Module 2: Why stormwater management matters

Module 2 Objectives

After completing this module, you will be able to:

- Summarize the hydrologic cycle and explain the changes to it from human influences
- List and identify stormwater impacts of precipitation changes in Virginia and consequences to current stormwater management approaches
- Explain the value and application of rainwater harvesting as a method of stormwater management
- Examine the relationship between landuse, stormwater runoff, and water quality
- Describe the various impacts and risks from human-influenced stormwater runoff to natural streams and downstream areas.
- Discuss how managing stormwater benefits public and private property and water quality

Module 2 Content

2a. Introduction

2b. Stormwater Runoff

2c. The Hydrologic Cycle

2d. Distribution of the Earth's Water – the Water Budget

2e. The Urban Water Cycle

2f. Understanding Stream Evolution and Urban Stream Syndrome

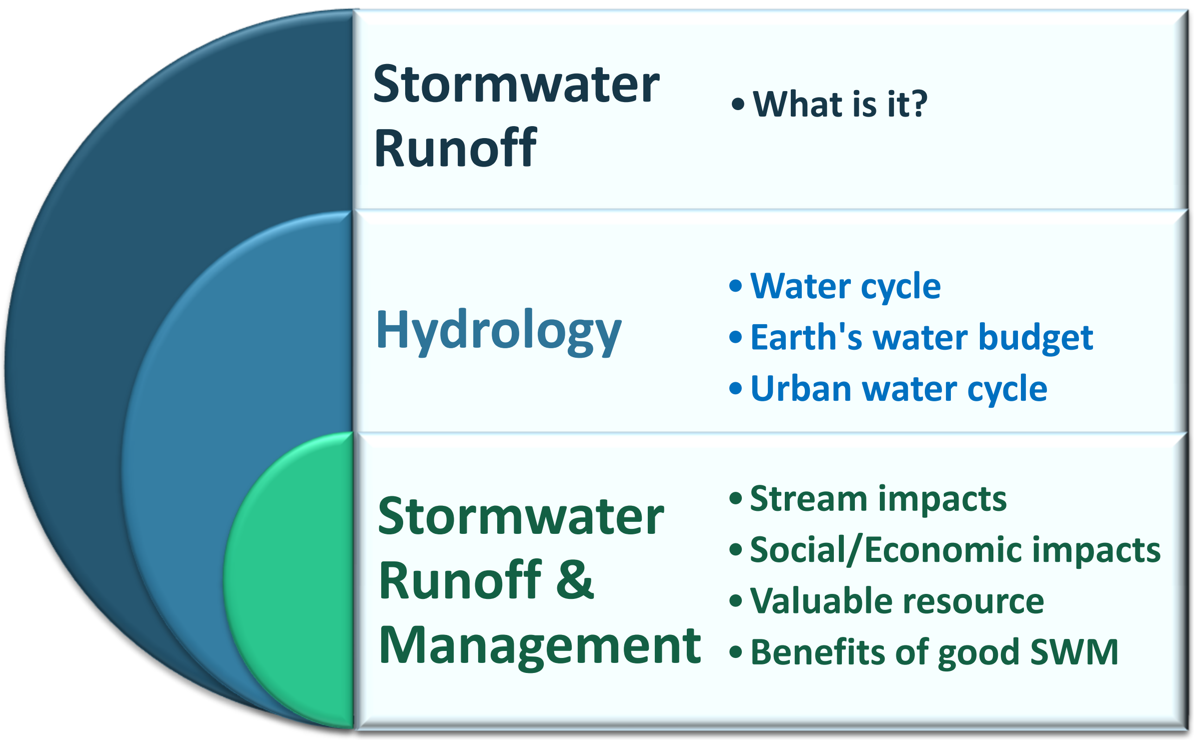
2g. Social and Economic Impacts of Stormwater on Virginia Communities

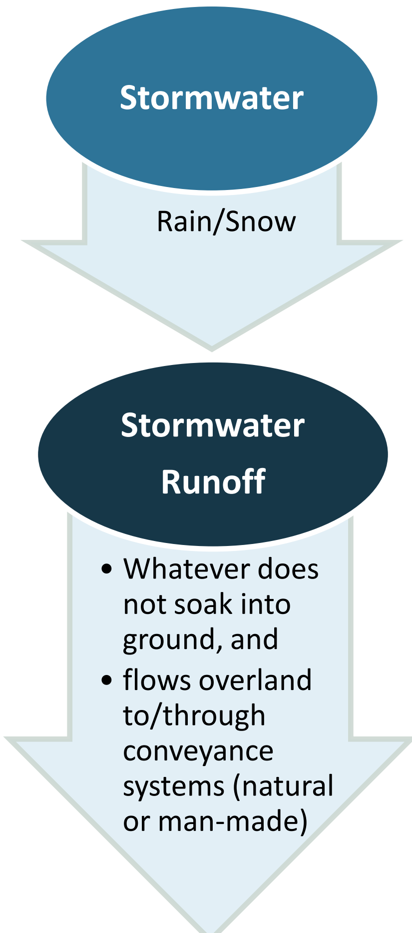
2h. Managing Stormwater and Rainwater Harvesting

2i. The Economic Benefits of Effective Stormwater Management

2a. Introduction

The following module provides the scientific foundation for understanding the consequences of ineffective stormwater on Virginia's natural waterways. It helps to provide some of the rationale for the legal and regulatory changes in stormwater management. The module is divided into several sections. The first few sections define stormwater and stormwater runoff; relate stormwater to the global movement of water (the water or hydrologic cycle) and to the allocation of water on earth. The next sections explain the hydrologic changes that occur due to human influences, and the various impacts of ineffectively managed stormwater. The final sections introduce the benefits of Virginia's focus on effective stormwater management and promote stormwater as a valuable resource.





Average annual rainfall across Virginia = 42 to 48 inches per year, isolated areas average less than 38 inches or more than 66 inches:

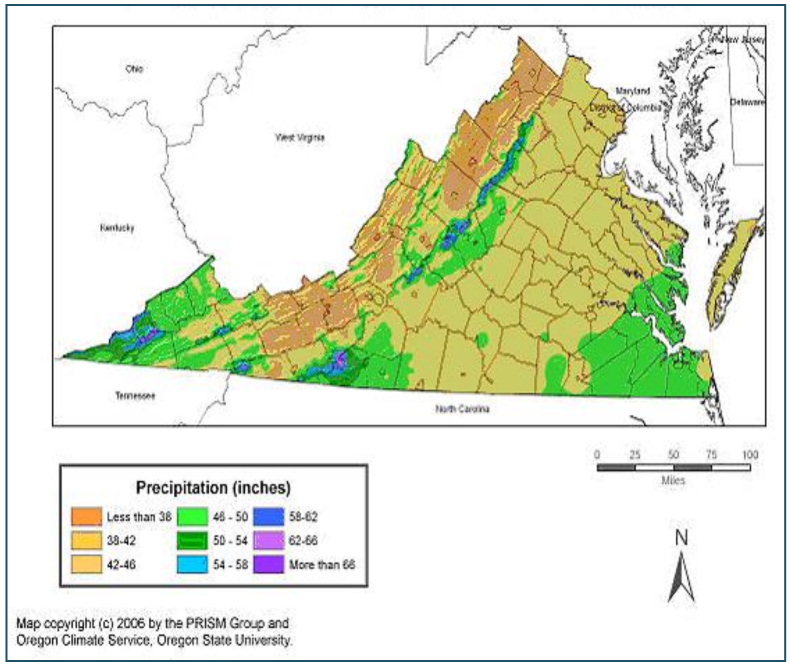


Figure 1. Average Virginia Annual Precipitation, 1970-2000.
(Source: Oregon Climate Service)

2c. The Hydrologic Cycle

The earth's water has been continuously moving and changing phases (between liquid, vapor, and ice) over millions of years. This process (earth's natural water recycling) is known as the hydrologic (or water) cycle (**Figure 2**).

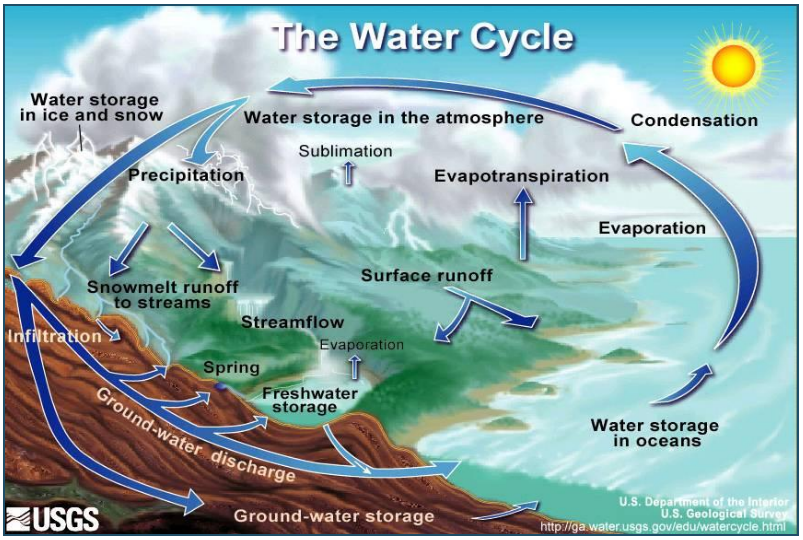


Figure 2. The Hydrologic Cycle
(Source: USGS web site)

Hydrologic cycle represented here is an over simplification of a very complex process and does not reflect human influences.

- Water is constantly being exchanged between the earth and the atmosphere (powered by the sun's energy)
- Water in oceans, lakes, rivers, other surface water, soils evaporate into the atmosphere
- Plants and animals also transpire water
- Water vapor rises with air currents up into the atmosphere and reaches cooler atmospheric layers

Evapotranspiration ***equals*** *water evaporation* ***plus*** *water transpiration*

- Water condenses to form clouds, then water droplets which fall or precipitate to the earth's surface (rain, snow, sleet or hail)
- Water precipitating during local rain events mostly transported from elsewhere within clouds (as moisture) and seldom due to localized evaporation and transpiration
- Once precipitation reaches the ground, water:
  (1) evaporates;
  (2) is absorbed by the ground and/or taken up by plant roots; or
  (3) moves into (infiltrates) soil and through soil (percolates) to groundwater
  - Excess water then drains to streams, rivers, and other surface waters (***surface or stormwater runoff***).

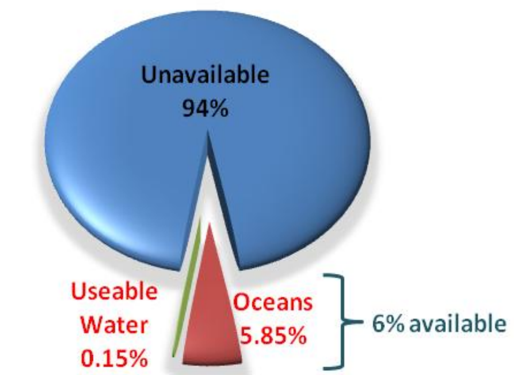
Key Points to Consider:

- Only a fraction of the earth's total water is available as fresh water
- This limited availability of fresh water is critical for human health and survival
- In Virginia, projected population increases and changes in precipitation patterns could make water availability much more concerning in the future

2d. Distribution of the Earth's Water – the Water Budget

Although water covers about three quarters of the earth's surface, most of it is *not* available for human use (**Figure 3** and **Figure 4**).

Figure 3. Overall Global Water Budget (top pie chart only)
(Source: Adapted from Day and Crafton, 1978)



94% of all water chemically bound in rocks and minerals (6% available) (**Figure 3**)

97% of the available water is in the oceans (**Figure 4**), but due to its salinity, is not a significant source for human consumption

for human basic needs: the remaining 2.5% of available water (less than 0.15% of all the earth's water)

and of this useable water, 69.5% is found stored in polar glacial ice masses and permafrost , and 30% in aquifers

the remaining 0.4 % is circulating in inland waterways, in the atmosphere or soil, or within organisms

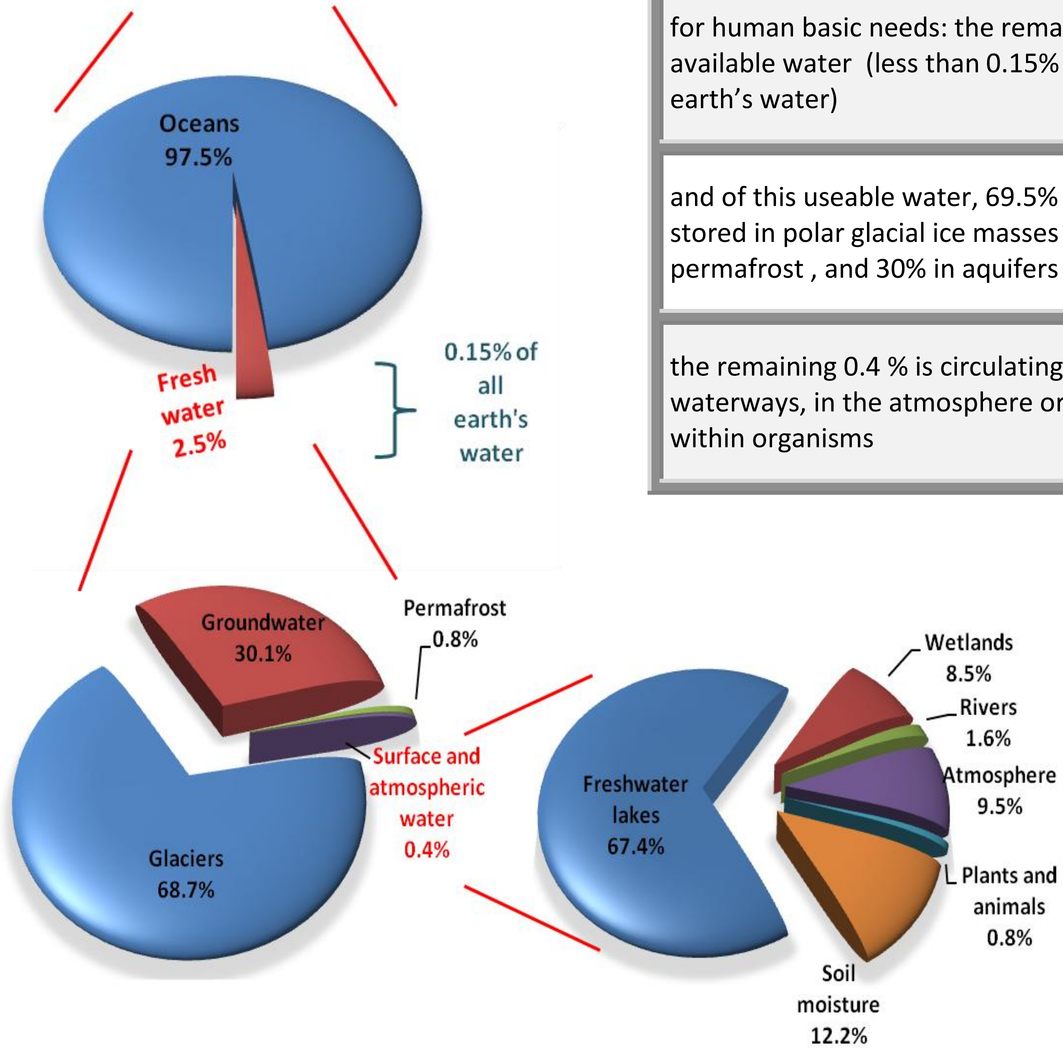


Figure 4. Available Water Budget (Bottom 3 pie charts)
(Source: Adapted from Day and Crafton, 1978 and GreenFact.Org, 2011)

2e. The Urban Water Cycle

It is important to understand that all of the world's available water has been, for many years, subject to human influences (**Figure 5**).

