Hydrology 101 – A Reference Document for Teachers and Students

(Words in italic are defined at the end of document)

Background:

As our natural landscape becomes more and more developed, it can have severe impacts on the natural *hydrology* of the landscape and our *watersheds*. In a naturally vegetated and undisturbed landscape, precipitation that falls onto the ground is allowed to infiltrate into the soils below, evaporates, or is taken up and used by plants and then released into the atmosphere through transpiration (as seen in Figure 1). In this kind of natural setting, approximately 50 percent of water actually infiltrates into the ground, 40 percent is transferred back to the atmosphere through evaporation and transpiration (evapotranspiration), while only 10 percent flows over the landscape as runoff and into nearby streams or water bodies (See Figure 2). As land becomes developed the percentage of infiltration and runoff can change drastically. When land is altered and built upon, some of the basic characteristics of the landscape no longer exist. Instead of a healthy vegetated landscape with soils that have useful properties and microbial activity that allow water to infiltrate, be cleaned of possible contaminants, and restore groundwater levels, *impervious surfaces* are placed on top of the earth's surface in the form of houses, driveways, roads, and sidewalks. These surfaces do not allow water to infiltrate into the ground and can increase the amount of runoff over the land to 55 percent of rainfall in extreme urban settings.

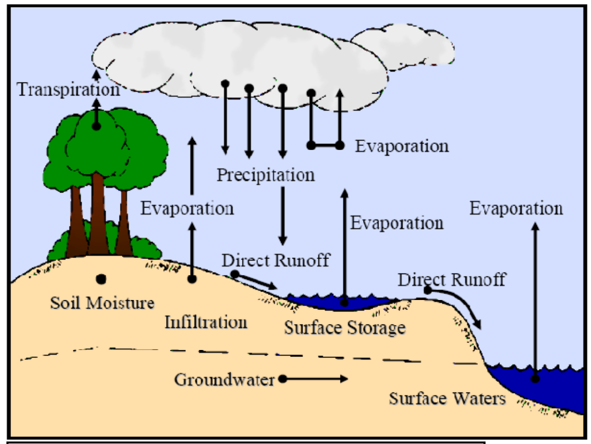


Figure 1 – Source: RI Stormwater Design and Installation Standards Manual.

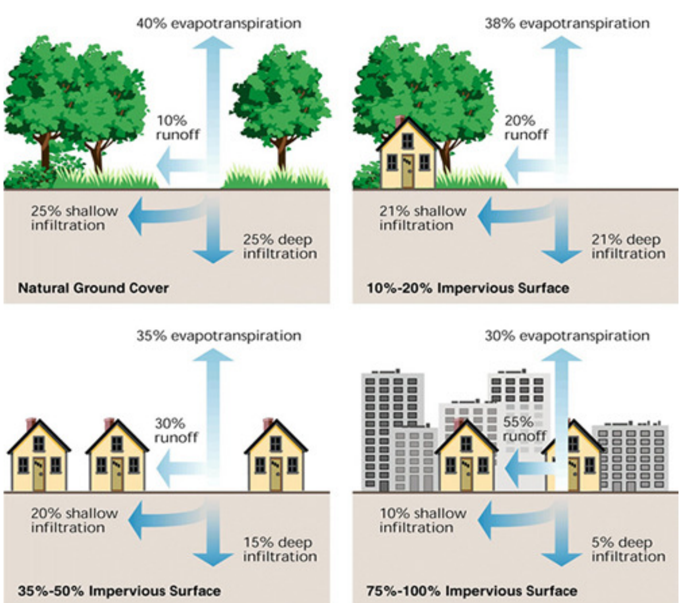


Figure 2 – Source: Minnesota Water: Let's Keep it Clean Act
http://www.cleanwatermn.org/resources/Hard-Surfaces.aspx

During development, not only is the landscape transformed and covered in impervious surfaces, but many times areas that aren't covered with impervious have been stripped of its natural vegetated cover, healthy topsoil has been cleared away, and the site sloped and shaped to allow easy access for large machinery and building placement. These activities can greatly impact the land that is not covered with impervious surfaces, making them compacted and bare, conditions that are not conducive for plant growth or infiltration. The landscape that is left after development is one that is extremely different from its original state, and one that does not perform useful and natural hydrologic functions. For many years this kind of development has been taking place all over the U.S and it has had detrimental effects on the health of our local water bodies, flood risks, and availability of clean drinking water found in groundwater aquifers and surface waters that many people rely on.

