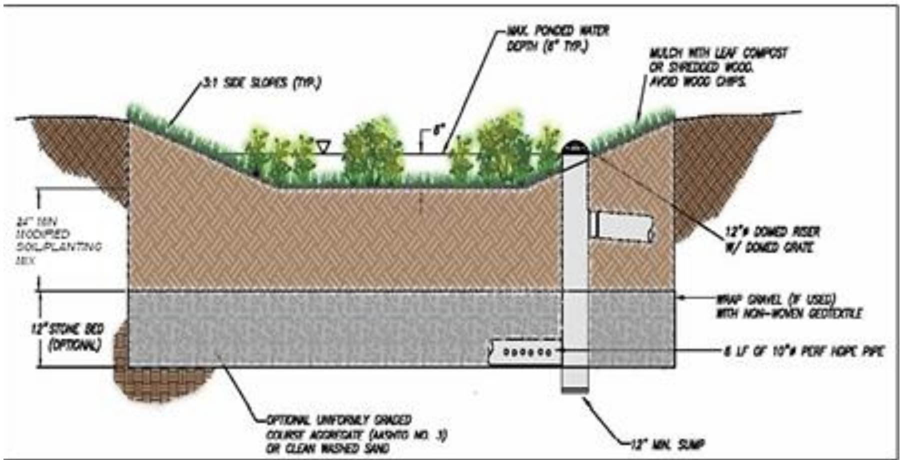
Even when sustainable design techniques are applied, development projects inherently increase the amount of impervious cover within a given watershed. Designing with an emphasis on sustainability not only attempts to minimize impervious cover, but also seeks to keep the impervious portions of a site disconnected. Disconnection of site impervious areas provides an opportunity for infiltration and evaporation, while also reducing the volume of concentrated storm water runoff generated from a given site. Methods of disconnecting impervious areas are presented as follows:

- Disconnecting roof drains and directing flows to vegetated areas.
- Directing flows from driveways and other impervious areas to stabilized vegetated areas.
- Breaking up flow directions from large paved surfaces.
- Grading so that overland flow is directed through vegetated areas.
- Carefully locating impervious areas so that their runoff is directed to natural systems, vegetated buffers, natural resource areas, or infiltration zones/soils.

Structural Controls

Civil engineers use structural controls such as bioretention cells, vegetated filter strips, vegetated swales, infiltration basins, and infiltration trenches to minimize the impacts of urbanization.

Perhaps the most popular sustainable practice for localized management of storm water runoff is *bioretention cells*, sometimes called *rain gardens*. Bioretention cells improve the quality of storm water runoff by means of adsorption, filtration, volitization, ion exchange, and microbial decomposition. In the most general sense, a bioretention cell can be thought of as an infiltration area comprised of a specific mix of trees, plants, and shrubs mimicking the ecosystem of an upland forest floor. Bioretention is an attractive runoff control option in high visibility residential areas because the practice appears to be simply a landscaped area within a yard or parking lot. In reality, however, bioretention cells are engineered storm water control practices capable of significantly improving the quality of storm water runoff as well as reducing the overall volume of runoff from a site. Additionally, because water is infiltrated into the subsoil upon passing through the vegetative filter media, the practice is capable of recharging groundwater supplies. Bioretention cells function particularly well on residential sites, where runoff from impervious areas such as rooftops and driveways can be directed to the cell. Often, bioretention areas are equipped with a bypass piping system to permit passage of extreme runoff events exceeding the storage capacity of the cell. The following figure illustrates a typical bioretention cell.



Profile View of Bioretention Area with Domed Riser Overflow
(Pennsylvania DEP Draft Stormwater Best Management Practices Manual, 2005

Another popular structural control practice for management of surface runoff quality is *vegetated filter strips*. Vegetated filter strips are engineered strips of planted or indigenous vegetation strategically located between nonpoint sources of pollution and receiving water bodies for the purpose of removing or mitigating the effects of nonpoint source pollutants such as nutrients, pesticides, sediments, and suspended solids. Vegetated filter strips often serve as one component of an integrated storm water runoff management system or *treatment train* where multiple structural practices are placed in series. Properly constructed and maintained, strips are capable of reducing runoff velocity, reducing runoff volume (slightly), improving runoff quality, contributing to groundwater recharge, reducing site impervious area, and providing aesthetic benefit to developed sites. Vegetated filter or buffer strips are suitable for use in residential, commercial, and highway settings.