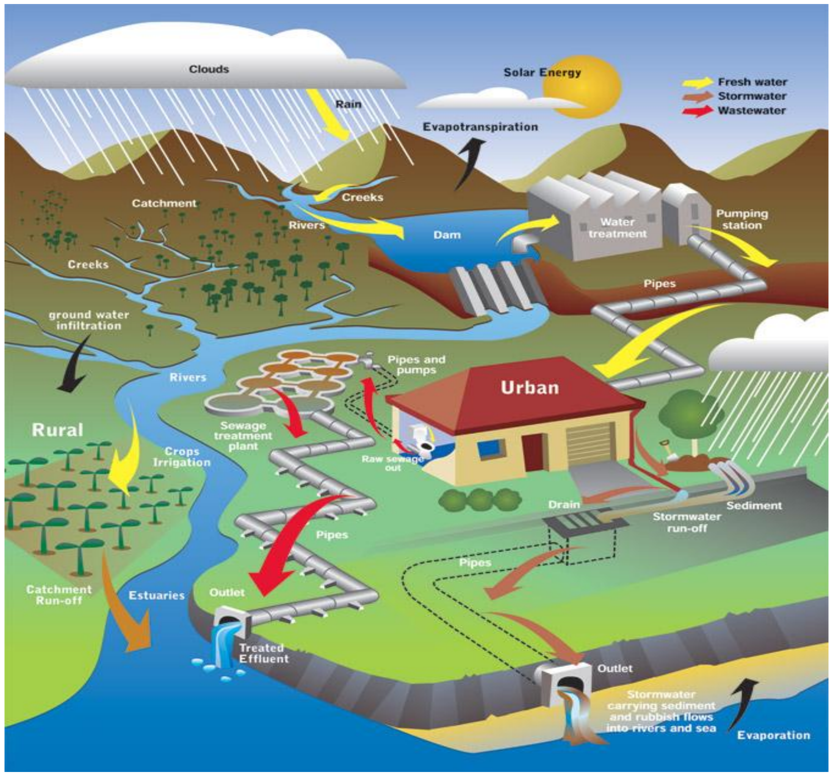
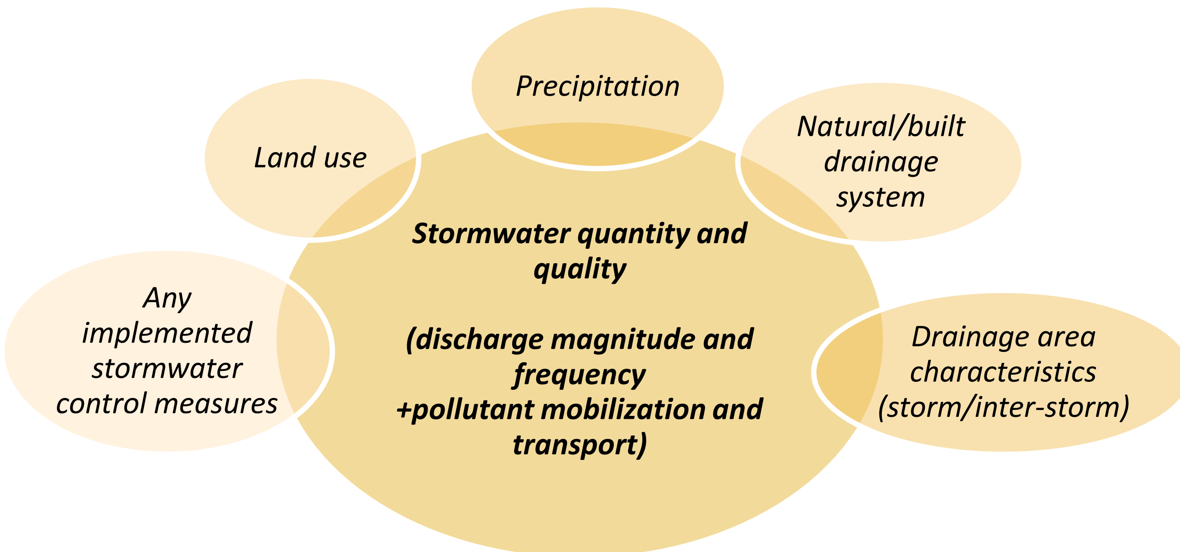


Figure 5. The Urban Water Cycle
(Source: Adapted from the SEQ Healthy Waterways partnership, http://www.healthywaterways.org)

- Smokestacks spew pollutants into the air which bind or attach to cloud water particles and subsequently drop to the earth as rain
- Pipes from industrial and sewage treatment plants and stormwater conveyance systems carry pollution into our streams and rivers
- Water that infiltrates into the soil can carry pollutants and percolate into groundwater tables that provide base flow for our streams, or even into deep aquifers that are often tapped for domestic water supply
- Natural water balance and flow is altered with increases in surface runoff, therefore less soil infiltration and less groundwater recharge

Since the water we see and use each day is such a small part of the total, we should consider it *all* to be a valuable resource and not view any of it, including stormwater, as disposable.

Focusing on stormwater runoff: the factors that influence stormwater discharge quantity and quality:



The following characteristics influence stormwater runoff quality and quantity:

- Soil characteristics, topography, vegetation, capacity of water storage areas
- Channel lengths (long meandering streams vs. short straight channels)
- Drainage density (total length of well defined channels that drain the watershed - developed areas tend to be more dense)
- Channel characteristics (roughness, slope)
- Stream flow characteristics
- Hydraulic structures, best management practices (BMPs)
- Weather patterns
    - Duration of dry periods
    - Rainfall duration, intensity, frequency

Any given storm is characterized by the storm's total rainfall depth, duration, and intensity

Changes in the hydrology cycle:

Land development leads to changes in the hydrology (the natural cycle of water) of a site or of a watershed (**Figure 6**).

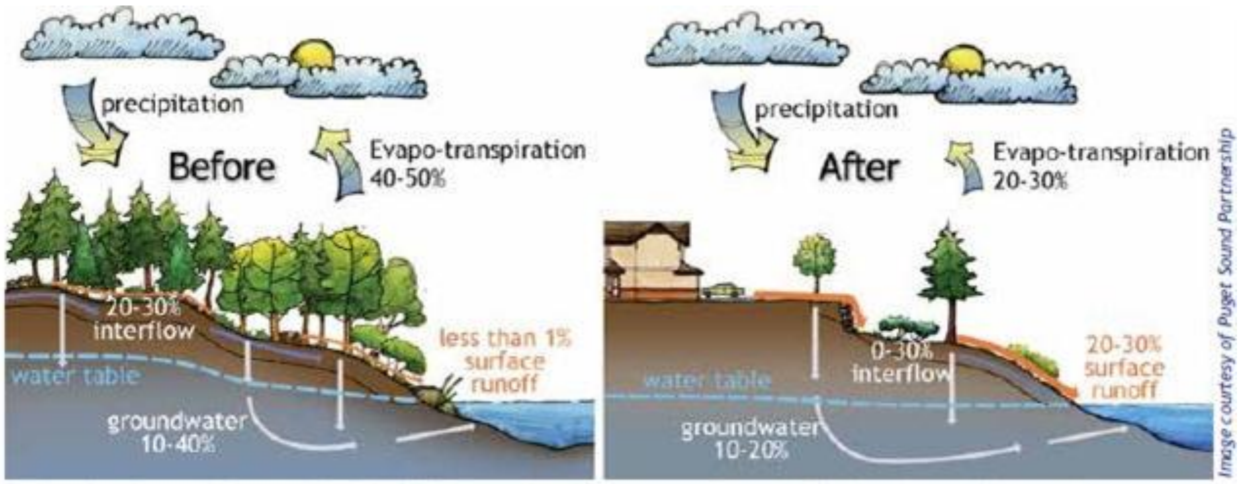


Figure 6. Changes in hydrology and land cover before (left) and after (right) development.
(Source: Puget Sound Partnership, 2013)

- Clearing removes the vegetation that intercepts, slows and returns rainfall to the air through evaporation and transpiration.
- A portion of the rainfall that once seeped into the ground now runs over the surface.
- Grading flattens hilly terrain and fills in natural depressions that would normally slow and provide temporary storage for rainfall.
- The topsoil (usually required to be replaced) and sponge-like layers of humus are scraped and removed, and the remaining subsoil is compacted.
- The addition of buildings, roadways, parking lots and other surfaces that are impervious to rainfall further reduces infiltration and increases runoff.

How does the change in impervious cover affect runoff?

Although the total amount of rainfall varies somewhat in different regions of the state, the basic changes to the hydrologic cycle holds true (**Figure 7** below).

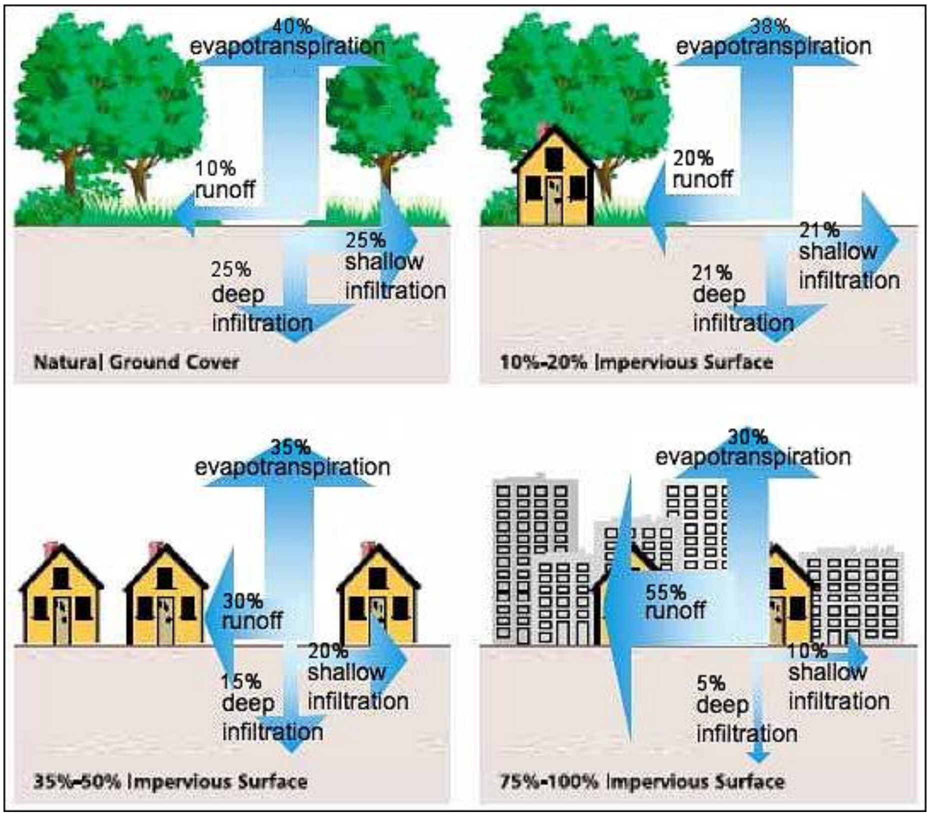


Figure 7. Relationship Between Impervious Cover and Surface Runoff.
(Source: Federal Interagency SWRG, 1998)

Impervious cover – ground surface that does not allow water absorption or infiltration but rather results in surface runoff

Impervious surfaces (roads, buildings, parking lots):

- Prevent rainfall from infiltrating into the soil and significantly increase surface runoff.
- Replace natural vegetation that alter natural drainage patterns
  - Evapotranspiration and infiltration decrease
  - Runoff increases in volume and flow rate

Altering one component of the water cycle affects all other elements of the cycle

Figure 8 is an example of the increased imperviousness (more roads, buildings, parking lots) that can take place as an area is developed over time:

Figure 8. Typical Changes in Land Surface (1958 – 1999) for a Commercial Area
(Source: ARC, 2001)

Hydrologic changes are further impacted with the widespread use of built drainage systems such as gutters, storm sewers (**Figure 9** and **Figure 10** below) and smooth-lined channels that are designed to quickly carry runoff to rivers and streams. This further reduces water infiltration into the soil and groundwater (and the amount of water that can recharge aquifers and feed streamflow during periods of dry weather).

Figure 9. Impervious Cover Increases Stormwater Runoff and Pollutants. (Source: ARC, 2001)

Figure 10. Constructed Storm Drainage System Components. (Source: Chesapeake Bay Stormwater Training Partnership)

How does the change in stormwater runoff influence stream hydrology?

Where land development has occurred, the increase in volume and velocity of stormwater runoff to receiving waters results in significant changes to stream flow characteristics:

- Increased peak discharges for a developed watershed can be two to five times higher than those for an undisturbed watershed.
- As runoff velocities increase, it takes less time for water to run off the land and reach a stream or other water body (time of concentration).
- Streams in developed areas can be more volatile because of their response to these altered runoff characteristics.

Time of concentration is the time needed for water to flow from the most remote point in a watershed to the watershed outlet **or** time required for 100% contribution from all points in a watershed during any uniform storm having sufficient duration

- This characterization translates into the sharp peak and increased size of the post-development hydrograph as seen in **Figure 11** below, which depicts typical pre-development and post-development streamflow hydrographs for a developed watershed.

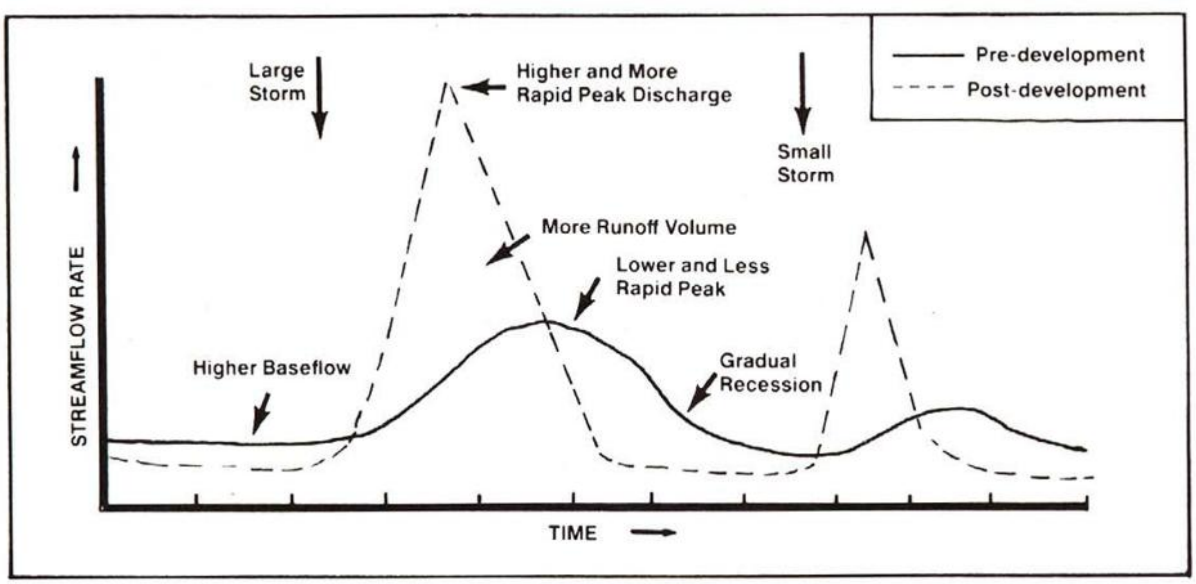


Figure 11. Pre- and Post-Development Stormwater Runoff Hydrographs

Stream flow alterations across the U.S:

A comprehensive nationwide study by the United States Geological Survey found that water flowing in streams and rivers has been significantly altered in nearly ***90 percent*** of waters that were assessed (**Figure 12** below). Flow alterations are considered to be the primary contributor to degraded river ecosystems and loss of native species. The USGS considers this assessment to provide the most geographically extensive analysis to date of stream flow alteration.

