Module 2: Fundamentals of Erosion and Runoff

Learning Objectives

At the end of this module, you will be able to:

- Define soil erosion
- Distinguish between accelerated erosion and geologic erosion
- Identify the five stages of erosion
- Discuss the four factors that influence erosion
- Describe how stormwater runoff can lead to erosion on construction sites
- Summarize the negative impacts of sediment in our waterways
- Discuss the principles of erosion and sediment control

2a. Erosion Defined

Soil erosion is the removal and transportation of soil particles by erosive forces, such as water, wind, ice, and gravity. Erosion is an important contributor to landscape formation by wearing away mountains; filling valleys; and creating sandbars, islands, and coastal plains. We refer to this as ***geologic erosion*** (Figure 1).

Figure 1: Example of geologic erosion

Bryce Canyon (UT)

Figure 2: Example of accelerated erosion

With sediment deposition from a construction site

NOTE

Geologic erosion accounts for 30% of total sediment production. Accelerated erosion accounts for 70%.

Erosion is a natural process, but in many places, it is ***accelerated*** by human activities that disturb the soil (Figure 2). For example, stream channels have been irreversibly changed because of agricultural practices dating back to the 1800s and early 1900s. At that time, forestland was cleared, leaving less vegetation to hold the soil in place. As a result, agricultural sediment yields increased (Wolman and Shick, 1967). Sediment yields increased again in the 1960s when rural areas near cities became urbanized (Figure 3).

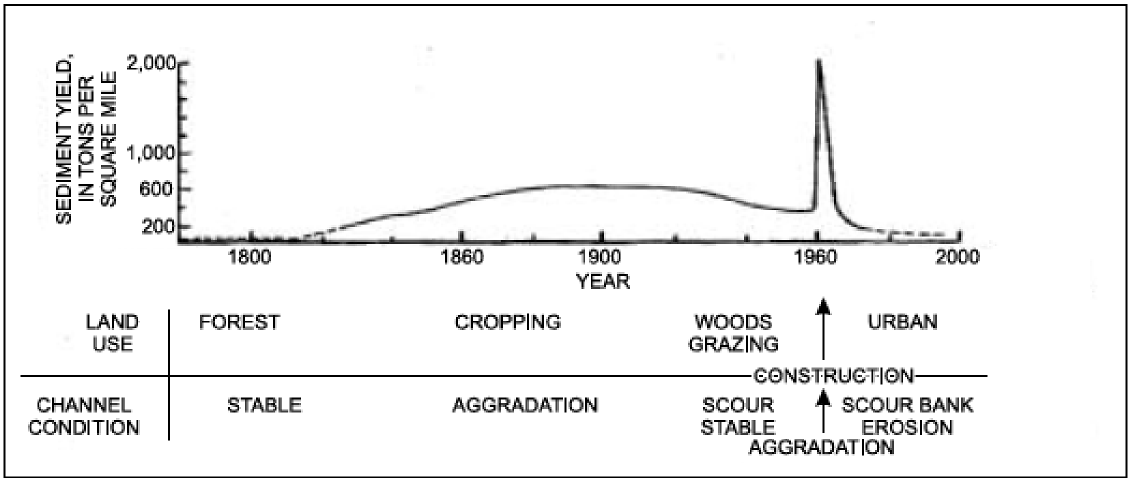


Figure 3: Land-use history and sediment yield from the Potomac River Basin from the late 1700s to the 1960s, projected to approximately 2000 (from Wolman and Shick, 1967).

Figure 4 shows the evolution of a stream channel through the agricultural period's increase in sediment and the widening that occurred because of increased urban runoff as present-day major cities were established.