Runoff Volume:

When precipitation falls onto the landscape, its fate is largely determined by the characteristics of the site it hits (soils, impervious surfaces, vegetation, amount of saturation currently in landscape, etc.), and the amount of precipitation that falls. In Rhode Island, we have an average yearly rainfall amount of 51 inches/year. This rain can fall in large or small storm events. Hydrologists have classified certain storm events and the amount of rain produced by them into statistical categories such as the 1 year storm, 10 year storm or 100 year storm. For example in RI, the 100 year storm refers to a large storm that produces over 8.5 inches of rain within a 24 hour period, and has a 1% chance of occurring each year (Note: A 100 year storm does not mean it occurs once every 100 years, but rather has a 1 out of 100 chance of occurring, thus a 1% chance). Figure 3 below is taken from the RI Stormwater Design and Installation Standards Manual and describes the rainfall amount for different storm events in Rhode Island. (RI Stormwater Manual)

RI County	24 – hour (Type III) Rainfall Amount (inches)*						
	1 – Year	2 – Year	5 – Year	10 – Year	25 – Year	50 – Year	100 - Year
Providence	2.7	3.3	4.1	4.9	6.1	7.3	8.7
Bristol	2.8	3.3	4.1	4.9	6.1	7.3	8.6
Newport	2.8	3.3	4.1	4.9	6.1	7.3	8.6
Kent	2.7	3.3	4.1	4.8	6.2	7.3	8.7
Washington	2.8	3.3	4.1	4.9	6.1	7.2	8.5

Figure 3 – Source: RI Stormwater Design and Installation Standards Manual

*All Rhode Island County rainfall values were obtained from the Northeast Regional Climate Center (NRCC) using regional rainfall data processed by NRCC from the period of record through December 2008.

The surface that rain falls upon will determine whether water will infiltrate into the ground or runoff the landscape. Hydrologists have also categorized different land uses and their potential for runoff by assigning *Curve Number* values to various landscapes. Curve numbers were developed by what is currently known as the Natural Resources Conservation Service (NRCS) when they first started studying runoff volume and graphically representing it with rainfall retention curves. These curve numbers help to determine how much water will runoff a surface given a specific rainfall amount. Figure 4 and Figure 5 on the following page are examples of curve number values assigned to different landscapes. The higher the curve number, the more rain will runoff the land surface. In the charts below, you will notice that not only does land cover determine the curve number, but also the *Hydrologic Soil Group* (A, B, C, D). A group "A" soil is one that has a low runoff potential when thoroughly wet, meaning water will still infiltrate into the soil even after large rainfall events and saturated conditions. A group "B" soil has moderately low runoff potential, a group "C" soil has moderately high runoff potential, and a group "D" soil has a high runoff potential (NRCS, 2007). These soil classifications are typically made by a professional soil scientist. Knowing the type of land cover that resides on a landscape and the hydrologic soil group, one can determine the curve number for a site. Knowing the curve number of an area and the amount of rainfall, the amount of water that runs off the landscape can be determined. See the graph (Figure 6) below to determine runoff amounts for a given curve number and rainfall amount.

Figure 4 – Curve Numbers for Agricultural Lands, Source: TR - 55

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods—grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.		59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.