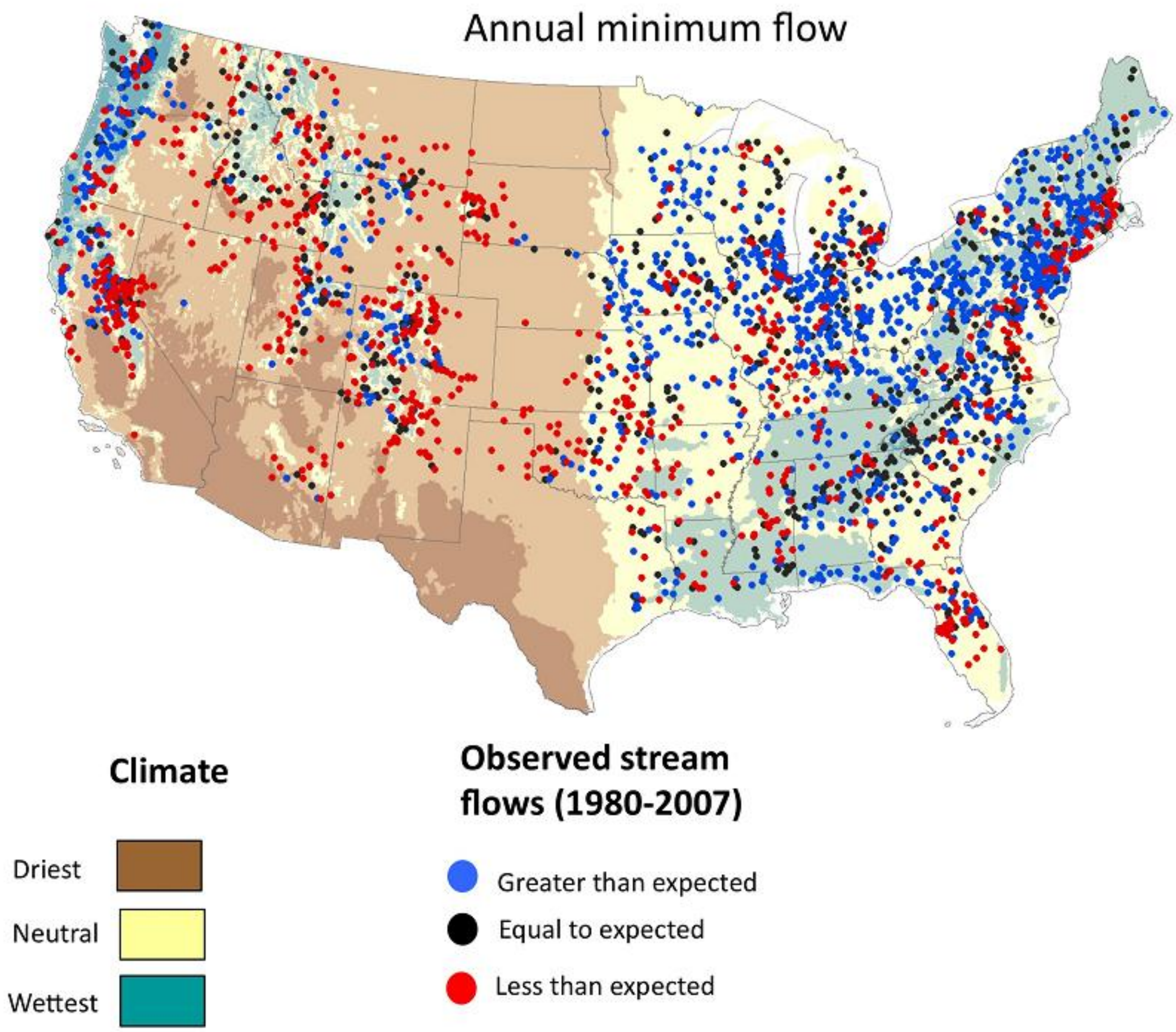


Figure 12. USGS Study Sites and Severity of Streamflow Alteration
(Source: Carlisle et al., 2010; http://water.usgs.gov/nawqa/home_maps/stream_flow.html)

What climate changes are we observing?

- Temperatures are increasing (air, ocean, land - melting glaciers and ice caps, rising sea levels)
- Global precipitation regimes are shifting systematically toward an increase in more intense rainfall events. There is a clear increase in heavy rainfall in the U.S. over the past few decades.
- Virginia has seen a ***25 percent increase*** in the frequency of extreme precipitation events since 1948. This is the greatest such increase among all states in the South Atlantic region (Maryland to Florida).
- The ***intensity and duration of drought periods*** is also increasing in Virginia (e.g., Lake Chesdin in the summer of 2007 and 2010). The consequences of this include soil moisture depletion, decrease of annual groundwater recharge, and increase of runoff from hardened dry soil surfaces.

An increase in the number of downpours does not necessarily mean more water will be available

What are the simple facts?

- The greater water-carrying capacity of a warmer atmosphere (even in a localized region) means that more water would accumulate there between rainfall events. When it does rain, there is a greater likelihood of a heavy downpour.
- The consequence of more frequent and intense storms may include flooding, erosion, pollution of waterways with excess runoff, wind damage, crop damage, and other environmental and economic damage. **Table 2-1** summarizes the potential effects of climate change on precipitation and stormwater runoff.

Warmer air can hold more water

Deciphering the complex components of our changing atmosphere is no simple task; natural variability in weather patterns, geographical disparities, and climate model limitations are some of the many challenges.

What are the long term implications?

- More surface runoff means less infiltration of water into the soil. This translates during the year into decreased stream base flow, since less water is stored in the shallow groundwater zone that feeds the baseflow (**Figure 13**). Less infiltration also means less groundwater recharge.

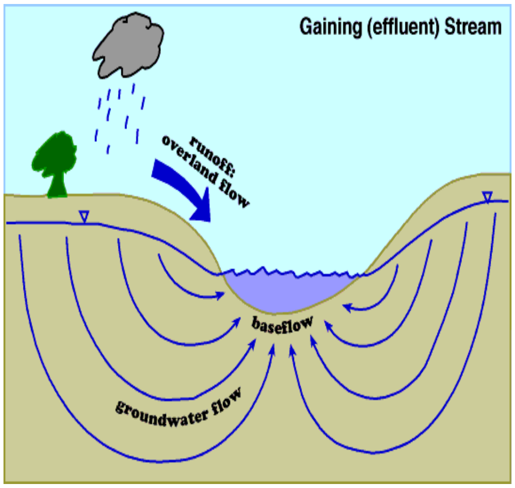


Figure 13. Gaining (effluent) stream

A gaining stream is a perennial stream that discharges water from the water table. Streams have two sources of water: ***stormwater*** *from overland flow after rain events, and* ***baseflow****, supplied by groundwater.*

(Source: New York Columbia University, Earth and Environmental Sciences; http://www.columbia.edu/~vjd1/streams_basic.htm)

- The combination of extreme events and droughts means that water level fluctuations become more common as storage areas (ponds, wetlands, floodplains) rapidly transition from dry, exposed conditions to flooded or high-water conditions that typically follow large storm events.

- More flooding is possible with less water infiltrating into the ground and more runoff.

- More frequent bankfull and flooding events are impacts resulting from increased run off volumes and increased peak flows.

  - ***Overbank*** or ***out-of-bank floods*** (flows that exceed the capacity of the stream channel and spill over onto adjacent floodplains) can damage downstream drainage areas.

  - The increase in stormwater volume is the direct result of more extensive impervious surface areas, combined with substantial tracts of natural landscape being converted to lawns on highly compacted soil.

  - Increased runoff volumes and peak flows increase the frequency and duration of smaller bankfull and near bankfull events (**Figure 14** and **Figure 15**), which are the primary channel forming events.

Figure 14. More Frequent Bankfull and Near Bankfull Flows
(Source: ARC, 2001)

Figure 15. Out-of-Bank Flooding Endangers Human Life and Property
(Source: ARC, 2001)

In many watersheds throughout the state, flooding problems have increased over time due to the changes in land use and ineffective stormwater management.

- During the 20th century, floods have caused more property damage and loss of life in the U.S. than any other type of natural disaster.

Coastal flooding will likely be more extensive due to the combination of rising sea level (related to climate change) and increases in tropical storms.

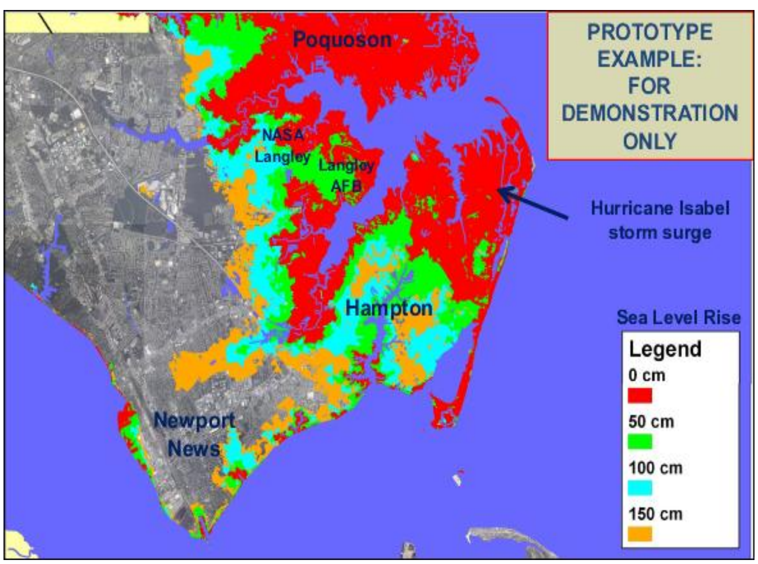


Figure 16. Hurricane Flood Prediction Model with Reference to Potential Level Rise
(Source: Virginia Institute of Marine Science and Noblis, Inc.)

Figure 16 shows the predicted extent of flooding in the Hampton-Poquoson area over the next 100 years resulting from a storm of the intensity of Hurricane Isabel if sea level were to remain at its current elevation (red), rise by 20 inches (green), 40 inches (blue) or 60 inches (orange).

Table 2-1
Summary of Climate changes* Leading to Stormwater Impacts

Changing Feature	Primary Impact	Secondary Impact
Precipitation	↑ mixed winter precipitation ↑ ice +/or rain-on-snow events	↑ winter runoff, ↑ ice ↑ road salt usage
	↓ summer rain	Drier surface-water bodies for longer periods ↑ water-level fluctuations wetland and floodplain disconnection
	Longer, more severe droughts over larger areas	Soil moisture depletion ↑ accumulated surface pollution ↓ available water supply
	↑ extreme precipitation events	Flooding erosion rapid water-level changes
Warmer winters	↓ snow accumulation more and earlier winter runoff earlier snowmelt	↓ water supply saved in snowpack (especially in the west) ↑ winter road salt application drier streams, wetlands, and floodplains earlier in the year ↓ groundwater recharge
	Shorter lake ice coverage	earlier lake turnover in spring, later in fall ↑ algal growth ↑ evaporation during winter longer lake water stratification period
Warmer summers	↑ temperature of runoff	depletion of cold-water fishery
	↑ humidity	greater severity of storms and extreme events like tornadoes
	More suitable vector environment	↑ in number and type of nuisance and health-related vectors (like mosquitoes in stormwater ponds)
	↓ water available in wetlands, lakes, reservoirs and streams	volume loss due to evapotranspiration-transpiration increases ↓ groundwater recharge ↓ stream base flow
	Gradual warming of the oceans	↑ tropical storm frequency and severity sea level rise
	Lower water levels	some perennial streams become intermittent hydrologic disconnect with riparian zone

*Variations will occur in different parts of North America

Additional considerations:

- Existing Best Management Practice (BMP) designs (based on old standards) may prove to be undersized in the future.
- Many of the design standards currently in use are based on historical data. Revisions may be needed due to the changing patterns of storm events (increases in intensity and frequency of extreme events).

For example: Intensity-duration-frequency (I-D-F) curves, used for design storm data, will need updating given the changing magnitudes of various design storms.

- Given future uncertainty, new BMPs may need to be designed conservatively to allow for additional storage that will be necessary for regions where increasing precipitation trends are predicted.

Even revised design standards may not be sufficient.

- Implementation of a monitoring program to check existing BMP inflows against original design inflows may be prudent to aid in judging whether retrofit of existing facilities or additional stormwater infrastructure is needed.

At the state and local level:

- Risks to public safety should be prioritized:
  - People living in floodplain areas and within potential dam break inundation zones should be educated risks (current and future), and steps they can take to prepare for potential floods.
  - Governments should consider strengthening land-use and building codes in these areas.
  - New development in flood-prone areas should be discouraged.
  - Natural systems (natural hydrologic flow patterns, natural retention areas, riparian zones) that help buffer against floods should be protected.
- Taking advantage of the natural water storage capacity of the floodplain provides benefits in terms of providing solutions that can overall function more efficiently and at lower costs to communities, localities, and the public.

- Some localities have started to account for climate change in their floodplain management programs.

One barrier to doing this is that floodplain maps and other planning tools are largely based on *historical* climate conditions.

***With more accurate regional climate projections now available; it is prudent to update these maps and planning efforts*.**

Additional Resources:

http://www.epa.gov/climatechange/science/future.html#Precipitation

http://www.vims.edu/research/units/programs/icccr/_docs/coastal_sea_level.pdf

http://www.vims.edu/bayinfo/storm_central/index.php

http://water.usgs.gov/nawqa/home_maps/stream_flow.html

Knowledge Check

1. Rainfall in Virginia averages between _____ and _____ per year?

2. Which of the following represent human influences on the natural water cycle (circle all that apply):

   A. Groundwater withdrawal.

   B. Rainfall capture in cisterns for dry period usage.

   C. Diverting stormwater runoff from steep slopes.

   D. Evaporation of water from ocean surfaces to the atmosphere.

   E. None of the above.

3. The frequency of extreme precipitation events in Virginia since 1948 has increased by what percent?

2f. Understanding Stream Evolution and Urban Stream Syndrome

From land development and urban sprawl to Urban Stream Syndrome (putting the pieces together):

While the Chesapeake Bay watershed population increases by about 1 million per decade, impervious cover also continues to increase (increased more than 30% between 1990 and 2007) (Source: USEPA, 2010)

Urban Stream Syndrome is the consistently observed degraded ecological condition of streams draining urban areas.

Characterized by:

- Increased flash flooding
- Elevated nutrient and pollutant levels
- Altered stream morphology
- Sedimentation from eroded stream banks
- Loss of biological diversity

Figure 17. A natural (left) and urban stream (right) ecosystem
(Source: USGS, 2013)

Streams and rivers naturally evolve over time. Changes to natural waterways are accelerated and deviate from natural conditions due to land and water uses in our modern watersheds.

How does it happen and what are the consequences?

I. Changes to the land surface (topography, *impervious cover*, vegetation)

II. Stream channel and flood plain impacts

III. Habitat and Ecological Impacts

IV. Water quality impacts

V. Impacts on other receiving environments

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Land cover changes due to development and subsequent impacts on the hydrologic regime of a site or watershed are discussed next:

- *Loss or change of vegetation*
- *Soil compaction*
- *Reduced groundwater recharge and stream base flow*
- *Increased imperviousness of land surface*

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Loss or Change of Vegetation

As illustrated in **Figure 6** (above) and **Figure 18** (below), vegetation in natural areas such as Virginia woodlands and meadows contributes to the natural management of stormwater:

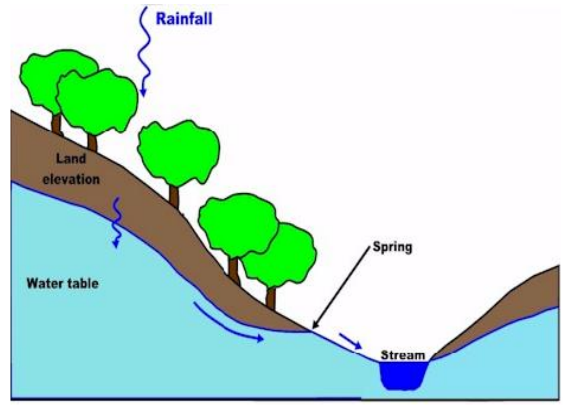


Figure 18. Relationship of infiltration to groundwater storage and stream base flow
(Source: PA DEP, 2006)

- **Rainfall and runoff is intercepted and slowed down *(reduces erosive capacity, decreases overland flow, opportunities for infiltration)***
  - Root systems of plants provide pathways for downward movement of water into soil
  - Water that moves down through soil (percolates) moves vertically or laterally
    - Vertical flow reaches the ground water table or aquifer
    - Lateral flow often emerges as springs or seeps (provides base flow for streams)
- **Very little rainfall leaves as runoff:**
  - Compared to developed sites, considerably more rain must fall before runoff will occur from wooded sites
  - Trees can effectively transpire most of the precipitation that falls in summer rain showers
  - During winter (as compared to summer):
    - More precipitation infiltrates and moves through the root zone, and the groundwater level rises (temperatures are lower and vegetation is dormant)
    - Less evapotranspiration
- **More than half of the annual amount of rainfall returns to the atmosphere through evapotranspiration:**
  - Surface vegetation, especially trees transpire water to the atmosphere (with seasonal variations and differences due to different types of vegetative cover)
  - Water is also stored in puddles, ponds and lakes on the earth's surface, where some of it will evaporate

Removing natural vegetation reduces evapotranspiration, reduces infiltration and increases the amount of stormwater runoff

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Loss or Change of Vegetation

What about residential lawnscapes?