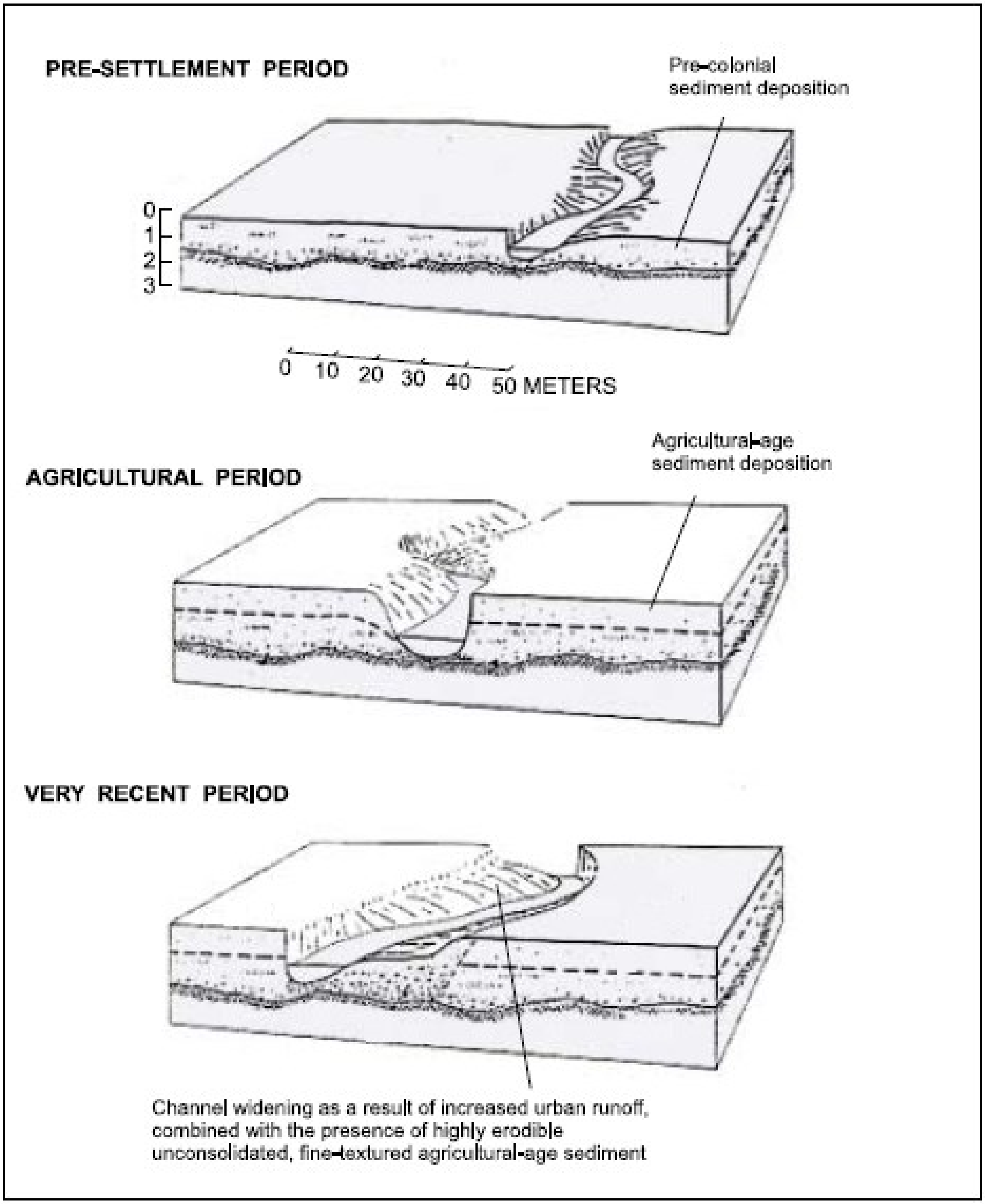


Figure 4: Floodplain stratigraphy observed by Jacobsen and Coleman, partitioned into three defining periods of sedimentation (Modified from Jacobsen and Coleman, 1986).

As discussed in Module 1, the amount of sediment that leaves a construction site is much higher than other types of land-disturbing activities, largely due to the nature of the construction process and methods used on a typical construction site. When a site is stripped of vegetative groundcover and topsoil (Figure 5), the remaining sub-soil is more susceptible to erosion.

Figure 5: Typical construction site

Photo credit: DEQ

FIVE STAGES OF SOIL EROSION

There are five stages at which soil can erode, based on the amount of water carried across denuded soil:

1. Raindrop impact
2. Sheet erosion
3. Rill erosion
4. Gully erosion
5. Channel erosion

(1) Raindrop impact is the first effect of rain on the soil – dislodging soil particles and splashing them into the air (Figure 6). The detached particles can be easily picked up by water flowing over a site. Of the five types of erosion, raindrop erosion is the most significant in the erosion process. Raindrop impact produces two damaging effects:

- The detachment of soil particles and
- Sealing of the soil's surface.

Figure 6: Raindrops impact the soil as little bombs.

NOTE

The action of falling rain on disturbed or denuded soil is responsible for 90% or more of total soil erosion.

The erosive capacity of rainfall comes from the energy of its motion, or *kinetic energy*.

The magnitude of this energy is dependent on the amount and intensity of rainfall, raindrop diameter, and raindrop velocity.

All rain events contain drops of various sizes. In Virginia, the most erosive rains are concentrated during the months of May through September because of their higher intensities, larger raindrops, and shorter durations (Table 1 and Table 2). ***This is also when land disturbance (construction) is typically most active.*** Precipitation in the winter generally falls as a finer mist with much less energy, causing less erosion.