2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Figure 5 – Curve Numbers for Urban Developed Lands, Source: TR - 55

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (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
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82

1 Average runoff condition, and $I_a = 0.2S$.

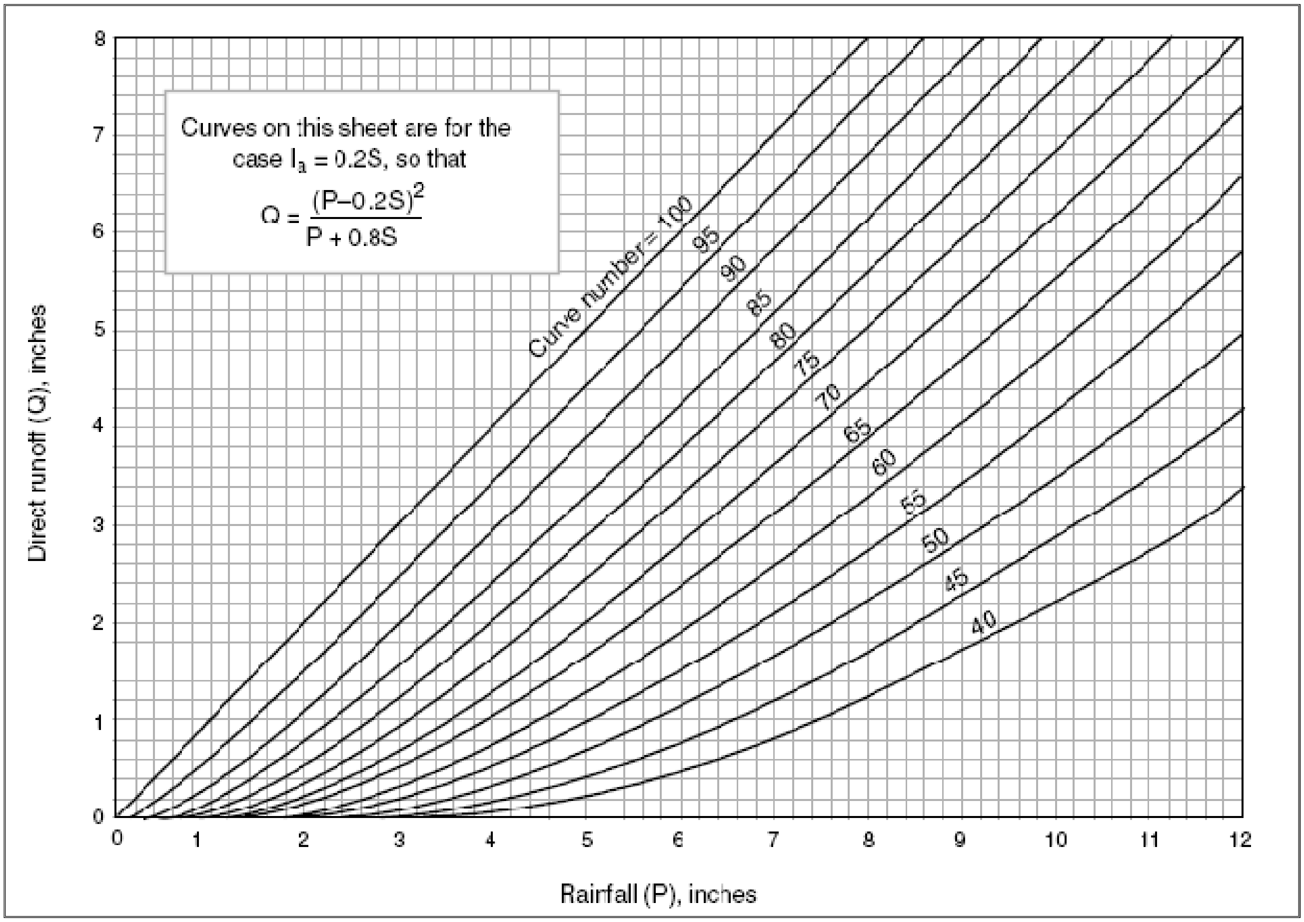
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Figure 6 – Inches of runoff for various rainfall and curve numbers, Source: TR - 55