The largest crop grown in the Chesapeake Bay watershed is ***turf grass*** – more than 3.8 million acres covering a staggering 9.5% of the watershed's total land area (**Figure 19** and **Figure 20**).

75% of all turf grass in the watershed is home lawns (3.8 million acres)

Turf produces more runoff than natural open space and forestland

Turf management involves application of large amounts of fertilizer and pesticides (delivered by urban runoff to the bulk pollutant load that must be treated to protect our waterways

Amount of turf cover in the watershed has tripled in the last 30 years

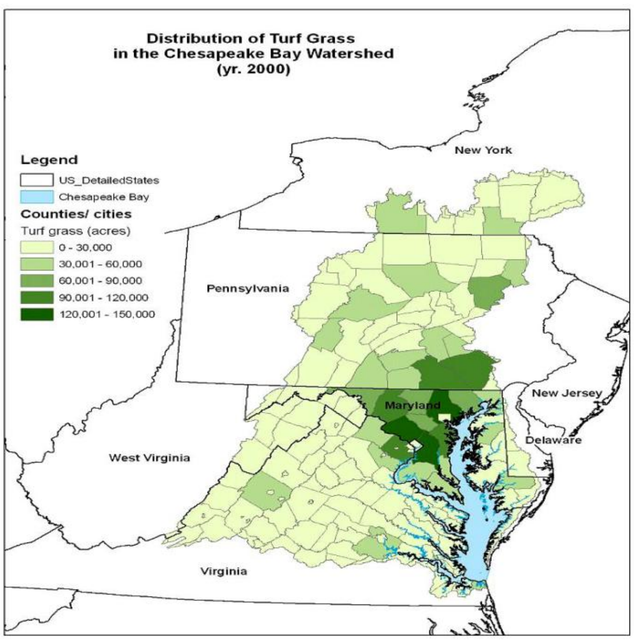


Figure 19. Distribution of Counties with High Turf Cover in the Chesapeake Bay Watershed.
(Source: Schueler, 2009a)

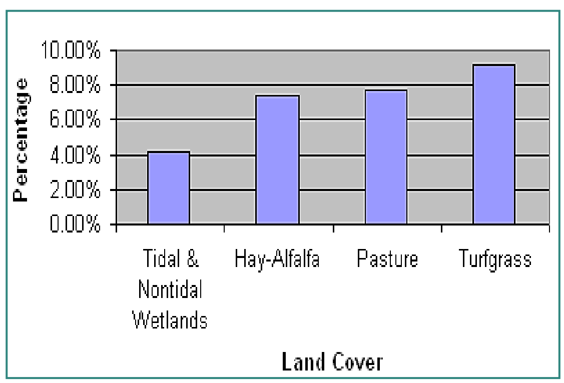


Figure 20. Comparative Land Coverages in the Chesapeake Bay Watershed (as a percent of total land area).
(Source: Schueler, 2009a)

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Loss or Change of Vegetation

Consider the following facts:

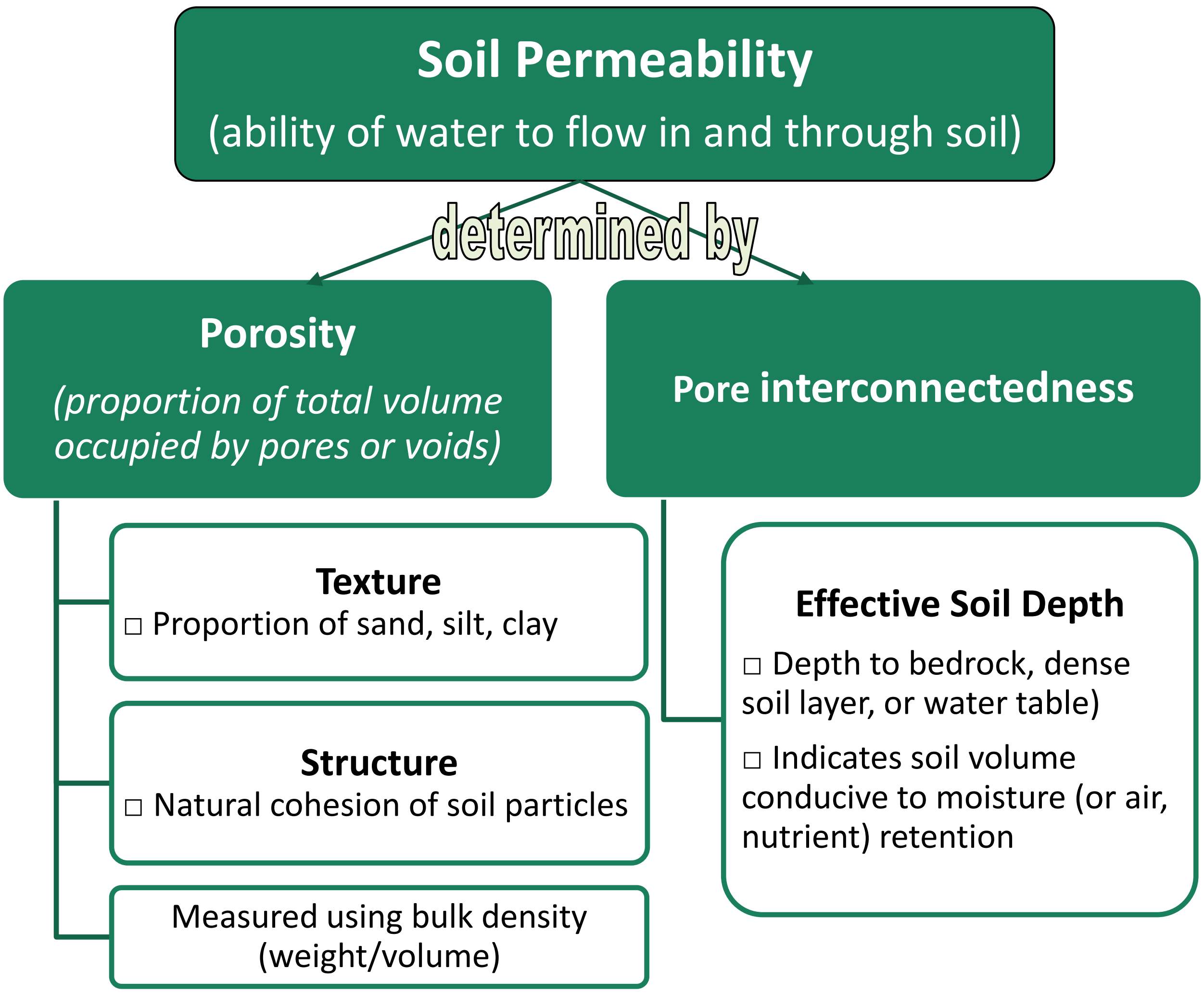
Summer lawn irrigation is calculated to use nearly 7,875 cubic feet per second (cfs) of water during the summer months. To put this amount of water consumption in perspective, it is roughly five times the *combined* summer flow of the Choptank, James, Monocacy, Pataspsco, Pamunkey, Patuxent and Rappahannock rivers in an average year

Our compacted lawns are roughly calculated to produce an extra storm runoff flow of 1,244 cfs *each day* to the Chesapeake Bay

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Soil Compaction

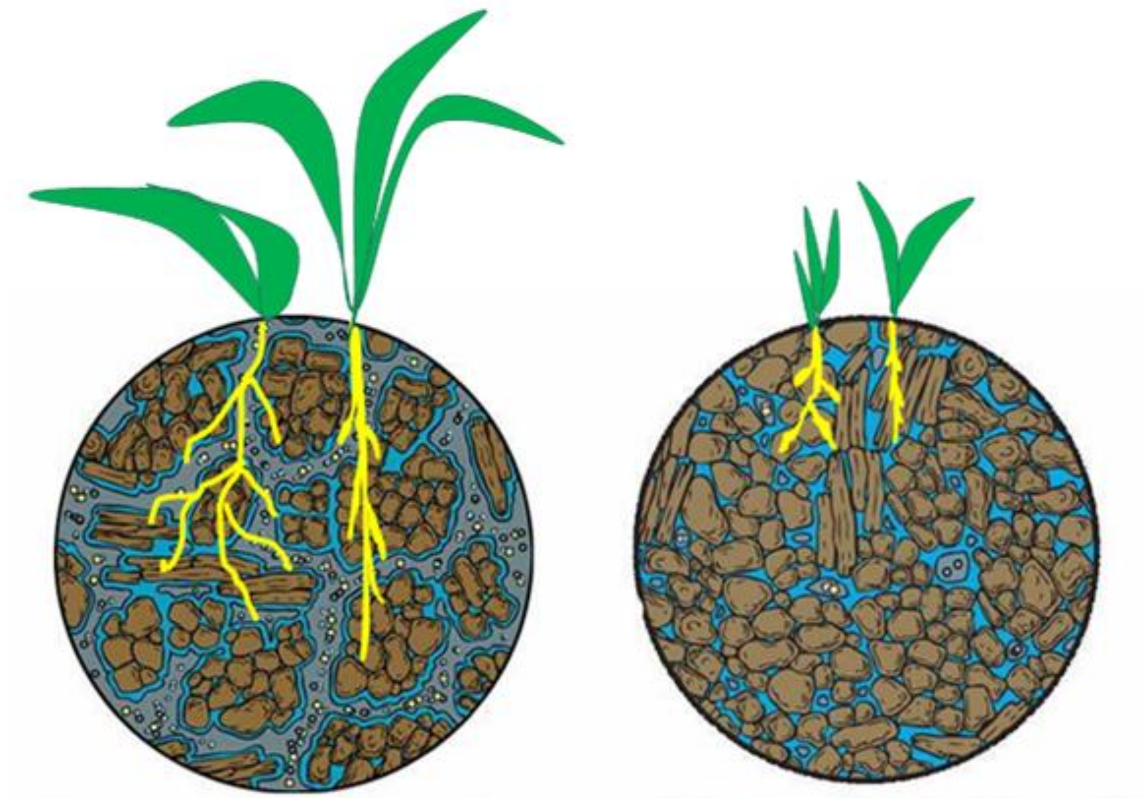
Soil basics:



I. CHANGES IN TOPOGRAPHY AND LAND COVER

Soil Compaction

Putting it together:



Lower bulk density
Lower Weight
More pore space

Higher bulk density
Higher Weight
Less pore space

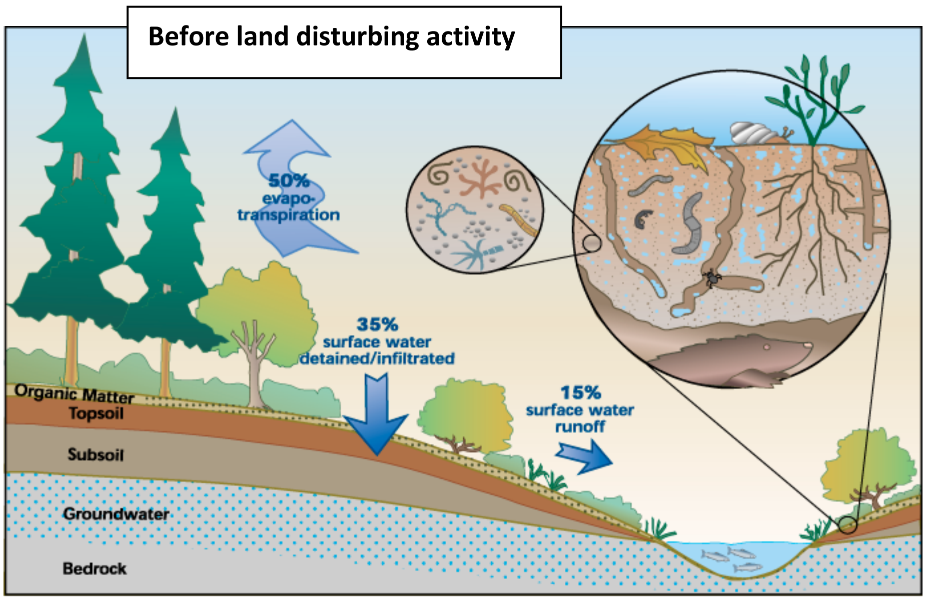
Figure 21. Adapted from international Society of Arboriculture, Bugwood.org

I. CHANGES IN TOPOGRAPHY AND LAND COVER

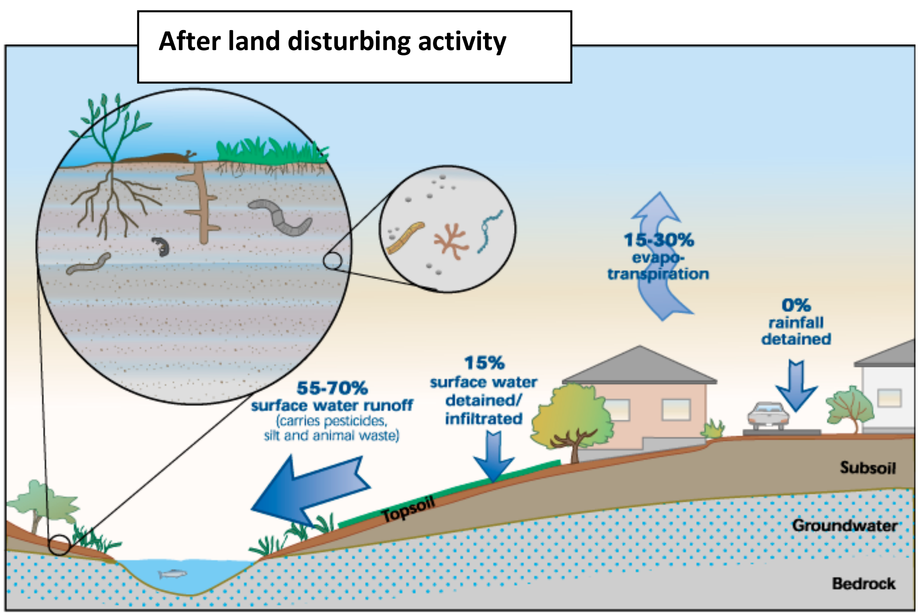
Soil Compaction

During land disturbing activities, soil is compacted and loses permeability; ***surface runoff increases***.

Figure 22. Soil Compaction in Urban Soils. (Source: http://chesapeakestormwater.net/wp-content/uploads/downloads/2012/01/SoilsforSalmonLIDrev9-16-04.pdf)



Thick topsoil, organic matter
Soil structure and texture intact
Good soil porosity (enhanced by biological channels – plant roots, soil organisms)
Soils permeable = very little surface runoff



Soil structure lost (compacted)
Thin topsoil (if any)
Organic matter often lost
Soil porosity and permeability decreases
More surface runoff

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Soil Compaction

You should know:

Construction equipment can cause such profound soil compaction (topsoil and subsoil) that the soil's bulk density can approach that of concrete and as a result, come functionally impervious (**Figure 23**, **Figure 24** and **Table 2-2** below).