Table 1: Precipitation Amounts by Month (Richmond, VA)

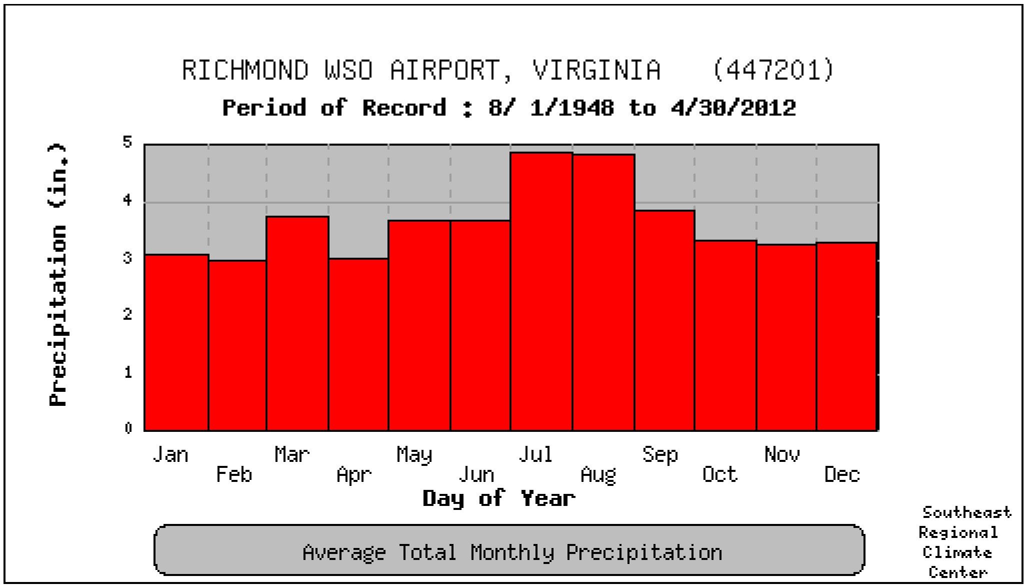
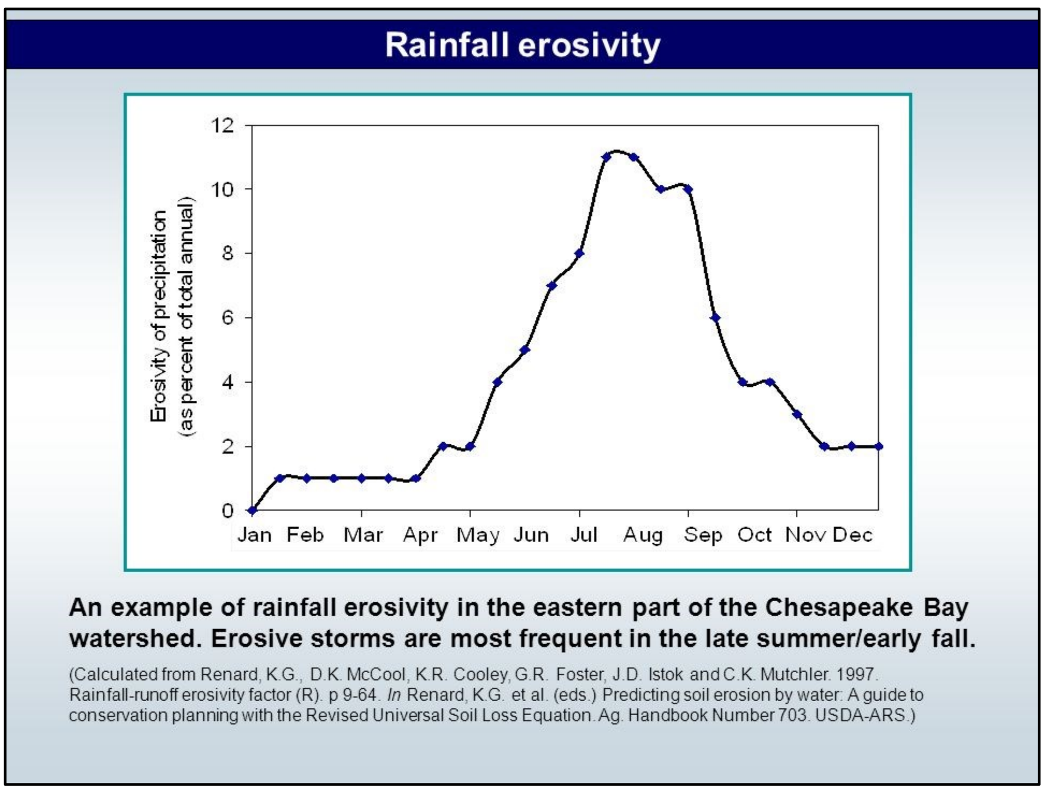


Table 2: Rainfall Erosivity by Month



Another damaging effect of raindrops is the compacting, puddling, and sealing of the soil surface. Repeated strikes churn the surface into a slurry, which seals the pore spaces in the soil, preventing water infiltration. As they continue to pound the land, raindrops will also compact the bare soil, forming an almost complete seal. Even on coarse sandy soil, this action reduces the infiltration of water into the soil and leads to increased erosion and runoff.