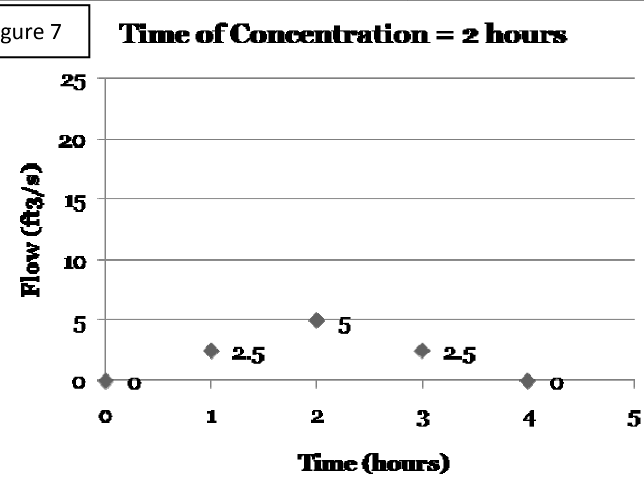


The actual volume of runoff can also be determined for a given area by knowing the rainfall amount, curve number, and drainage area you are analyzing (see example calculation in the Runoff Volume: The Importance of Land Cover Lesson). As you can see from the charts, highly developed landscapes have higher curve numbers. For example, an impervious area such as a paved parking lot has a curve number of 98; whereas a wooded area in good hydrologic condition with a hydrologic soil group “B” has a curve number of 55. By using the graph above, one can see that for a rainfall event that produces 2 inches of rain, the parking lot (curve number = 98) would have approximately 1.8 inches of runoff, while the wooded area (curve number = 55) would have no runoff at all. Over a large area, this can drastically change the volume of water that runs off the surface of a landscape. In the following sections, you will discover how this increase in runoff volume can contribute to serious problems on the landscape and within a community.

Runoff Flow:

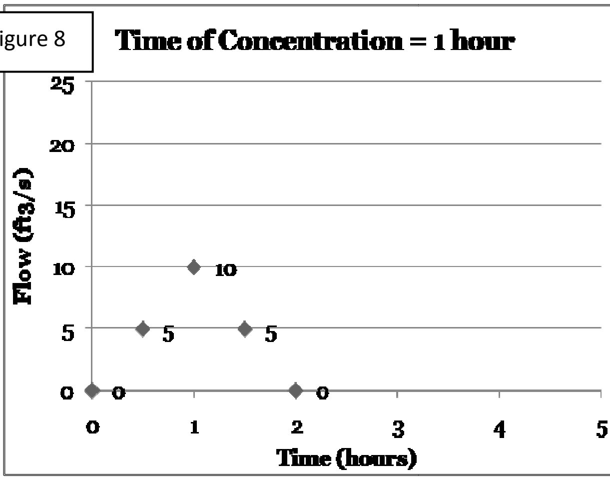
Development has an obvious impact on the volume of runoff that flows over a landscape, but there are other hydrologic impacts resulting from impervious surfaces. Not only is there an increase in volume of *stormwater runoff*, but there is also an increase in the rate of flow. *Flow* is the volume of water that is transported in a certain time period. The point when a drainage outlet such as a stream or river experiences its maximum flow rate is called *peak flow*. When a storm occurs and water runs over a natural landscape, it is typically slowed down by vegetation, and variations in slope and landscape shapes. This kind of natural landscape contributes characteristics to a site's time of concentration. *Time of concentration* is the amount time that it takes for water flowing over the landscape to travel from the furthest point in the watershed to a drainage outlet. For naturally vegetated landscapes that slow down the flow of runoff, this time of concentration can be very high, meaning it takes a long time for water from the furthest reaches of a watershed to get to a stream or river and contribute to the *peak flow*. When the natural landscape is developed and covered with smooth impervious surfaces like parking lots, roads, and storm drains, the speed that water flows over the landscape to a stream or drainage outlet can be extremely fast. This decreases the time of concentration drastically. (NRCS, 1986) The graphs and tables below (Figure 7, 8, and 9) depict how time of concentration impacts the peak flow rates for a watershed generating 36,000 ft^3 of runoff in a given storm.