As previously discussed, one sustainable design strategy is to avoid the use of curb and gutter for low traffic roadways, opting instead for vegetated storm water conveyance systems. Vegetated storm water conveyance swales are used throughout the United States in residential, commercial, industrial, and highway settings. These water quality swales are usually heavily vegetated with a dense, diverse mix of native water-resistant plants exhibiting high pollutant removal potential. In selecting the vegetative mix, the primary focus is the improvement of surface runoff quality. Vegetated swales are most often broad, shallow, earthen-lined channels that permit infiltration, and filtering of runoff. The environmental benefits of a vegetated storm water conveyance channel far outweigh those of conventional curb and gutter systems. Most often, vegetated swales are characterized by a layer of dense vegetation, underlain by at least 30 inches of high to moderate permeability soil. Another variety of filter is characterized by a 12- to 24-inch deep aggregate layer underlying the vegetated top layer. The void space found in the aggregate provides for storage of runoff, thereby leading to a significant reduction in the overall volume of runoff observed from a site.

The final category of sustainable structural control practices is *infiltration*. Infiltration basins are shallow impoundment areas designed to temporarily store and infiltrate storm water runoff. Infiltration basins use the existing soil mantle to reduce the volume of storm water runoff through infiltration and evapotranspiration. Additionally, the quality of the runoff is improved by the natural filtering process of the existing soil mantle and also by the vegetation planted in the basins. Infiltration basins function much like the conventional detention ponds previously described. However, instead of releasing all inflow to downstream receiving channels, a significant portion of inflow is infiltrated into the basin's subsoil.

Infiltration trenches are linear storm water control practices that function by detaining and infiltrating inflow over a designated period of time. Usually an infiltration trench is part of a storm water conveyance system and is designed so that even large storm events are conveyed through the trench with some runoff volume reduction. During small, frequent storm events, the observed volume reduction may be quite significant. While different types of infiltration trenches exist (surface versus subsurface), the common design element is the underlying aggregate layer and its pore space, which is allocated to storing inflow until it can infiltrate into the surrounding soil.

Key Terms

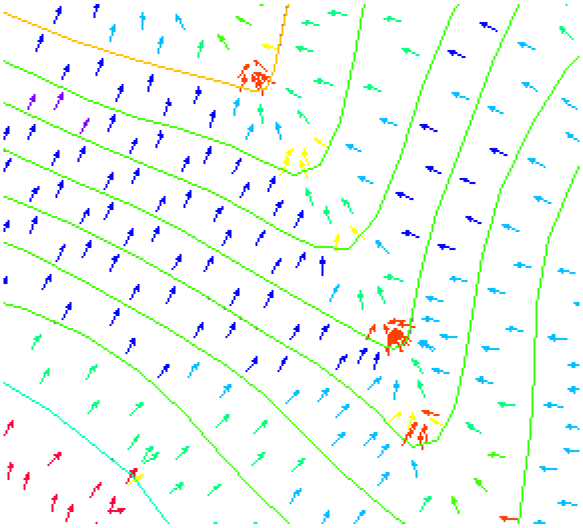
Hydrologic cycle	The ongoing process in which water is cycled through precipitation, runoff, infiltration, evaporation, and transpiration.
Watershed	A watershed is the total area of land that contributes surface runoff to a particular point of interest.
Runoff volume	A volumetric measure of the amount of precipitation that runs off the surface of the land.
Flow rate	A measure of the volumetric flow per unit time. Cubic feet/second or cubic meters/second are typical units.
Runoff coefficient	The ratio of runoff volume to precipitation volume. A ratio of 1 indicates no infiltration or interception, that is, that all precipitation runs off. A ratio of 0 indicates that no precipitation runs off.
Pervious, impervious land cover	Pervious and impervious are general terms describing the tendency of a land cover to infiltrate water. A pervious surface has strong infiltration, while an impervious surface sheds water.
Urbanization	Urbanization is a term used for the conversion of land cover from a forest or agricultural use to one with more buildings, roads, and impervious surfaces.

Detention pond	Earthen structures constructed either by damming a naturally-occurring drainage channel or by excavating existing soil. Detention ponds temporarily store surface runoff and release it at a volumetric flow rate that is comparable to the predevelopment conditions of the watershed.
Groundwater recharge	Groundwater aquifers supply water for many uses. Recharge is the term used to denote the promotion of infiltration of precipitation back into the aquifer to sustain it.
Runoff water quality	Precipitation that runs off the land is often adversely affected by the surfaces and materials it interacts with. Runoff water quality has been a concern in most areas.
Low Impact Development Strategies	Low Impact Development, or LID, refers to strategies designed to minimize the impact of urbanization on water quality and quantity. These include strategies such as footprinting, preserving natural hydrologic pathways, minimizing the area of new impervious areas, and disconnecting impervious to slow storm water runoff.
Structural controls	Structural controls are physical elements that mitigate the inevitable impacts of land use conversion on the environment. These controls include bioretention cells, vegetated filter strips, vegetated swales, infiltration basins, and infiltration trenches.

Exercise 1: Visualize Flow Patterns

In this exercise, students build a surface model to help visualize surface runoff flow patterns.

At the end of this exercise, the drawing displays as shown.