Figure 7: Sediment-laden water and raindrop impact are slowly sealing the soil across this construction site.

(2) Sheet erosion is the second stage of erosion. The soil's ability to infiltrate water is exceeded, and water starts to run across the surface of the soil (sheet flow). Although sheet erosion seldom detaches soil particles, the dislodged soil particles are transported by sheet flow.

Figure 8: Example of sheet erosion

Sediment-laden water flowing across a roadbed

(3) Rill erosion begins when shallow sheet flow begins to concentrate in low spots. As the flow changes from sheet flow to deeper flow in these low areas, the velocity and turbulence increase. The energy of this concentrated flow detaches and transports soil material, cutting tiny channels, or rills, that are only a few inches deep. At this stage, hand tools or other surface treatments will easily repair erosion damage.

Figure 9: Rill erosion can be easily repaired.

(4) Gully erosion occurs when rills converge to form larger channels or gullies. The major difference between gully and rill erosion is size. Gullies are too large to be restored with conventional tillage equipment and usually require heavy equipment to repair.

Figure 10: Gully erosion has larger, more difficult to repair cuts than rill erosion.

(5) Channel erosion can occur in two ways:

1. When gullies are not repaired in time and large volumes of water increase the size of the gully and
2. In existing streams or drainage ways when the volume and velocity of flow destroys the structural integrity of streambeds and banks.

Typically, you can observe vertical sides and downcutting of the receiving channel.

Figure 11: Channel erosion can have vertical sides.

FOUR FACTORS INFLUENCING EROSION

The stages of erosion discussed above can all be correlated back to the four factors that influence erosion:

1. Climate
2. Groundcover
3. Soil properties
4. Topography

(1) Climatic factors influencing erosion include precipitation type (rain, snow, etc.); rainfall intensity and raindrop size; location; snowmelt; and temperature extremes (freezing, excessive heat, etc.).

On page 7, we discussed how raindrops are responsible for 90% of the erosion that occurs on a site and that summer storms are generally more intense and more erosive because of their higher intensities and shorter durations (Table 2, Page 8).

A one-inch precipitation event will also vary in intensity depending upon location across the state.

(2) Groundcover is perhaps the most important factor in reducing erosion. As discussed earlier in this chapter, the size of raindrops and the speed by which they hit the soil are among the most important factors influencing erosion. Research has shown that erosion potential is directly proportional to the amount of bare soil exposed to raindrop impact. Groundcover, such as vegetation or mulches, slows down the velocity of the raindrops by intercepting them on leaves, branches, and stalks and by breaking them up into smaller drops.

> The most cost-effective and protective measure in controlling erosion from a site is to preserve existing vegetation.

While vegetative cover is ideal, the use of any surface cover material, including mulch, blankets, or matting, can reduce soil erosion by 90-99% (Table 3).

Table 3: Effectiveness of Various Groundcovers in Preventing Soil Erosion

This table compares fully established stands of groundcover with bare soil

Type of Groundcover	Percent Reduction
Permanent grass	99
Perennial ryegrass	95
Annual ryegrass	90
Small grains	95
Millet or Sudan grass	95
Field bromegrass	97
Grass sod	99
Hay or straw (@2 tons/acre)	98

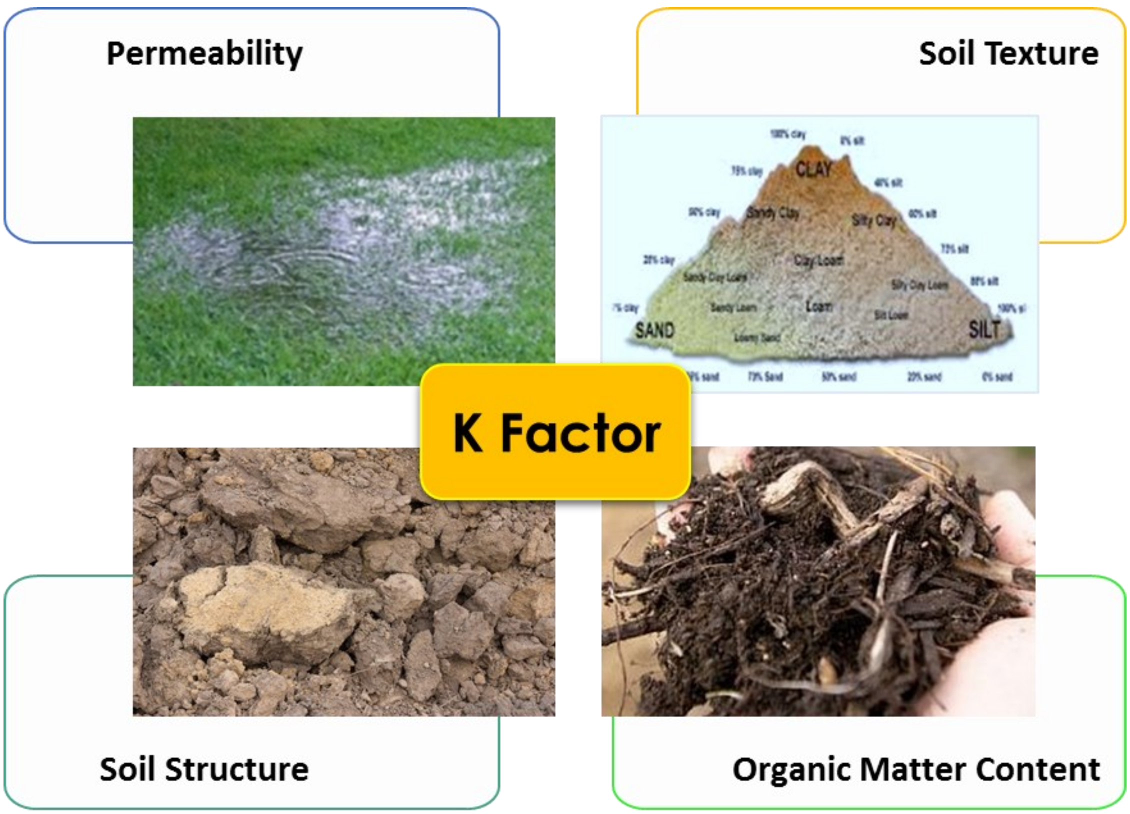
(3) Soil properties are also important factors when looking at the erodibility of a site. Key soil properties include:

- Soil structure (soil particles adhere to each other)
- Soil texture (the size of the particles in the soil)
- Bulk density (how tightly those particles are packed together)

- Percentage of organic matter
- Infiltration rate (the speed by which water enters the soil)
- Permeability rate (the speed by which water moves through the soil)

Under similar climatic, topographic, and vegetative conditions, different soils may erode at different rates. These differences in erosion rates can be tenfold and are caused by differences in soil characteristics. The susceptibility of a particular soil to erosion is called its **erodibility factor,** or **K factor**. In addition to susceptibility of the soil to erosion, the soil erodibility factor (K) is used to represent the rate of runoff.

Soil properties used to develop a K factor include:



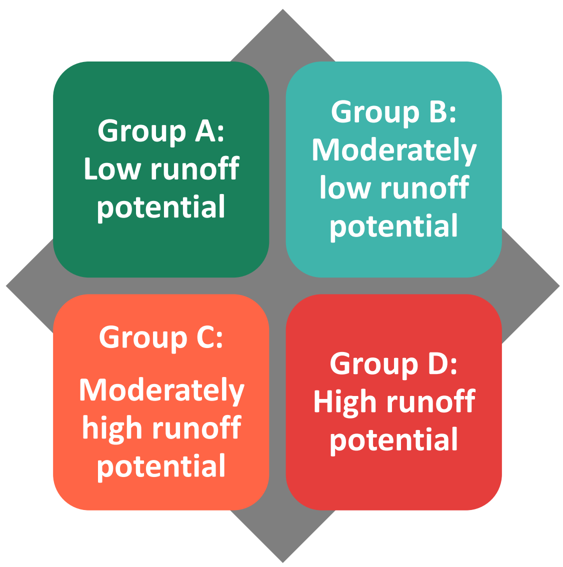
The higher the K factor value, the more susceptible the soil is to erosion.

K factors can be grouped into three general ranges:

0.23 or lower	-	Low erodibility
0.24 to 0.36	-	Moderate erodibility
0.37 or higher	-	High erodibility

The K factor of a soil can be found in various sources, including a county soil survey and online at the Natural Resources Conservation Service (NRCS) web soil survey (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

The NRCS has also developed a soil classification system that consists of four hydrologic soil groups (HSG), identified as A, B, C, and D. Soils are classified into one of these categories based upon their minimum infiltration rate. Soil characteristics associated with each HSG are generally described as follows:



Group A: Soils with low runoff potential due to high infiltration rates, even when thoroughly wetted. These soils consist primarily of deep, well to excessively drained sands and gravels with high water transmission rates (0.30 inches per hour or in/hr.). Group A soils include sand, loamy sand, or sandy loam.

Group B: Soils with moderately low runoff potential due to moderate infiltration rates when thoroughly wetted. These soils consist primarily of moderately deep to deep, and moderately well to well-drained soils. Group B soils have moderate water transmission rates (0.15-0.30 in/hr.) and include silt loam or loam.

Group C: Soils with moderately high runoff potential due to slow infiltration rates when thoroughly wetted. These soils typically have a layer near the surface that impedes the downward movement of water or soils. Group C soils have low water transmission rates (0.05-0.15 in/hr.) and include sandy clay loam.