Figure 7



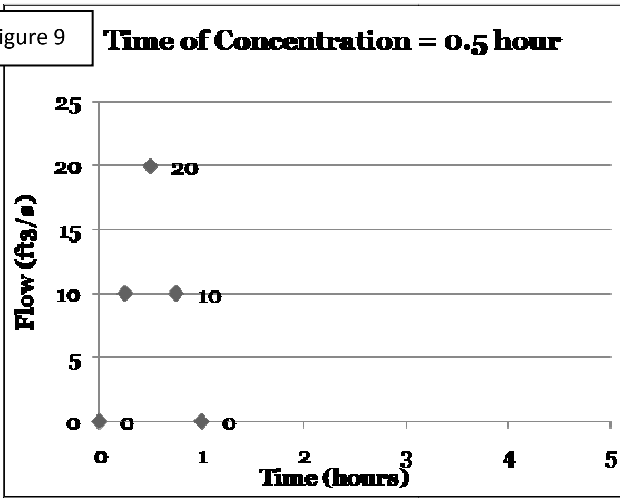
Time (Hours)	Flow (ft^3/s)	Length of Interval(hrs)	Total Flow/ Interval (ft^3)
0	0		
		1	4,500
1	2.5		
		1	13,500
2	5		
		1	13,500
3	2.5		
		1	4,500
4	0		
		Total Flow	36000

Figure 8



Time (Hours)	Flow (ft³/s)	Length of Interval(hrs)	Total Flow/ Interval (ft³)
0	0		
		0.5	4,500
0.5	5		
		0.5	13,500
1	10		
		0.5	13,500
1.5	5		
		0.5	4,500
2	0		
		Total Flow	36000

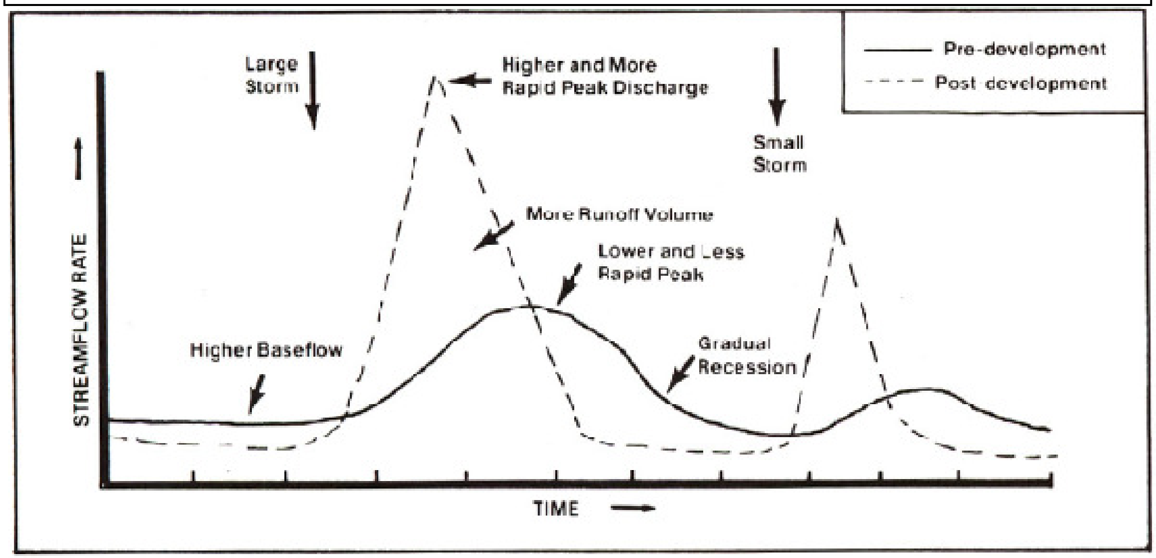
Figure 9



Time (Hours)	Flow (ft³/s)	Length of Interval(hrs)	Total Flow/ Interval (ft³)
0	0		
		0.25	4,500
0.25	10		
		0.25	13,500
0.5	20		
		0.25	13,500
0.75	10		
		0.25	4,500
1	0		
		Total Flow	36000

These graphs are a practical example of how given the same volume of runoff, variations in time of concentration can greatly impact peak flow. Since development alters the landscape to decrease time of concentration, a more appropriate visual aid can be used that compares flow rates in an undeveloped landscape versus a developed landscape.