Figure 23. Construction soil compaction
(Source: Virginia Tech archived photos, http://clic.cses.vt.edu)

Figure 24. Compacted Soil
(Source: Center for Watershed Protection)

Table 2-2
Common Bulk Density Measurements

Land Surface/Use	Bulk Density
Undisturbed Lands Forest & Woodlands	1.03 g/cc
Residential Neighborhoods	1.69 to 1.97 g/cc
Golf Courses - Parks Athletic Fields	1.69 to 1.97 g/cc
Concrete	2.2 g/cc

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Soil Compaction

Consider also:

Soils with the highest permeability (**Figure 25**, **Table 2-3**) are often considered most suitable for construction ***(and it is this characteristic that is typically reduced or eliminated by the construction process)***.

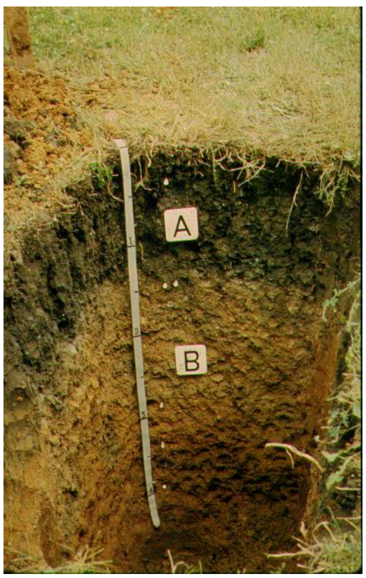


Figure 25. Soil horizons (Various soil properties are used to group soils into hydrologic soil groups, based on their ability to infiltrate and percolate water).

Table 2-3
USDA-NRCS Estimates of Annual Groundwater Recharge Rates, Based on Soil Type

Hydrologic Soil Group (HSG)	Recharge Rate
Hydrologic Soil Group A	18 inches/year
Hydrologic Soil Group B	12 inches/year
Hydrologic Soil Group C	6 inches/year
Hydrologic Soil Group D	3 inches/year

NOTE: Average annual rainfall varies from approximately 42 - 48 inches across Virginia

All of these factors have some effect on how water will move through the soil. It is important to understand these factors when designing an appropriate stormwater system at a particular location. These factors are especially critical when considering BMPs that rely on infiltration to remove runoff volume or pollutants.

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Reduced Groundwater Recharge and Reduced Stream Base Flow

Eventually the groundwater table intersects the land surface and forms springs, and can provide baseflow to headwaters and wetlands (see **Figure 13** and **Figure 18** above).

- Perennial streams receive continuous baseflow from this groundwater discharge, during both wet and dry periods. Much of the time, all of the natural flow in a stream is from groundwater discharge.
- Groundwater discharge can be seen as the "life" of streams, supporting all water-dependent uses and aquatic habitat (**Figure 26**).
- During periods of wet weather, the water table may rise to near the ground surface in the vicinity of the stream.
- As a result, this area saturates quickly during rain events; surface runoff begins to flow to streams from the saturated areas surrounding streams.
- More stormwater runoff means less groundwater recharge (the hydrologic balance is altered)
- Stream base flow is deprived of constant groundwater discharge, and the flow may diminish or even cease.
- Wetlands and headwaters reflect changes in groundwater levels most profoundly, and the reduced flow can stress or even eliminate the aquatic community.
- During a drought, reduced stream base flow may also significantly affect the water quality in a stream *(reduced dissolved oxygen → aquatic community stressed (fish, macroinvertebrates) + chemical reactions can release pollutants previously bound up in bottom sediments)*.

Figure 26. Headwater stream
(Source: Chesapeake Bay Stormwater Training Partnership)

As the most hydrologically and biologically sensitive elements of the drainage network, headwaters and first order streams warrant special consideration and protection in stormwater management planning

I. CHANGES IN TOPOGRAPHY AND LAND COVER

Increased Imperviousness of the Land Surface

Impervious cover has emerged as a measurable, integrating concept used to describe the overall health or, conversely, degradation of a watershed.

- When impervious cover in a watershed reaches between 10 and 25 percent (**Figure 27**), ecological stress becomes apparent.
- Beyond 25 percent impervious cover, stream stability is reduced, habitat is lost, water quality is degraded, and biological diversity is diminished.

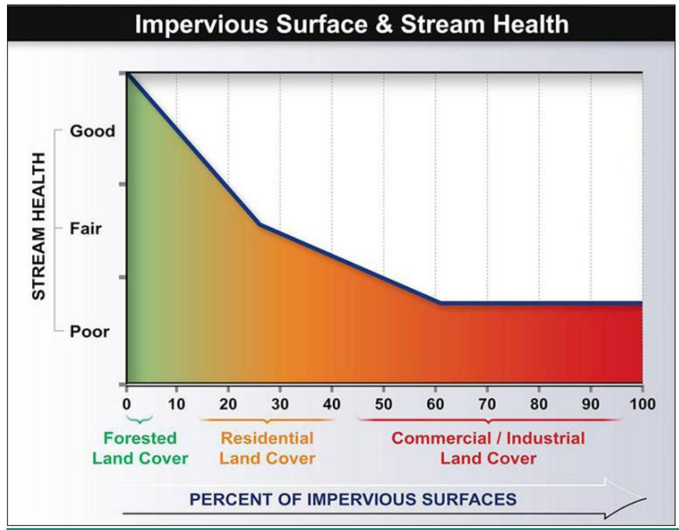


Figure 27. The Impervious Cover Model: How Imperviousness Impacts Stream Health. (Source: Chesapeake Bay Stormwater Training Partnership)

When considering specific land use imperviousness **(Table 2-4)**:

Table 2-4
Typical Site Impervious Coverage of Land Uses in the Northeast U.S.

Land Use	% Impervious Cover
Commercial and Business District	65-100
Industrial	70-80
High Density Residential	45-60
Medium Density Residential	35-45
Low Density Residential	20-40
Open (Natural Areas)	0-10

Source: MADEP, 1997; Kauffman and Brant, 2000; Arnold and Gibbons, 1996; Natural Resource Conservation Service, 1975

- Typical single-family home residential neighborhoods ranges from 15 to 60 percent.
- *Note: Table values reflect impervious within specific land uses, not overall watershed imperviousness.*
- In watersheds with significant residential, commercial, and industrial development, ***overall watershed imperviousness often exceeds ecological stress thresholds.***

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

The impacts of altered stormwater runoff characteristics *(greater volumes more often and at higher flow rates)* on stream channels and floodplains include the following:

Altered stream flow

Channel erosion, widening and downcutting

Increased frequency of bank-full and over-bank

Floodplain expansion

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Altered Stream Flow

Annual and seasonal cycles of water flows – particularly the low and high flows – shape ecological processes in rivers and streams.

- Adequate minimum flow maintain suitable water conditions and habitat for fish and other aquatic life.
- High flows replenish floodplains and flush out accumulated stream sediment that can degrade habitat.
- Flows are altered by a variety of land- and water-management activities, including reservoirs, diversions, subsurface tile drains, groundwater withdrawals, wastewater inputs, and impervious surfaces, such as parking lots, sidewalks and roads.
- 42% of the U.S's wadeable stream segments were rated by the USEPA in 2006 as is in poor biological condition.

In wet climates, like that in Virginia, watershed management is typically focused on flood control, which can result in lower maximum flows and higher minimum flows.

Altered flow affects stream biota as much or more than pollution does.

Stream biota refers to the stream's combined flora and fauna

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Channel Erosion, Widening, and Downcutting

There is undoubtedly a link between altered stream channels and land development:

- The natural shape, form and stability of stream channels are influenced by increases in runoff volume from each storm *(more frequent bank-full or nearly bank-full conditions)*.
- Downstream channels enlarge through widening and stream bank erosion in order to accommodate and convey increased runoff volumes and higher stream flows.
- Increased stormwater runoff volume can turn small meandering streams into highly eroded and deeply incised stream channels (**Figure 28**).
- Increased stormwater runoff undercuts and scours the lower parts of the streambank and causes steeper banks to slump and collapse during larger storms. Higher flow velocities further increase streambank erosion rates.

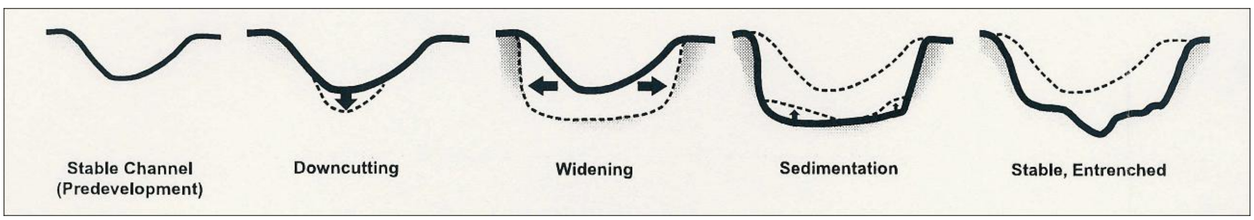


Figure 28. Typical Changes to a Stream's Physical Character Due to Watershed Development

- The majority of this stream channel devastation is intensified during the frequently occurring small-to-moderate rainfall events, rather than major flooding events.

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Channel Erosion, Widening, and Downcutting

Rainfall events, or *storms*, are typified by their total rainfall, time span, and average and peak intensity. Storms are ranked in terms of the statistical frequency of their return interval (**Figure 29**). For example, a storm that has a 50% chance of occurring in any given year is termed a “2-year” storm (i.e., it is statistically likely to occur once every two years).

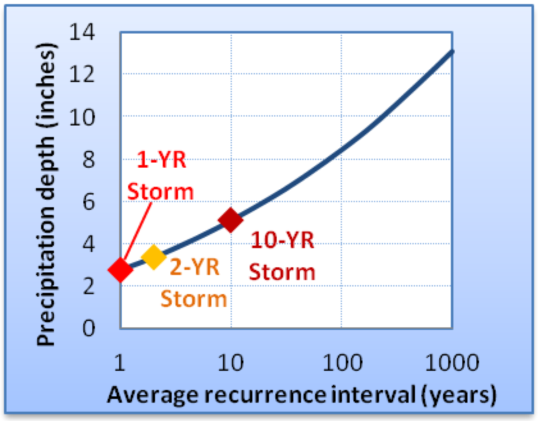


Figure 29. 24-Hr Storm Precipitation Frequencies for Richmond, VA

(Source: Data for this graph obtained using NOAA's National Weather Service, Precipitation Frequency Data Server, http://hdsc.nws.noaa.gov/hdsc/pfds/index.html)

- Traditionally, the 2-year storm was believed to represent the typical bankfull flow of a stream channel, because earlier research had indicated that most natural stream channels in the Commonwealth have just enough capacity to carry the 2-year flow without spilling out of the stream’s banks.

- In Virginia, a 2-year storm produces from 2.5 to 5.2 inches of rain in a 24-hour period. The majority of the state experiences from 3.2 to 3.6 inches of rain from a two-year 24-hour storm. *This rainfall depth is called the 2-year design storm.*

- Stream channels in urban areas may be formed by flows as little as the 0.9-year storm, whereas channels in rural areas are typically formed by the 1.5-year to 1.7-year storm (i.e., a storm that is statistically likely to occur once every 18 to 21 months).

- In Virginia, a 1-year storm produces from approximately 1.9 to 3.2 inches of rain in a 24-hour period. However, the majority of the state experiences from 2.6 to 3.0 inches of rain from a 1-year 24-hour storm. *This rainfall depth is called the 1-year design storm.*

For regulatory purposes, most states including Virginia, have begun to establish the *1-year 24-hour storm* event as the average channel-forming storm.

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Channel Erosion, Widening, and Downcutting

- In Virginia, a 10-year storm (10% chance of occurring in any given year) produces from approximately 3.5 to 8 inches of rain in a 24-hour period. However, the majority of the state experiences from 4.8 to 5.5 inches of rain from a 10-year 24-hour storm.
- Considering the implications of changing precipitation patterns, as discussed above, it is paramount to update applicable I-D-F curves in order to better assure stormwater management facilities will be able to accommodate more intense precipitation.

Under traditional engineering practice, most channels and storm drains in Virginia are designed with enough capacity to safely pass the peak discharge from a *10-year design storm*.

Additional Resources:

For a network of precipitation gauge data, visit the National Climatic Data Center online at http://www.ncdc.noaa.gov/oa/ncdc.html or the Cooperative Weather Observer Program at http://www.nws.noaa.gov/om/coop/. Additionally, the National Weather Service offers a service that estimates the return period for a range of depth-duration events. It can be found at http://www.nws.noaa.gov/om/coop/.

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Channel Erosion, Widening, and Downcutting

The shape of a stream channel (i.e., its width, depth, slope, and how it moves through the landscape) is influenced by the amount of flow the stream channel is *expected* to carry (**Figure 30**).

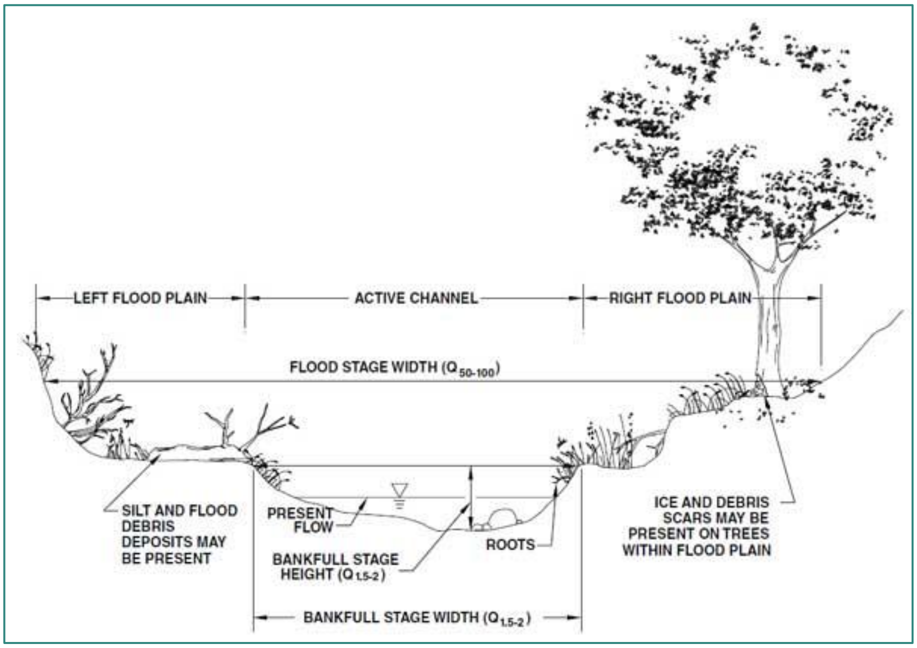


Figure 30. Schematic showing water level stages.
(Source: US Dept. of Agriculture, US Forest Service, http://www.fs.fed.us/eng/pubs/htmlpubs/htm10232808/page03.htm)

- The stream channel's physical shape and character (morphology) is determined by the energy of typical stream flows ranging from "low flow" to "bankfull".
- During bankfull flows, the speed (velocity) of the water flow is typically at its maximum.
- If these high-velocity flows last long enough or occur often enough, they can generate enough energy to scour soil from streambanks and transport sediment and rocks from the stream bottom.
- During larger flood events, the flow overtops the stream banks and flows into the floodplain.

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Channel Erosion, Widening, and Downcutting

- As the flow spreads out, velocity is reduced, resulting in much less impact on the shape of the stream channel itself.
- In a developing watershed, bankfull flows occur more often. *(Remember: Increases in stormwater runoff volume and flow rate during small storm events change the shape of the stream channel as it transforms to accommodate greater flows.)*
- ***Greater flows occurring more often and for longer periods of time will erode the stream banks and/or cut down the channel bottom, configuring the stream channel geometry for these larger flows.***
- A stream can become many times wider than its original size due to post-development runoff (**Figure 31. Stream Channel Widening**).