Group D: Soils with high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material. Group D soils have very low water transmission rates (0-0.05 in/hr.) and include clay loam, silty clay loam, sandy clay, silty clay, or clay.

(4) Topographic features that influence site erodibility include *slope grade, length, shape,* and *orientation.*

Slope steepness, or *grade,* influences erosion in two ways. First, water will flow faster as the length and angle of a slope increase. Second, there is more "splash effect" on steeper slopes.

These principles are the reason for the grouping of slope gradients into three general ranges of soil erodibility (Table 4).

Table 4: Relationship between Slope Gradient and Erosion Hazard

Slope gradient	Erosion hazard
0-7%	Low
7-15%	Moderate
15% & over	High

Increasing *slope length* will increase the velocity of runoff, further increasing the potential for erosion on disturbed soils.

The primary topographic considerations for erosion potential of a slope are its length and steepness. Table 5 provides the critical slope length for different slope gradient ranges.

Table 5: Slope Gradient and Length Combinations at Which the Erosion Hazard Will Become Critical

Slope gradient	Slope length
0-7%	300 feet (100 meters)
7-15%	150 feet (50 meters)
15-25%	75 feet (25 meters)
25% & over	0 feet (0 meters)

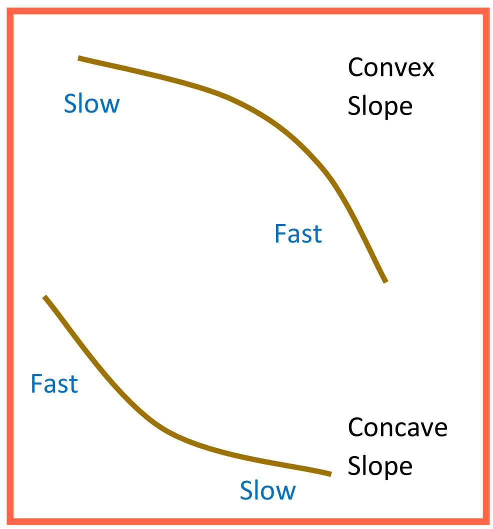
> The combination of slope length and steepness will create a point on the slope where water volume and velocity will begin to form rills and gullies if adequate ESC practices are not used.

Slope shape also affects erosion potential.

Convex slopes are steeper at the lower end and tend to be constructed.

Concave slopes flatten at the lower end and tend to be naturally occurring.

Erosion will be more likely on convex and less likely on concave slopes than what would be expected if the effect were calculated based on an average grade.



Slope orientation, or *aspect,* also affects erosion. South and southwest facing slopes are usually warmer and drier because of sun exposure and exposure to warmer winds. Therefore, the vegetation on these slopes may be sparse, and establishment of new vegetation on south and southwest facing slopes is generally more difficult than northern slopes. Conversely, northern slopes are cooler, less exposed to the sun, and usually hold more moisture; therefore, they have different challenges in establishing vegetation.

2b. Stormwater Runoff

Runoff occurs when the rate of rainfall exceeds the infiltration capacity of the soil. Runoff can begin quickly after it starts raining. The quantity of runoff and erosive capacity of that runoff depends on the amount of disturbance, groundcover, and capacity of soil to infiltrate water. Runoff on the soil surface gains energy as it begins to run down slopes and moves faster across impervious surfaces like compacted soils, roofs, driveways, sidewalks, and roads.

In the early stages of construction, the major potential for damage caused by stormwater runoff is the ability of runoff to transport loose soil particles.

Sediment-laden stormwater runoff can lead to:

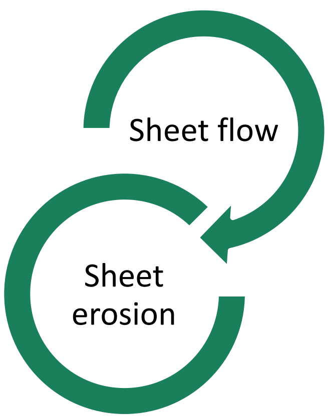
- Sediment deposition on land and in waterways,
- In-stream erosion, and
- Flooding, resulting in property damage.