Figure 10 - Undeveloped vs. Developed stream flow rates in large and small storms, Source: RI Stormwater Design and Installation Standards Manual (Adapted from MDE, 2000).



Impervious surfaces and development have not only increased the volume of runoff flowing over the landscape and into local water bodies, it also increases the rate at which that water flows into surface waters. As you will see in the following sections, this increase in peak flow contributes to the negative impacts of stormwater runoff.

Flooding Potential:

Floods are a major concern for many communities around the world. The loss of life during a major flood event can devastate a community. Damage to homes, buildings and property can contribute millions if not billions of dollars worth of monetary loss to a community. Despite the potential devastation and loss to a community, many housing developments and factories are built on naturally flood prone properties. In addition, changes in land use in the form of increased development can contribute to flooding hazards as well as expand flood prone zones. As developed areas increase runoff volumes and peak flow rates, more water ends up draining to streams and rivers at a faster rate. *Floodplains* that have evolved over time to handle flooding in a natural hydrologic setting are now overwhelmed with the high volumes and rates of runoff. Storms generating larger rainfall amounts that were once infiltrated into soils now run over the landscape and overtop stream banks. Many emergency flood maps have not revised high risk flood areas due to changes in land use, so more and more developments are being built in areas that historically are not prone to flooding, but are now hazardous. It is important for the public to understand the risks associated with increased stormwater runoff due to development in order to be prepared for flooding events that have not been historically common. (Dunne and Leopold)

Stream Erosion:

The high volume and velocity of runoff entering a stream or river can drastically alter the geometry of the stream that has evolved over time. Streams and rivers have developed their shapes and sizes based on many factors including depositional loads, geology, and flow of water. Streams and rivers are not designed to handle all flows and tend to discharge onto an adjacent floodplain when the stream or river overflows. In addition, stream channels are self – adjusting, which means that any changes made by man, climate, or vegetation will cause the stream to alter its shape and conditions. (Dunne and Leopold) Developed land is one example of a man made change to the landscape that alters the geometry of a stream. Water moving at a high velocity has more energy. When it enters a stream bank, it can scour the sides of the stream, eroding away the channel that has evolved over time. As banks are eroded, plant roots that once protected stream banks are exposed and trees can topple over. Without the protection of trees and vegetated buffers, the setting is even more prone to erosion. The sediments that were scoured away at the point where runoff enters the stream, is carried downstream and deposited. This alters the geometry of the channel downstream as well. If the downstream channel is filled with sediment, the stream is unable to accommodate for excess water in flooding conditions and the downstream area is much more prone to flood. Stream bank erosion is a problem facing many streams and rivers that not only contributes to flooding, but can also severely impact the ecological habitat of the system.

Groundwater Recharge:

One component of hydrology that often goes unnoticed is the abundant water found underground in the voids or spaces within rocks or soil (*groundwater)*. The saturated zone under the surface of the Earth contains 21 percent of the entire world's freshwater and 97 percent of all the world's unfrozen fresh water on Earth. If this underground source of water has high volumes and supplies water to wells, it is called an *aquifer* (Dunne & Leopold). Groundwater is an extremely important resource for people all over the country. Approximately 30 percent of Rhode Islanders rely on groundwater for their drinking supply through private or public wells (RI Stormwater Manual). In addition, groundwater provides

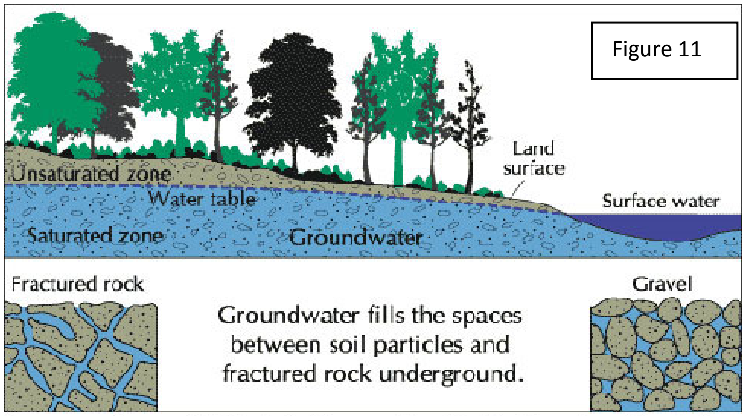


Figure 11

Image compliments of US Geological Survey, adapted by The Groundwater Foundation.