Figure 31. Stream Channel Widening
(Source: Center for Watershed Protection)

- As streambanks are gradually undercut and slump into the channel, trees that had protected the banks are exposed at the roots, making them more likely to be uprooted during major storms, further weakening bank structure.

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Channel Erosion, Widening, and Downcutting

Another way that streams accommodate higher flows is by downcutting the streambed (**Figure 32**). This causes instability in the stream profile, or elevation along a stream's flow path, which increases velocity and triggers further channel erosion both upstream and downstream.

- Shoreline and bank erosion diminish property values. In fact, many urban governments find themselves engineering degraded stream channels, straightening them and lining them with concrete, in order to prevent further erosion and speed the stormwater through their jurisdiction.

Stormwater regulations have attempted to assure that runoff from development sites should not exceed the capacity of the receiving stream channel.

Figure 32. Stream Channel Downcutting
(Source: ARC, 2001)

- This transfers the damage into another part of the stream wherever the concrete channel ends, and the higher-volume, higher-velocity flows are released.

- Traditionally, stormwater managers have used detention basins to capture (detain) excess stormwater runoff and slowly release it over a period of days into the receiving stream channel. However, the release rate of flow from the basin typically mimics the bankfull flow.

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Channel Erosion, Widening, and Downcutting

- In Virginia, previously the 2-year 24-hour design storm, *(originally considered to be the bankfull storm)* was used to regulate post development runoff to natural streams.
- Damage and negative impacts to streams and channels have still been observed.
- The problem is that, unlike a normal "flashy" rainstorm, after which runoff flow recedes rather quickly, the outflow from a detention basin often exposes the channel to a longer *duration* of erosive flows than it would have otherwise received. Thus, in order to prevent flooding, the stream bed and banks stay wet and subject to high-velocity flows for a longer period of time, which makes them more susceptible to erosion. Channel deterioration is often most pronounced downstream of detention basins or where similar stormwater management practices are placed as a result of land development.
- These physical changes, in turn, degrade stream habitat and produce substantial increases in sediment loads resulting from accelerated channel erosion. The typical stream bed structure of pools, riffles and meanders disappears. Sediments are deposited in the stream as sandbars and other features, covering the channel bed, or substrate.

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Floodplain Expansion

Floodplains (the land area bordering streams that would be flooded during a 100-year storm, see **Figure 30** above) are very important habitat areas, encompassing riparian forests, wetlands, and wildlife corridors.

- Floodplains are natural storage areas that help to attenuate downstream flooding.
- In most of Virginia, a 100-year storm results in approximately 8 to 9 inches of rainfall in a 24-hour period. Floods of this scale can be very destructive and can pose a threat to human life.

Remember, the 100-year storm has a 1% chance of occurring in any given year.

All local jurisdictions in Virginia restrict or even prohibit new development within the 100-year floodplain, to prevent flood hazards and conserve habitats. *(Prior development in floodplains remain subject to periodic flooding)*

- Development sharply increases the peak discharge rate associated with the 100-year design storm.
- The elevation of a stream's 100-year flood crest and floodplain have become higher and the boundaries of floodplains have expanded laterally (see **Figure 33** below).
- This problem is compounded by building and filling in floodplain areas, which cause flood heights to rise even further. In some instances, property and structures that had not previously been subject to flooding become at risk.
- Additionally, such a shift in a floodplain's hydrology can degrade wetlands and forest habitats.

II. STREAM CHANNEL AND FLOODPLAIN IMPACTS

Floodplain Expansion

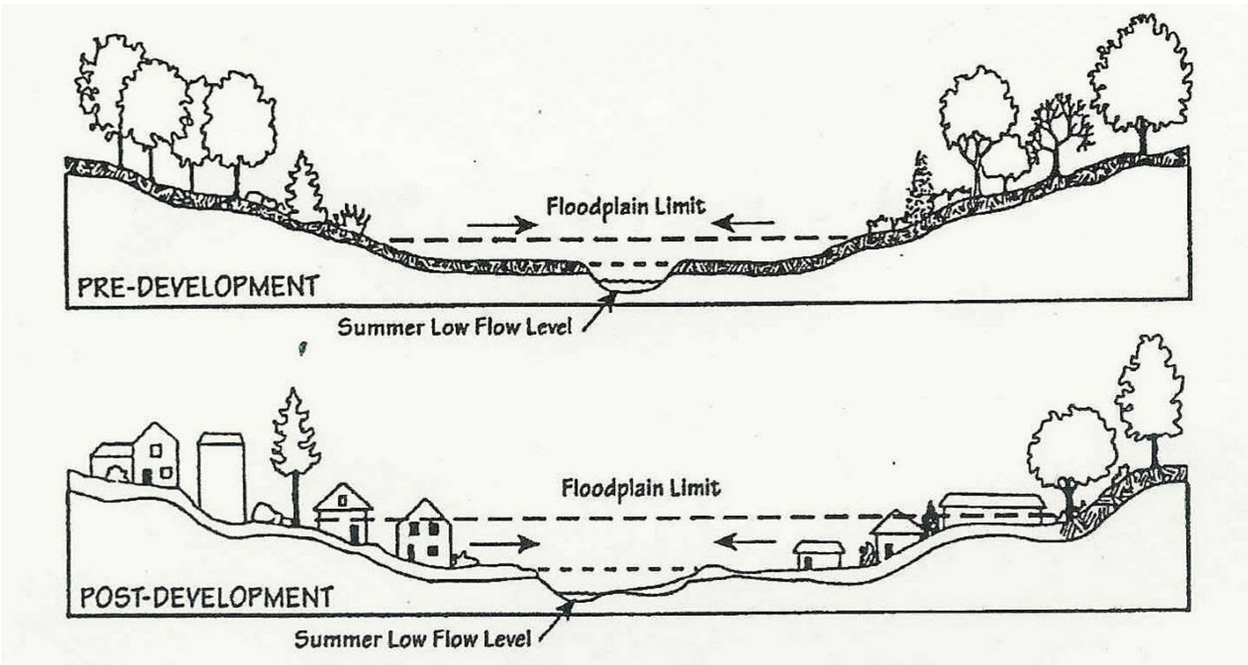


Figure 33. Response of Stream Geometry to Land Development

III. HABITAT AND ECOLOGICAL IMPACTS

As the shape of the stream channel changes to accommodate more runoff, aquatic habitat is often lost or altered, and aquatic species decline. Destruction of freshwater wetlands, riparian buffers, and springs often occurs as a result of land development.

Degradation of Habitat Structure

- Effects occur at many levels in the aquatic community.
- Higher and faster flows due to development can scour channels and wash away entire biological communities.
- Sediment from runoff and eroding stream banks deposit along stream bottoms, burying the substrate material of stream beds (the habitat for many benthic organisms)
- The amount and types of microorganisms that live along the stream bottom decline.

Loss of Pool-Riffle Structure

- Meandering streams draining undeveloped watersheds often contain pools of deeper, more slowly flowing water that alternate with "riffles" or shoals of shallower, faster flowing water.
- These pools and riffles provide valuable habitat for fish and aquatic insects.
- Increased flows and sediment loads from urban watersheds lead to elimination of these pools and riffles and replacement with wider, more uniform streambeds that provide less varied aquatic habitat.
- Much larger channels have lower and shallower flows. The result is a decline in diversity and abundance of fish and aquatic insects and changes in which species tolerate the new conditions.

Reduced Baseflows

As noted earlier, reduced baseflows – due to increased impervious cover in a watershed and the loss of rainfall infiltration into the soil and water table – adversely affect in-stream habitats, especially during periods of drought.

III. HABITAT AND ECOLOGICAL IMPACTS

Increased Stream Temperature

- Runoff from warm impervious areas, storage in impoundments, loss of shading as riparian trees and shrubs topple or are removed, and shallower channels can all cause an increase in the water temperature in urban streams.
- Increased temperatures can reduce dissolved oxygen levels and disrupt the food chain.
- Certain aquatic species can only survive within a narrow temperature range.
- Thermal problems are especially critical for many Piedmont streams which straddle the borderline between cold water and warm water stream conditions.

Shift in Aquatic Food Sources

A shift takes place from external food sources (leaf matter) for the aquatic species to internal stream production (algal organic matter). This also results in diminished biomass.

Decline in Abundance, Richness and Biodiversity of the Stream Community (aquatic insects, fish, amphibians, etc.)

- Just as weeds can invade and overwhelm preferable vegetation when conditions provide the opportunity, less desirable species begin to replace desirable species in degraded streams when there is a reduction in various habitats and habitat quality.
- Both the number and the variety (diversity) of organisms (wetland plants, fish, macroinvertebrates, etc.) are reduced.
- Sensitive fish species and other life forms disappear and are replaced by those organisms that are better adapted to the poorer conditions.
- For example, in streams with severely diminished flow, native trout, a popular sport fish that requires cold, fast-flowing streams with gravel bottoms, are replaced by less desirable non-native species, such as carp.
- The diversity and composition of the benthic, or streambed, community have frequently been used to evaluate the quality of urban streams.

III. HABITAT AND ECOLOGICAL IMPACTS

Water Quality Impacts on Aquatic Species

Fish and other aquatic organisms are impacted not only by the habitat changes brought on by increased stormwater runoff quantity, but are often also adversely affected by water quality changes due to development and resultant land use activities in a watershed (**Figure 34** and **Figure 35**). These impacts are discussed more specifically in the next section of this module.

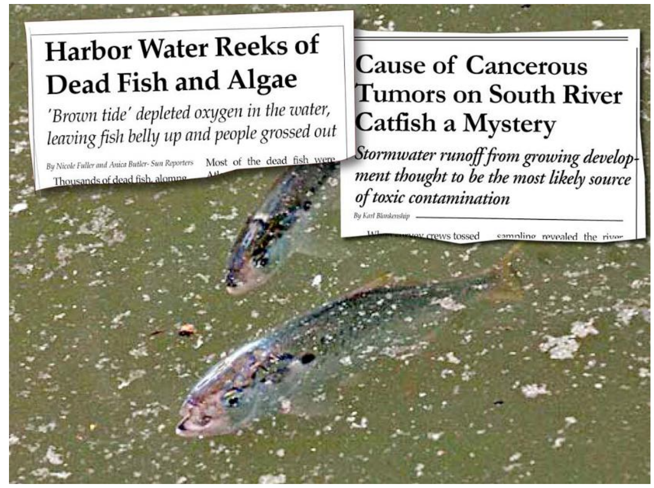


Figure 34. Fish Kills.
Source: Chesapeake Bay NEMO Program

IV. WATER QUALITY IMPACTS

Point and nonpoint source water pollution from pipes, streets, rooftops, and parking lots swell downstream waterways every time it rains. Since the natural vegetation and soils that could absorb it have been paved over, stormwater becomes a high-speed, high-volume conduit for pollution into streams, rivers, lakes and coastal waters (**Figure 35** below).

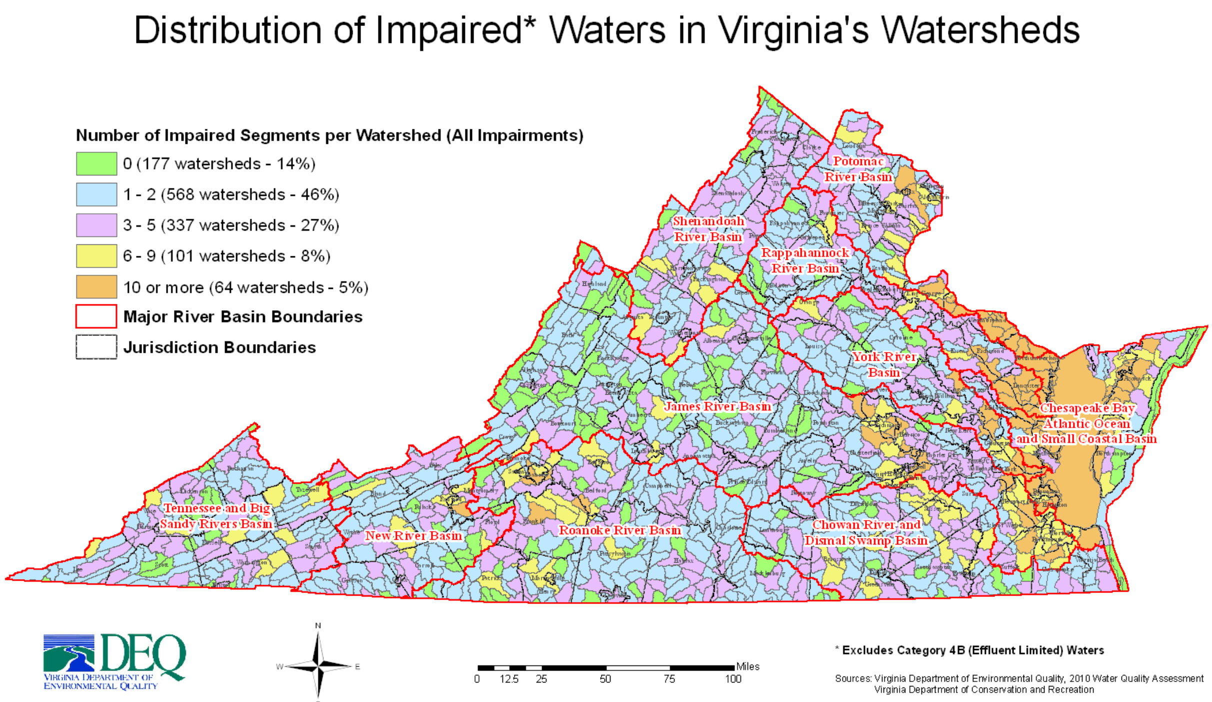


Figure 35. Impaired Waters in Virginia
(Source: Virginia DEQ, 2010)

- Urban stormwater runoff can be considered both a point source and a nonpoint source of pollution. Stormwater runoff that flows into a conveyance system and is discharged through a pipe, ditch, channel, or other structure is considered a *point source* because it discharges from a discrete location (point on a map).
- Stormwater runoff that flows across the land surface and is not concentrated in a defined channel or pipe is considered *nonpoint source (NPS)* pollution, which is the primary cause of polluted stormwater runoff and water quality impairment.
- NPS pollution comes from many diffuse or scattered sources, many of which are the result of human activities within a watershed.

IV. WATER QUALITY IMPACTS

- Development concentrates and increases the amount of these nonpoint source pollutants.
- As stormwater runoff moves across the land surface, it picks up and carries away both natural and human-made pollutants, depositing them into Virginia's streams, rivers, lakes, wetlands, coastal waters and marshes, and underground aquifers.
- Both point and nonpoint sources of urban stormwater runoff have been shown to be significant causes of water quality impairment to rivers and streams. Urban runoff is also reported as a contributor to excessive nutrient enrichment in numerous lakes and ponds throughout the state, as well as a continued threat to estuarine waters and the Chesapeake Bay.
- The USEPA has ranked stormwater runoff as the second most prevalent source of water quality impairment in the nation's estuaries (agriculture is currently ranked as number one).