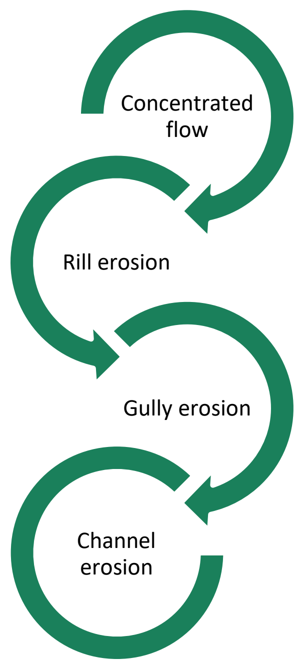

Figures 12 and 13: Construction site erosion and runoff

Source: Chesapeake Bay Stormwater Training Partnership

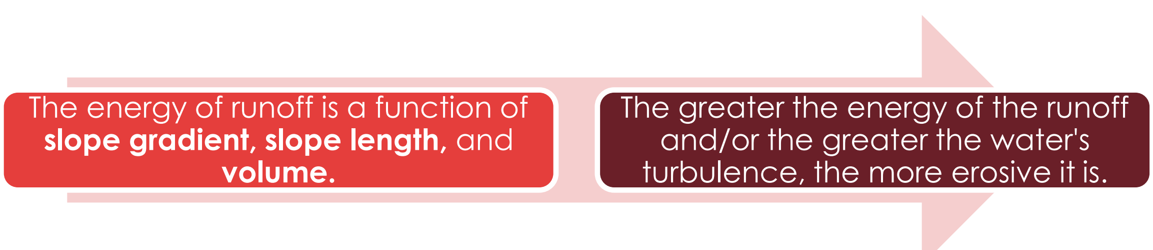
Runoff initially presents itself as **sheet flow**, a shallow layer of water flowing more or less uniformly over the land. Sheet flow can effectively transport sediment particles kept in suspension from the action of falling raindrops on a disturbed area.

Concentrated flow is a result of the depth of sheet flow and irregularities in the soil surface, such as low spots, depressions, rocks, plant stems, and roots. Runoff concentrated in tiny rills may then expand into larger gullies, acquiring more energy to detach and transport soil particles. As the volume of water increases, the velocity and turbulence also increase, dislodging additional soil particles. These suspended soil particles strike and abrade the soil's surface and channel beds like sandpaper, causing more soil particles to detach and mobilize, even further increasing the abrasive force.





Additionally, as slope length and steepness increase, the depth of runoff increases; hence, the velocity also increases.



WATER QUALITY

Stormwater runoff that flows across polluted land surfaces, such as construction sites or residential and/or commercial developments, is considered *non-point source (NPS)* pollution. NPS pollution is the primary cause of pollution and water quality impairments in our waterways.

Erosion from construction sites and other disturbed areas can potentially contribute large amounts of sediment to streams. In addition to sediment, as stormwater runoff moves across the land surface, it picks up many natural and human-made pollutants, before depositing them into Virginia's waters.

Excess sediment is also harmful for the following reasons:

- Sediment shades the lower layer of the waterway and weakens or kills the aquatic vegetation, which oxygenate the water and serve as cover for young fish and other aquatic organisms
- Sediment and contaminants in the water plug gills of fish and other aquatic organisms, thus weakening and/or killing them or exert other toxic effects
- Sediment settles in waterways and smothers spawning beds, oyster reefs, crab habitats, etc.
- Stocks of fish, oysters, and crabs decline and reduce the income of commercial watermen and sports fishermen, thereby hurting the economy of the region

Figure 14: A Sediment Plume Entering a River

Source: ARC (2001)

Virginia ranks stormwater runoff as the ***second most prevalent source of water quality impairment*** in the state's estuaries. Agriculture is currently ranked number one, which follows the national trend.

QUANTIFYING EROSION AND SEDIMENT CONTROL

The U.S. Environmental Protection Agency estimates that 20 to 150 tons of soil per acre are lost every year to stormwater runoff from construction sites. Some of this sediment will settle onto neighboring properties, but most of it will enter stream channels. A portion of the sediment will settle into drinking water reservoirs while the remainder will be carried as far away from Virginia as the Gulf of Mexico, via the Mississippi River. When this sediment fills up drinking water reservoirs, the water is displaced, causing the reservoir to lose capacity (Figure 15), becoming a concern in times of drought. The cost to treat the water before it reaches the faucet is also increased. In addition, significant costs can be incurred to dredge the reservoir to return it to full capacity.