many of our streams, rivers and lakes with their water supply and helps to maintain an environmentally sufficient flow that allows organisms and habitats to survive during dryer times. When groundwater seeps into stream channels it is called base flow. Stormwater runoff can have serious impacts on the quality and quantity of groundwater. As precipitation falls and hits a developed landscape, the amount of water infiltrating into the ground is dramatically reduced. This prevents groundwater aquifers from restoring the water it loses to wells, streams or evaporation. The restoration of groundwater due to precipitation is called recharge. So as more and more water runs off our land due to the addition of impervious surfaces and people continuing to extract water through wells, our groundwater resources become depleted. This can eventually lead to reduced volumes of water that can be used as drinking water, causing people to have to find other water sources or dig deeper and deeper wells. Urbanization has been found to decrease stream base flow as a result insufficient groundwater recharge (Ferguson and Suckling, 1990). If a river or stream can not maintain an environmental base flow, many organisms that rely on that flow will not survive. In addition, as the volume of groundwater decreases, the risk for contamination increases. With a wealth of water underground, small amounts of pollutants that infiltrate will be extremely diluted, whereas with a smaller volume of groundwater, even low levels of pollutants can contaminate a groundwater aquifer. The impacts of development have severe consequences on the physical characteristics of natural hydrology, but they also contribute to a great deal of habitat loss and polluted waters that humans and other organisms rely on and enjoy.

Pollution Sources:

Human actions on a landscape can produce multiple sources of pollution. As water runs over the landscape, it can pick up these pollutants and carry them to the closest surface water body. These pollutants are considered "*non-point" pollutants* since they are the result of various activities happening all over the landscape and can be extremely harmful to plants, animals and impact the enjoyment of and reliance on local water bodies for people. One serious impact to water quality comes in the form of sediment. Sediment can come from stream bank erosion as described earlier, construction sites, and winter roadway sanding. The presence of excess sediment in a stream, river, lake or bay can smother organisms, reduce light penetration necessary for submerged plants, and can elevate channels to cause flooding and navigation problems. Another source of pollution carried by stormwater runoff is nutrients. Typically nutrients are needed in aquatic habitats as food sources for various organisms. Due to human impact the levels of nutrients entering water bodies is extremely high and in long term or extreme cases can lead to algal blooms that eventually block sunlight and deplete oxygen in waters. This can create dead zones similar to where the Mississippi River drains into the Gulf of Mexico. Fertilizers (used in agriculture or on residential lawns), animal waste (agricultural or pet waste), and sewage are major contributors to the excess levels of nutrients. Often animal waste and sewage that enters water bodies through leaking septic tanks and wastewater treatment discharges, carry pathogens that are harmful to public health. Pathogens are the most common pollutant that causes beach and shellfish bed closures. In addition to these sources of contamination, there are toxic pollutants that contribute to poor water quality. Stormwater can pick up many harmful chemicals before entering a stream, river, lake or bay. Oils and greases, heavy metals, pesticides and other toxic chemicals that harm wildlife and bioaccumulate in food chains are washed away from cars, machinery, industrial activities, paints, landfills and improperly disposed household chemicals. Other sources of pollution are trash and debris found in urbanized areas (RI Stormwater Standards Manual). These pollutants degrade the quality of water we find in streams, lakes, bays and aquifers causing loss of aquatic life, drinking water contamination risks, and beach and fishing area closures.