IV. WATER QUALITY IMPACTS

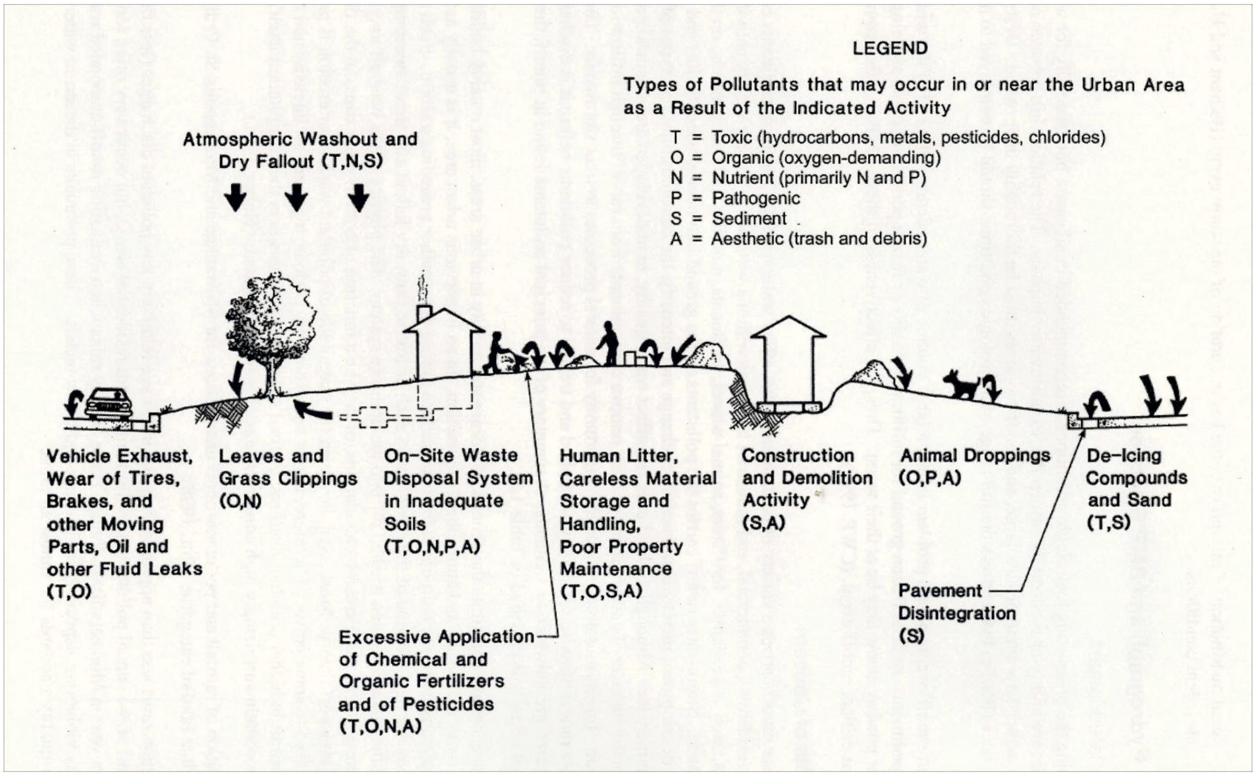


Figure 36. Availability of Potential Pollutants on the Land Surface
(Source: Walesh, 1989)

What are some of the sources?

- Combined sewer overflows (CSOs). Cities with older sewer infrastructure (Richmond, Lynchburg) have sewer pipes that are also open to stormwater flow. Some storms cause excessive flows to the wastewater treatment plants which exceed holding and treatment capacity. The result is the discharge of untreated human, commercial, and industrial wastewaters into our waterways.
- Most Virginia cities have separate stormwater sewer systems through which stormwater discharges directly into waterways. These storm flows often cause streambank erosion and carry pollutants directly into waterways.
- Stormwater can also carry sewage leaching from failing septic drainfields to waterways.

IV. WATER QUALITY IMPACTS

- Erosion from construction sites and other disturbed areas (**Figure 37** below) can potentially contribute large amounts of sediment to streams.
- Increased impervious surfaces that replace natural land cover become a surface depository for pollutants from human activities. During storm events, these pollutants are washed off and transported to streams.
- There are a number of other causes of NPS pollution in urban areas that are not specifically related to wet weather events, including leaking sewer pipes, sanitary sewage spills, fluid leaks from vehicles, residue from tire wear, and illicit discharge of commercial/industrial wastewater and wash waters to storm drains.

Figure 37. Construction Site Erosion
Source: Chesapeake Bay Stormwater Training Partnership

IV. WATER QUALITY IMPACTS

How does development contribute to pollutant load?

- Structural stormwater collection and conveyance systems allow stormwater pollutants to quickly wash off and concentrate during rainfall or snowmelt events and discharge to downstream receiving waters. By contrast, in undeveloped areas, natural processes such as infiltration, interception, depression storage, filtration by vegetation, and evaporation can reduce the quantity of stormwater runoff and remove pollutants. Impervious areas decrease the natural stormwater purification functions of watersheds and increase the potential for water quality impacts in receiving waters.

- Many areas assumed to be pervious, such as lawns and landscaped areas, also add significantly to the pollutant load, especially where these pervious areas drain to impervious surfaces and storm sewers.

- As noted above, compacted soils at many land development sites result in vegetated surfaces that are, in many instances, nearly impervious and produce far more runoff than the natural (pre-development) soil did. These new lawn surfaces are often loaded with fertilizers that result in polluted runoff that degrades receiving streams, ponds, and lakes.

- Urban land uses and activities can also degrade groundwater quality if stormwater with high pollutant loads is directed into the soil without adequate treatment.

- Certain land uses and activities, referred to as stormwater "hotspots" (e.g., commercial parking lots, vehicle service and maintenance facilities, fuel stations, etc.), are known to produce higher loads of pollutants such as trace metals, petroleum hydrocarbons and toxic chemicals (**Figure 38**).

Figure 38. Fueling Stations Can Be Stormwater Hotspots
Source: Chesapeake Bay Stormwater Training Partnership

IV. WATER QUALITY IMPACTS

- Soluble pollutants from hotspot sites can migrate into groundwater and potentially contaminate wells in groundwater supply areas (aquifers). The potential for groundwater pollution from stormwater is even greater in regions of karst geologic formations, where seams and channels dissolved in the limestone base material can quickly transport pollutants into perched groundwater and deeper aquifers.
- The actual transport process of stormwater pollution is more complex than just the "first flush" would indicate (first flush typically considered the first 1/2-inch of runoff from impervious surfaces during the first half-hour of a storm).
- Capturing the first flush pollutant load was the focus of earlier quality control criteria In Virginia's stormwater management regulations.
- In areas with high impervious cover, the first flush can make up as little as **20%** of the annual runoff pollution load.
- Rainfall volumes of 1-inch or more must be treated to capture the majority of the load.
- Capturing the first flush only does not necessarily ensure effective treatment of the majority of pollution in runoff.

Due to the magnitude of the problem, it is important to understand the nature and sources of urban stormwater pollution.

IV. WATER QUALITY IMPACTS

What are some of the pollutants of concern?

Solids, suspended solids, particulates:

- Solids suspended in the water column make the water cloudy or turbid and impact submerged aquatic vegetation (SAV), fish habitat, overwhelm suspension feeding shellfish, and settled solids can suffocate bottom-dwelling (benthic) organisms.
- Sediment deposition in water bodies can reduce the capacities of reservoirs, lakes, and streams.

Figure 39. A Sediment Plume Entering a River
Source: ARC (2001)

- Oils, grease, gasoline and antifreeze are also carried by sediments into water bodies.
- Particulates (soil, sediment) can carry pollutants such as nutrients, metals, pathogens, and hydrocarbons (oils, grease).
- Organic substances such as grass clippings, leaves, animal waste, street litter commonly found in stormwater are oxygen demanding when they end up in streams and can lead to depleted dissolved oxygen levels, impairments, and even fish kills.

IV. WATER QUALITY IMPACTS

Excess Nutrients

- Nutrients are a major source of degradation in many of Virginia's water bodies.
- Urban runoff has been defined as a key and controllable source of nutrients by the USEPA Chesapeake Bay Program.
- Urban stormwater runoff typically contains elevated concentrations of nitrogen and phosphorus compounds that are most commonly derived from lawn fertilizer, detergents, animal waste, atmospheric deposition, organic matter, sewer overflows and leaks, and improperly installed or failing septic systems.
- Elevated nutrient concentrations in stormwater runoff can stimulate excessive growth of vegetation or algae in streams, lakes, reservoirs, and estuaries (**Figure 40** below), a process known as accelerated eutrophication.
- This abundance of plant growth (algae) are decomposed by organisms that simultaneously use up of a waterbody's dissolved oxygen during this part of the process and lead to inhabitable conditions for most existing aquatic organisms.
- Phosphorus is typically the growth limiting nutrient in freshwater systems, while nitrogen is growth limiting in marine systems.
- Without added phosphorus from human activities, phosphorus is normally contained in a closed loop from plants, to animals that eat them, to decomposers like fungi, into the soil and back to the plants again. Very little, if any, is released to waterways compared to the kind of phosphorus discharges that currently occur from developed areas.

IV. WATER QUALITY IMPACTS

Figure 40. Algae Bloom in the James River
Source: Richmond Times-Dispatch

Pathogens

- Pathogens such as bacteria, viruses, and other microbes that can cause disease in humans, in urban runoff routinely exceed public health standards for water contact recreation and shellfish harvesting.
- Sources of pathogens in stormwater runoff include animal waste from pets, wildlife, and waterfowl; combined sewer overflows; failing septic systems; and illegal sanitary sewer cross-connections.
- High levels of indicator bacteria in stormwater have commonly led to the closure of beaches and shellfish beds along coastal areas of Virginia.

Trace Metals

- Metals such as copper, lead, zinc, mercury, aluminum, chromium, nickel and cadmium are commonly found in urban stormwater runoff from industrial and commercial sites, including marinas, urban surfaces such as rooftops and painted areas, etc.

IV. WATER QUALITY IMPACTS

- Antifreeze from automobiles is a source of phosphates, chromium, copper, nickel, and cadmium.
- Building roofs, gutters, downspouts can be sources of copper and zinc stormwater runoff.

Other pollutants/water quality impairments:

- Pesticides/Synthetic Organic Chemicals
- Chlorides/Deicing Constituents
- Trash and Debris
- Thermal Impacts
- Freshwater Impacts into brackish/tidal areas

Table 2-5 below lists the main pollutants found in urban stormwater runoff, typical pollutant sources, related impacts to receiving waters, and factors that promote pollutant removal. The Table also identifies the pollutants that commonly occur in dissolved or soluble form, which has important implications for the selection and design of stormwater treatment practices.

Concentrations of pollutants in stormwater runoff vary considerably between sites and storm events.

IV. WATER QUALITY IMPACTS

Consider the following facts:

The annual biomass generated by lawn clippings is equivalent to 272 million bushels of corn (over 6.8 million tons - fill over 17,400 standard corn silos).

An estimated $600 million annually is spent on lawn fertilizer and pesticides across the Bay watershed

The best estimate of nitrogen fertilizer applied to lawns in the Bay watershed is nearly 215 million pounds per year – enough to grow nearly 2 million acres of corn

About 19 million pounds of pesticide active ingredients are used each year (mostly herbicides to kill weeds). These pesticides are reaching local streams and rivers. According to USGS monitoring data, one or more pesticides were detected in 99% of urban streams, and one out of every five samples exceeded water quality standards, endangering aquatic life

IV. WATER QUALITY IMPACTS

Table 2-5
Summary of Urban Stormwater Pollutants

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted by[1]
Excess Nutrients Nitrate, Nitrite, Ammonia, Organic Nitrogen, Phosphate, Total Phosphorus	Animal waste, fertilizers, failing septic systems, landfills, atmospheric deposition, erosion and sedimentation, illicit sanitary connections	Algal growth, nuisance plants, ammonia and nitrate toxicity, reduced clarity, oxygen deficit (hypoxia), pollutant recycling from sediments, decrease in submerged aquatic vegetation (SAV), eutrophication, loss of recreation and aesthetic value	***Phosphorus:*** Filtering/settling sediment, high soil exchangeable aluminum and/or iron content, vegetation and aquatic plants, alum in pond ***Nitrogen:*** Aeration, alternating aerobic and anaerobic conditions, maintaining near neutral pH (7)
Sediments Suspended, dissolved, sorbed pollutants, turbidity	Construction sites, stream bank erosion, washoff from impervious surfaces	Increased turbidity, lower dissolved oxygen, deposition of sediments, aquatic habitat alteration, sediment and benthic toxicity, contaminant transport, filling of lakes and reservoirs, loss of recreation and aesthetic value	Low turbulence, increased residence time
Pathogens Total and Fecal Coliforms, Fecal Streptococci, Viruses, E. Coli, Enterocci	Animal waste, failing septic systems, illicit sanitary connections	Human health risk via drinking water supplies, contaminated swimming beaches, and contaminated shellfish consumption	High light (ultraviolet radiation), increased residence time, media/soil filtration, disinfection
Organic Materials Vegetation, sewage, other oxygen	leaves, grass clippings, brush, failing septic systems	Dissolved oxygen depletion, odors, fish kills, algal growth, reduced clarity	Aerobic conditions, high light (ultraviolet radiation), high soil organic content,

IV. WATER QUALITY IMPACTS

Table 2-5

Summary of Urban Stormwater Pollutants

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted by[1]
demanding materials (BOD/COD)			maintaining near neutral pH
Hydrocarbons Oil and grease	Industrial processes, commercial processes, automobile wear, emissions, and fluid leaks, improper oil disposal	Toxicity of water column and sediments, bioaccumulation in food chain organisms	Low turbulence, increased residence time, physical separation or capture technique, volatilization
Metals Copper, lead, zinc, mercury, cadmium, chromium, nickel, aluminum (soluble)	Industrial processes, normal wear of automobile brake linings and tires, automobile emissions and fluid leaks, metal roofs and pipes	Toxicity of water column and sediments, bioaccumulation in food chain organisms	High soil organic content, high soil cation exchange capacity, maintaining near neutral pH (7), controlling sludge applications
Synthetic Organic Chemicals Pesticides, VOCs, SVOCs, PCBs, PAHs (soluble)	Residential, commercial, and industrial application of herbicides, insecticides, fungicides, rodenticides, industrial processes, commercial processes	Toxicity of water column and sediments, bioaccumulation in food chain organisms	Aerobic conditions, high light (ultraviolet radiation), high soil organic content, low levels of toxicants, near neutral pH (7), high temp. and air movement for volatilization of VOCs
Deicing Constituents Sodium chloride, calcium chloride, potassium chloride, ethylene glycol,	Road salting and uncovered salt storage, snowmelt runoff from snow piles in parking lots and along roads during the spring	Toxicity of water column and sediments, contamination of drinking water, harmful to salt-intolerant plants;	Aerobic conditions, high light (ultraviolet radiation), high soil organic content, low levels of toxicants, near neutral pH (7)

IV. WATER QUALITY IMPACTS

Table 2-5

Summary of Urban Stormwater Pollutants

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted by[1]
other pollutants (soluble)	snowmelt season or during winter rain and snow events	concentrated loadings of other pollutants as a result of snowmelt	
Trash and Debris	Litter washed through the storm drain networks	Degradation of aesthetics, threat to wildlife, potential clogging of storm drainage	Low turbulence, physical straining/capture
Thermal Impacts	Runoff with elevated temperatures from contact with impervious surfaces (asphalt)	Dissolved oxygen depletion, adverse impacts to aquatic organisms that require cold and cool water conditions	Use of wetland plants and trees for shading, increased pool depths
Freshwater Impacts to Saltwater	Stormwater discharges to tidal wetlands and estuarine environments	Dilution of the high marsh salinity and encouragement of the invasion of brackish or upland wetland species, such as Phragmites	Stormwater retention and volume reductions

[1] Factors that promote removal of most stormwater pollutants include: (1) Increasing hydraulic residence time;
(2) Low turbulence; (3) Fine, dense, herbaceous plants; and (4) Medium-fine textured soil

Source: Adapted from Connecticutt DEP, 1995, Metropolitan Council, 2001; Watershed Management Institute, Inc., 1997

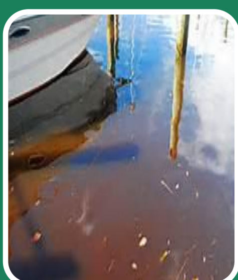
V. IMPACTS ON OTHER RECEIVING ENVIRONMENTS

Ecological impacts of urbanization and stormwater runoff are not just focused on streams:

Development alters the physical, geochemical, and biological characteristics of aquatic systems creating impacts that destroy natural environments and public beneficial uses.