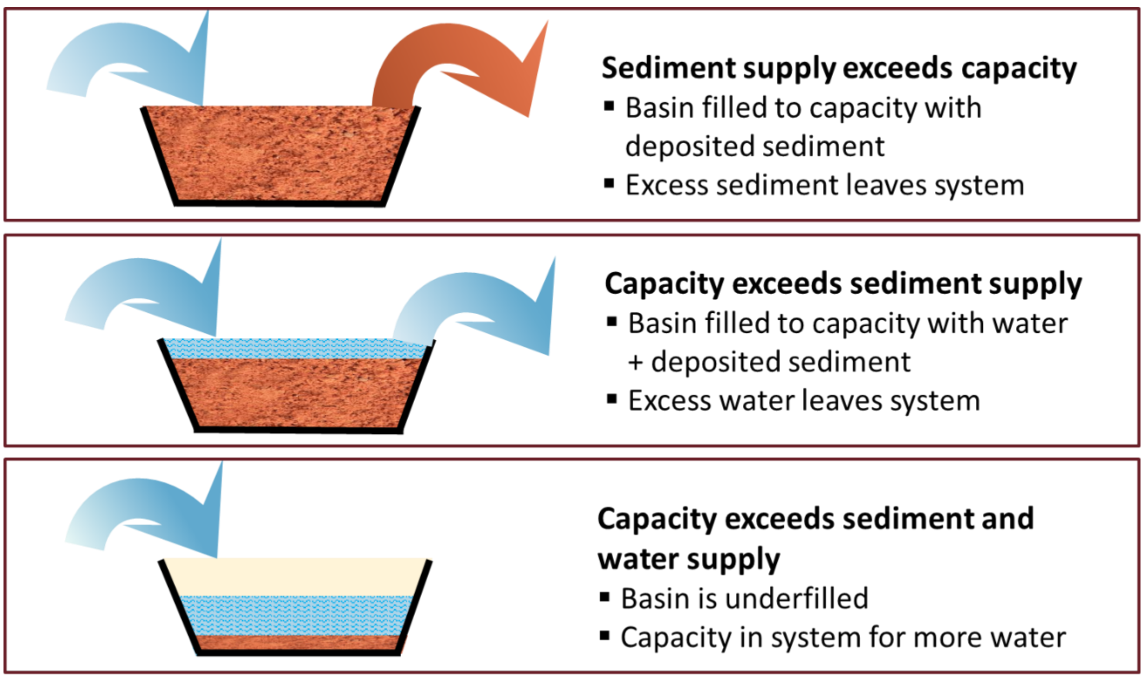


Figure 15: Cross-sections on the left show that when sediment fills reservoirs, the capacity remaining for water is greatly reduced, if not completely lost. (Columbia)

Sediment will also block shipping channels. As of May 2012, vessels carry 53% of U.S. imports and 38% of exports (U.S. Department of Commerce, Merchandise Trade). Norfolk was the fifth busiest port in the nation in 2013. In late 2017, the U.S. Army Corps of Engineers awarded the contract to deepen the final portion of the Delaware River by five feet, at a cost of $50.2 million. The Delaware River Main Channel Deepening project has taken seven years to provide a deeper channel for more efficient transportation of cargo ships to and from the Delaware River ports. Assuming the cost of each of the 10 portions dredged was $50 million, that's $500 million to deepen the river from Philadelphia to the Delaware Bay – about 43 river miles! Dredging costs can also increase exponentially when it involves excavating contaminated or otherwise toxic sediment because special handling and disposal procedures must be followed.

Figure 16: Cutter suction dredger *Charleston* prepared for maintenance dredging on the upper Delaware River

Source: Norfolk Dredging Company, owner of the *Charleston*

Sediment accumulation is costly to remove, as well as creates safety hazards to vessels and the public. The cost of these dredging operations will be passed on to the consumer at some point, either directly by utility companies or indirectly through purchasing costs of the goods brought through shipping channels. It pays to keep sediment on-site and out of our waterways.

2c. Principles of Erosion and Sediment Control

The Virginia erosion programs target ***accelerated erosion*.** More specifically, as the title of this section indicates, the programs address:

1. Erosion control
2. Sediment control

> The two principles of erosion and sediment control work together to accomplish the main goal of **keeping sediment on the site**.
>
> If we can control erosion, we can effectively control sediment.

The order – *erosion* and *sediment* control – was chosen for a reason. Erosion control is often considered a first line of defense. If we can control erosion, there is less sediment to be managed by structural controls.

Sediment control is considered a second line of defense. It catches the sediment from areas where erosion controls could not be installed or where they failed to work properly. Sediment control is always necessary on land disturbance projects since, by definition, a site can never be completely stabilized when land disturbance takes place.

Erosion control is generally less costly than installing sediment control measures and, therefore, reduces the overall cost of the project. Even when structural controls are required, minimizing erosion will greatly reduce the number of structures and associated maintenance, which also reduces project costs.

Vegetative Erosion Control
1st Line of Defense

Inexpensive
Easy to install

Structural Sediment Control
2nd Line of Defense

Expensive
Require maintenance

Summary

As an inspector, it is important to be able to:

- Identify soil erosion on construction sites and understand how and why erosion has occurred. The ability of the inspector to explain these processes to the regulated community will enhance their efforts to minimize poor practices.
- Explain to the regulated community how and why good erosion and sediment control practices should be used to promote compliance with the erosion program. If the inspector can identify and describe which practices are best used on a site, this assists operators and owners towards compliance and often overall cost savings.

Knowledge Check Questions

1. Which stage of erosion accounts for the highest erosion percentage?
    a. Rill
    b. Raindrops
    c. Sheet flow
    d. Gully
2. In which month would precipitation intensity have the greatest impact on soil?
    a. Oct.
    b. July
    c. Feb.
    d. About the same
3. Vegetative controls are ________ costly than structural controls.
    a. More
    b. Less