Rain Gardens

Rain gardens are shallow depressions in the landscape that intercept, treat, and infiltrate stormwater, are typically planted with native plants and covered with a mulch layer. Often times they look just like a regular garden you might have in your backyard, but are specifically designed to handle runoff from a nearby impervious surface that allow infiltration, recharge aquifers, and reduce peak flows (Dietz, 2005). Most rain gardens are designed to capture the first one inch of rainfall flowing off a surface which helps to treat the majority of pollutants that are washed off in the beginning of a storm event and accounts for approximately 90% of yearly Rhode Island storms (Clayton & Schueler, 1996).

Rain gardens perform many processes that help to reduce the negative hydrologic and biologic effects caused by development. The first and most important characteristic of a rain garden is the placement and ability to capture runoff. The rain garden is sited down gradient from a driveway or roof downspout and can capture the runoff with plants and soils. The rain garden allows for infiltration of runoff into the planting soil and native soils underneath the garden which can recharge groundwater resources and reduce runoff volumes. Soil can remove pollutants through a number of processes. The soil acts as a filter to remove many particles and suspended solids as runoff infiltrates through the mulch and soil. Through the process of adsorption, the ionic attraction of holding a substance to a solid surface, organic soils can adsorb metals and nitrates. In addition, the microbes found in soils can help to degrade toxic chemical compounds. Bacteria can be found in well oxygenated soils that can convert ammonia compounds into a soluble form that plants can use. In parts of the soil that do not have much oxygen (in an area that pools with water regularly) different microorganisms can transfer nitrates to gaseous forms that are released into the atmosphere. Plants in addition to the treatment from the soil, take out pollutants found in stormwater runoff through the process of assimilation. Plants use the nutrients for energy to grow. (Prince George's County) The processes that occur in an easy to install rain garden, are extremely beneficial to maintaining good water quality and hydrologic functions.

Rain gardens are an ideal management practice for stormwater related issues that fall into a group of practices called low impact development. As people begin to fully understand the problems associated with traditional development and urbanization, a new set of principles need to be developed to allow for functional landscapes that promote natural hydrologic processes to take place. Low impact development is a technique used to minimize the impacts of development on the landscape. For example, town planners are promoting the use of new methods of development such as reducing road, parking and driveway widths, and clustering homes in order to minimize the land disturbed in a development. In addition, new technologies help to reduce the amount of stormwater runoff. Green roofs are an excellent way to capture precipitation right at the point it hits a building. Green roofs have a special roof that has a thin layer of soil and is planted with small shrubs that can capture and absorb precipitation. Another practice that is being used more often is the use of permeable pavements for driveways and parking lots. These are specially designed materials that can handle the weight of cars without compacting the soil below and allows water to infiltrate the surface. Many of the low impact development practices are highly engineered and put in place at the time of development if not before. Rain gardens are a practice that are easy to build and can be installed even after development on any kind of site and provide functions that can restore the natural hydrologic functions of our landscape.

Poor land use decisions have left us in a precarious situation where 45 percent of our water bodies are polluted due to non-point pollution (National Ass. Land Trust).   In addition the natural hydrologic processes we rely on to maintain stable streams and groundwater levels have been altered by the same poor land use choices. Fortunately, there is a way to counteract many of the problems caused by development and urbanization.

Definitions:

Aquifer: A body of saturated rock through which water can move.

Watershed: The divide separating one drainage basin from another.

Hydrology: The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground.

Impervious Surface: A surface that does not allow water to infiltrate through.

Hydrologic Soil Group: A set of four soil groups that are defined by their ability to infiltrate water.

Curve Number: A number assigned to a land cover that describes how much water will runoff the surface.

Stormwater Runoff: Rainfall that does not infiltrate into the earth and flows over the land.

Flow: The volume of water that is transported in a certain time period

Peak Flow: Maximum stream flow rate during a storm.

Time of Concentration: The amount time that it takes for water flowing over the landscape to travel from the furthest point in the watershed to a drainage outlet.

Flood Plain: The area adjacent to a river that floods periodically

Groundwater: Water found underground in the voids or spaces within rocks or soil.

Non-point Pollution: Pollution sources that can not be contributed to a specific point, but rather encompass many different sources of pollution spread out over the landscape.

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