Wetlands

- Pollutant sink (nutrients, metals, sediments are not quickly flushed out)
- Accelerated eutrophication
- Sediment deposition and turbidity impact biota
- Loss of habitat and particular biota
- Scour and erosion lead to permanent loss of wetlands



Lakes and Ponds

- Pollutant sink (nutrients, metals, sediments are not quickly flushed out)
- Accelerated eutrophication
- Sediment deposition and turbidity impact biota
- Aesthetic impairment (trash, debris)

Estuaries

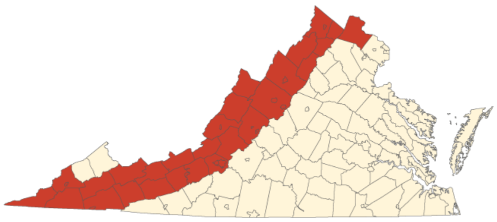
- Pulses of runoff and reduced base flow
- Pollutant sink due to trapping nature of tidal flows
- Variations in salinity change create intolerable conditions for many estuarine species
- Sediment deposition and turbidity impact biota
- Accelerated eutrophication

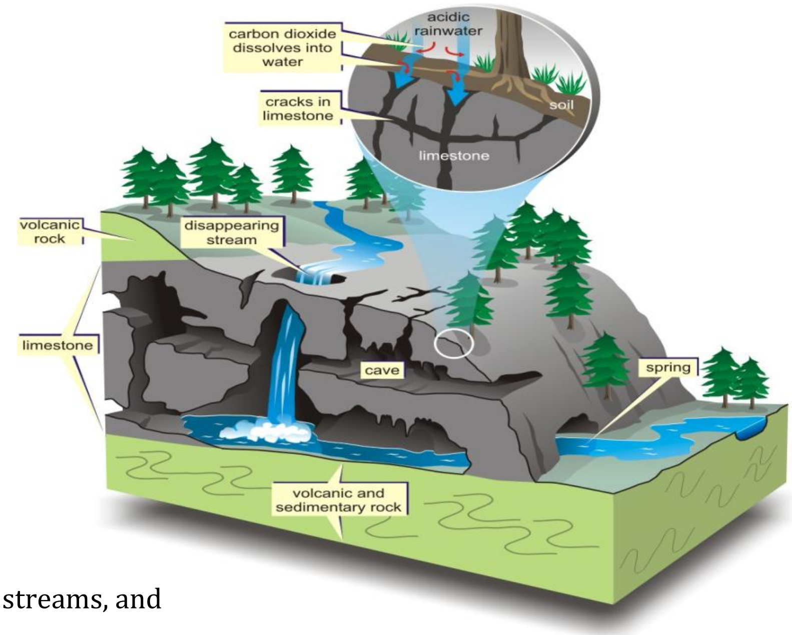
Karst Systems

- Erosion and underground sediment deposition
- Decreased recharge of aquifers
- Transport of pollutants directly to groundwater
- More sinkholes

V. IMPACTS ON OTHER RECEIVING ENVIRONMENTS

Karst areas:





The valleys of western Virginia are underlain largely by soluble bedrock (limestone and dolomite), which slowly dissolved over the millennia to form karst areas with unique hydrologic systems (fissures, sinkholes, underground streams, and caverns). These areas supply drinking water and support base flow of local streams.

The effects of poor stormwater management are exacerbated in this setting:

- Karst terrain soils are not very permeable
- Rainwater is diverted underground through fractured bedrock or other karst features to aquifers and springs without the usual natural attenuation (natural ground filtration) process that accompanies groundwater flow (leads to increased contamination of groundwater and base stream water)
- After development, increased surface runoff is typically routed overland to surface streams or discharged to karst features which lack sufficient capacity
- Increased stormwater ponding or infiltration form sinkholes (surface sediments collapse due to the intrusion of stormwater runoff)
- More runoff deprives the karst system of recharge (groundwater table and base stream flows diminished)

Additional Resources:

http://chesapeakestormwater.net/training-library/design-adaptations/stormwater-in-karst-topography/

Knowledge Check

4. Traditionally, Virginia has used what design storm for discharges into a natural channel or stream?

   A. 2 Year / 24 hour

   B. 2 Year / 12 hour

   C. 10 Year / 24 hour

   D. 10 year / 12 hour

5. True or False? When stormwater runoff is allowed to drain away instead of being used to recharge the groundwater it alters the hydrologic balance of a watershed.

   A. True

   B. False

6. Nationwide, significant flow alterations have occurred in what proportion of assessed waters?

   A. 50%

   B. 60%

   C. 75%

   D. 90%

7. Ecological stress becomes apparent when impervious cover in a watershed reaches between:

   A. 40-50%

   B. 30-40%

   C. 20-30 acres

   D. 10-25%

8. Increased peak discharges for a developed watershed can be how many times higher than an undisturbed watershed?

2g. Social and Economic Impacts of Unmanaged Stormwater

The effects of unmanged stormwater runoff due to land development are not only environmental, but also have very real social and economic impacts on Virginia's communities. These include the following, some of which have been mentioned above:

- ***Endangerment of human life from floodwaters***.
    - The hydrologic changes in a watershed (leading to increased runoff peak flows and volumes) can potentially overwhelm under-designed stormwater drainage facilities, structural controls and downstream conveyances, putting human life and property at risk.
    - Floodwaters can cause driving hazards by overtopping roadways and washing out bridges, as well as carrying sediment and debris onto streets and highways.
- ***Property and structural damage due to flooding*.**
    - Upstream development extends floodplains and risk to property damage previously located outside the 100-year floodplain.
    - Increased occurrences and severity of flooding create more risk.
    - Increased property and infrastructure damage can also result from stream channel widening, undersized runoff storage and conveyance facilities, and development in the floodplain.
- ***Loss of Reservoir Capacity.***
    - Sediment deposition in lakes and reservoirs gradually displaces storage capacity and water supply volume.
- ***Impairment of Drinking Water Supplies (Surface and Groundwater).***
    - Water quality degradation from polluted stormwater runoff can contaminate both surface and groundwater drinking water supplies and potentially reduce the availability of this resource.

- ***Increased Cost of Treating Drinking Water.***
  - Even if a drinking water supply remains viable, heavy concentrations of contaminants such as sediment and bacteria can increase the costs of water treatment to a community and water customers.
- ***Increased Cost of Remediating Pollution and Other Damages.***
  - Degraded water bodies and exceedences of state water quality standards necessitate expensive remediation projects.
  - Example: Hundreds of millions of dollars have been spent over the past 25 years for the Chesapeake Bay Program, which still has a long way to go to achieve a truly restored Bay.
- ***Loss of Recreational Opportunities on Streams, Lakes, Rivers and Ocean Beaches*.**
  - Turbidity from sediment, odors, floating trash, toxic pollutants and microbial contamination from stormwater runoff all reduce the viability of water bodies for recreational activities such as swimming, boating and fishing.
  - Aesthetic loss along these waterways reduces public enjoyment (eg. non-contact recreation such as picnicking, jogging, biking, camping and hunting).
- ***Declining Property Values of Waterfront Homes and Businesses.***
  - As water quality and/or aesthetic values of water bodies decrease, so does desirability of working, living, travelling or owning property nearby.
  - For example, shoreline and bank erosion diminish property values.
- ***Loss of Sport and Commercial Fisheries.***
  - Polluted water bodies in Virginia have lead to numerous fish consumption health advisories, can lead to fish losses directly and through degradation of fish habitat.
  - Commercial fisheries, a significant part of Virginia's economy, can quickly decline when water quality declines.

  - In 1989 the USEPA estimated that stormwater runoff costs the commercial fish and shellfish industries approximately $17 million to $31 million per year.
  - High levels of nutrients associated with stormwater runoff have been linked to fish kills caused by toxic algal blooms (one species in particular). It is estimated that the Chesapeake Bay seafood industry lost $43 million in 1997, and the recreational fishing industry $4.3 million, due to this one species.

- ***Closure of Shellfish Harvesting Areas.***
  - Bacterial contamination due to urban stormwater runoff has made many of Virginia's estuaries *unsafe* for shellfish consumption.

- ***Increased Litigation.***
  - Increased legal action can result against local governments that have not adequately addressed stormwater runoff drainage and water quality problems or against developers or private citizens who do not comply with stormwater management requirements.

Knowledge Check

9. Beneficial uses for the Chesapeake Bay include:

   A. Swimming and sport fishing

   B. Human consumption of fish or shellfish

   C. A depository for excess nutrients

   D. A. and B.

   E. All of the above

2h. Managing Stormwater and Rainwater Harvesting

What are the problems with stormwater runoff?

High Stormwater Volume and Velocity

- More impervious surfaces lead to less ground infiltration, more higher energy runoff
- Increased stream volumes and flow rates, flooding, more erosion

Pollutants in Stormwater Runoff

- Pollutants transported untreated to our waterways (nutrients, sediments, toxics, litter, debris, bacteria and pathogens, higher water temps)

Ecological Impacts

- Altered or lost habitats (aquatic, riparian)
- Reduced species richness and diversity
- Shift in ecological balance (aquatic food sources, opportunistic species)

Loss of Beneficial Uses

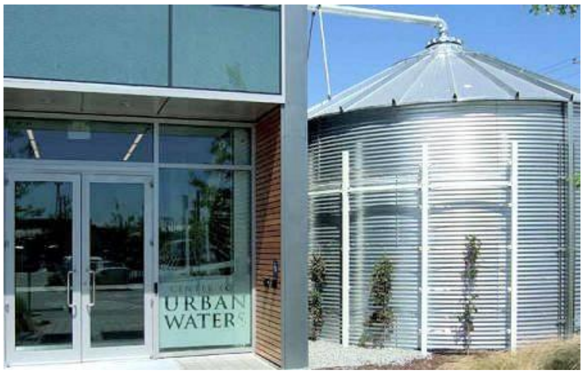
- Reduction in desirable fish species
- Shellfish contamination
- Contamination of drinking water sources
- Contamination of swimming beaches
- Loss of recreation and aesthetic value of state waters

What do we do?

How has our approach changed over time?

Stormwater as a valuable resource:

As changing precipitation patterns and human influences alter the hydrologic cycle, it is more important than ever to make smart and conscientious use of water supplies. Recycling or reusing stormwater ***(rainwater harvesting)*** presents a tremendous opportunity to do just that.



Stormwater harvesting is encouraged in the Virginia Stormwater Management Program Regulations (9VAC25-870-74) [Module 4]

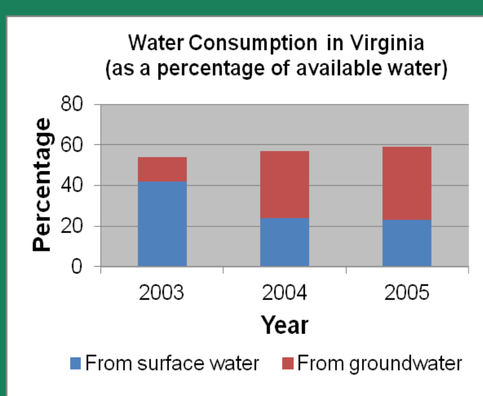
&

Is included as one of Virginia's non-proprietary BMPs [Module 6]

Why is this important?

Water Demand → **Water Supply**

- Virginia's water consumption continually increasing while population growing (**Figure 41**)



- Overall global water consumption outpacing population growth

Figure 41. Virginia water consumption

- Water treatment plants struggling to keep up with current demands
- More runoff = Less groundwater
- Decreased stream base flow (and clean water supply)

Why rainwater harvesting?

rainwater harvesting is a sustainable approach with the added benefit of providing an alternative water source

- Excellent alternative non-potable water source
  - affordable
  - cost-effective
  - simple
  - reliable
  - sustainable
- Reduction in water consumption (and associated costs) – costs will continue to rise with decreasing supply and increasing demand
- Less stormwater runoff needing treatment prior to off-site discharge
- Use can reduce damaging delivery of site runoff to surface waters (erosion potential and nonpoint pollution source)
- Rainwater typically softer than tap water – less detergent needed for laundry and other types of washing
- Can be treated (e.g. reverse osmosis, etc.) for potable uses

Where can it be used?

- Large commercial and industrial buildings (*diverted from flat roofs to onsite storage tanks or pond*; used for toilet flushing, laundry, cleaning, fire suppression, cooling towers, industrial processes, landscape supplementary irrigation)
- Homes (*rain barrels, cisterns*; used for toilet flushing, laundry, fill swimming pools, vehicle and home power-washing, watering lawns-borders-gardens)

Proactive efforts to both protect property and the environment and conserve water are beneficial now and in the future

What next?

- Stormwater runoff reduction via Low Impact Development (LID) practices are being required for new developments in Virginia and other states (state and local authorities)
- Virginia building codes and health regulations are currently being reviewed to enable more extensive use of rainwater harvesting options

How do we do it?

- Take proactive approaches (before, during, and after land development)
- Move beyond less effective traditional stormwater management approaches
- Control flooding and erosion
- Prevent hazardous materials from polluting environment
- Construct stormwater systems/utilize effective BMPs to remove contaminants and detain/slow down stormwater runoff
- Protect natural waterways
- Focus on maintaining the natural land conditions
- Educate communities about how they can improve water quality and what the benefits are of doing so

Creating beneficial uses for stormwater ultimately:

- *Serves to minimize impacts from urban and developed runoff rates and volumes*
- *Decreases reliance and demand on progressively stressed groundwater and surface water sources*
- *Provides time needed for these stressed sources to replenish and allow for future sustainable use*

Example: Orlando, FL current runoff volumes exceed resident annual water demand by over 50%

(see 2013 Virginia Stormwater Management Handbook, Chapter 4, Section 4.4.

Additional Resources:

The Cabell Brand Center in Salem, Virginia, has produced the *Virginia Rainwater Harvesting Manual 2007*, which details the benefits of rainwater harvesting, both economical and environmental.

http://www.cabellbrandcenter.org/Downloads/RWH_Manual2009.pdf

Virginia developed a new Rainwater Harvesting best management practice design specification (discussed more in **Chapter 8** of the 2013 Virginia Stormwater Management Handbook) and provides a spreadsheet tool for sizing and designing rain storage cisterns, which can be found at the following web URL:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html .

2i. The Economic Benefits of Effective Stormwater Management

The economic value of the Chesapeake Bay is estimated to be nearly **$1 trillion** to the economies of Virginia and Maryland through commercial fishing, marine trade, water recreation and tourism, port activities, and land values.

There are two types of economic benefits of implementing sound stormwater management regulations and programs:

(1) Income generated by economic activities that rely on water and related natural resources; and

(2) A reduction in or avoidance of costs which may result from environmental degradation and consumption of natural resources. These benefits are listed in **Table 2-6** below.

Table 2-6

Economic Benefits of Sound Stormwater Management

Watershed Protection Tool	Economic Benefit
Open Space Protection – forest conservation, wetland protection, preservation of parkland and open space	• Income from recreation and tourism • Increased property values • Reduction of energy costs, health care costs, flood control and stormwater quality and quantity treatment costs
Aquatic Buffers – Resource Protection Areas, stream buffers	• Enhanced aquatic habitat • Income from fishing • Increased property values • Reduction of flood control and stormwater quality and quantity treatment costs • Reduction of stream channel erosion and related degradation • Reduction of stream restoration costs
Environmental Site Design – cluster development, reduction of impervious cover, natural stormwater conveyances	• Increased property values • Reduction of construction, maintenance, and infrastructure costs • Reduction of flood control and stormwater quality and quantity treatment costs
Erosion and Sediment Control – channel protection, limiting clearing and grading, construction site erosion and sediment control	• Reduction of dredging costs • Improved income from marine and port activities • Reduction of drinking water treatment costs • Increased property values • Reduction of construction costs • Reduction of stream restoration costs
Stormwater Management Practices – stormwater management regulations, floodplain protection, etc.	• Increased property values • Reduction of flood damage costs • Reduction of flood control costs • Reduction of stream channel erosion and related degradation • Reduction of stream restoration costs • Improved water quality in our streams and rivers • Protected or improved aquatic habitat • Enhanced recreational opportunities • Lower water supply and laundry supply costs

Source: Adapted from DCR and CWP-2001

Knowledge Check

10. Rainwater harvesting presents an option that could alleviate pressures on water supplies in Virginia. What are some of these pressures?

11. How does increasing surface runoff change groundwater recharge rates?