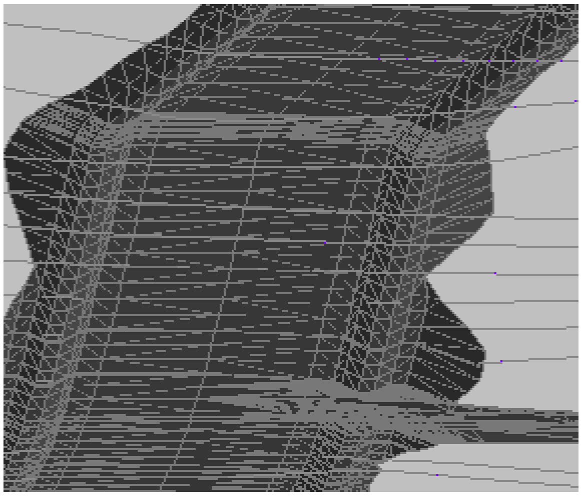
For this exercise open ...*I_SustainableDesign-EX1.dwg.* Note that there is no separate metric version of this drawing.

The existing terrain in the vicinity of the proposed subdivision is provided in the form of contours and spot elevations.

Exercise 2: Visualize Roadway Drainage

In this exercise, students import a roadway corridor to the site and inspect the drainage pattern.

At the end of this exercise, the drawing displays as shown.



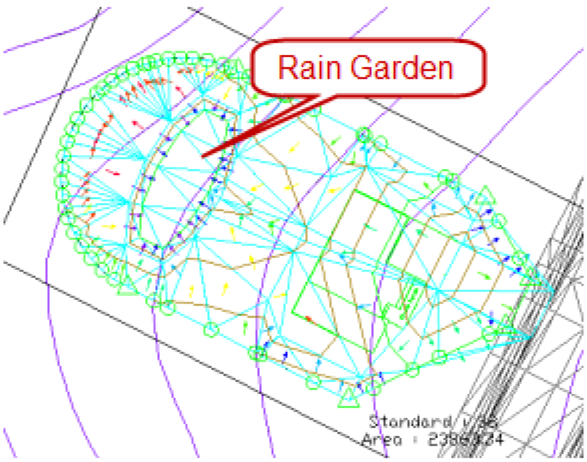
For this exercise open …\I_SustainableDesign-EX2.dwg. Note that there is no separate metric version of this drawing.

Students import the roadway surface information using a LandXML file. LandXML is a file format that enables you to export and import information about objects used in the site design process.

Exercise 3: Create a Rain Garden

In this exercise, perform detailed grading on a parcel in order to ensure that storm water drains in the correct direction.

At the end of this exercise, the drawing displays as shown.



For this exercise open …\I_SustainableDesign-EX3.dwg. Note that there is no separate metric version of this drawing.

Import Parcels and Feature Lines

Students import the parcel information using a LandXML file. LandXML is a file format that enables you to export and import information about objects used in the site design process.

Assessment

Challenge Exercise

Instructors provide a master or challenge exercise for students to do based on this lesson.

Questions

1. What are typical units for flow rate?
2. Groundwater recharge is most closely associated with what element of the hydrologic cycle?
3. What is the purpose of a detention pond?
4. Which will have a lower runoff coefficient, pervious or impervious land cover?
5. What is footprinting? Is it a strategy or a structural control?
6. Name at least three major types of sustainable design structural controls.
7. What is a rain garden?

Answers

1. Cubic feet/second or cubic meters/second.
2. Infiltration. Without adequate infiltration, groundwater aquifers will not be recharged.
3. Detention ponds temporarily store surface runoff and release it at a volumetric flow rate that is comparable to the predevelopment conditions of the watershed.
4. Pervious land cover will have a lower runoff coefficient. The runoff coefficient is the ratio of runoff volume to precipitation volume. Since pervious land will have less runoff and more infiltration, the ratio will be lower.
5. Footprinting is a *strategy* where clearing of vegetation and disturbance of soil are carefully limited to a prescribed distance from proposed structures and improvements. The primary objective in applying this design strategy is to maximize the preservation of existing vegetation and soil.
6. Bioretention cells, vegetated filter strips, vegetated swales, infiltration basins, and infiltration trenches are all used to minimize the impacts of urbanization.
7. A rain garden, or bioretention cell, can be thought of as an infiltration area comprised of a specific mix of trees, plants, and shrubs mimicking the ecosystem of an upland forest floor. It appears to be simply a landscaped area within a yard or parking lot. In reality, however, bioretention cells are engineered storm water control practices capable of significantly improving the quality of storm water runoff, as well as reducing the overall volume of runoff from a site.

Lesson Summary

In this lesson, students learned about the concepts of the hydrologic cycle, land cover, flow rate, traditional design for mitigating water quantity impacts, and sustainable design strategies and structural controls. Students visualized flow drainage paths using contour analysis and slope arrows on a site and visualized flow along the ditch lines of a corridor. Lastly, students used designed feature lines in the backyard of a parcel to create a rain garden and visualize the storm water drainage path into the rain garden.