NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Losing the Farm:
How Changes in Land Surface Affect Storm Runoff

by
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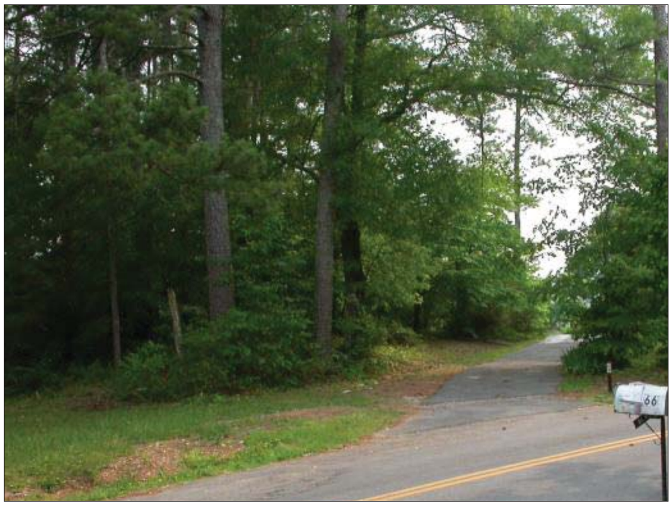
Part I – Leala's Old Farm



Leala and Jake raised their son, Jimmy, on Leala's family farm in north Georgia. Jake built their modest home in the 1940s from recycled pieces of an old schoolhouse that were on the site.

Summers in north Georgia are usually "green" because of high annual precipitation, about 53 inches. No one plowed the fields for several years and, through ecological succession, the fields grew into pine forest. Leala's 30-acre property became filled with mixed hardwood trees and young pine forest. All soil was covered with vegetation and forest litter. The long driveway was through native loblolly pines and large oak trees.

The old farm's soil is typical for this area and is locally called "Georgia red clay," a fairly poor-quality silty clay. After a rain, the soil is "sticky," and low spots can hold puddles for days.

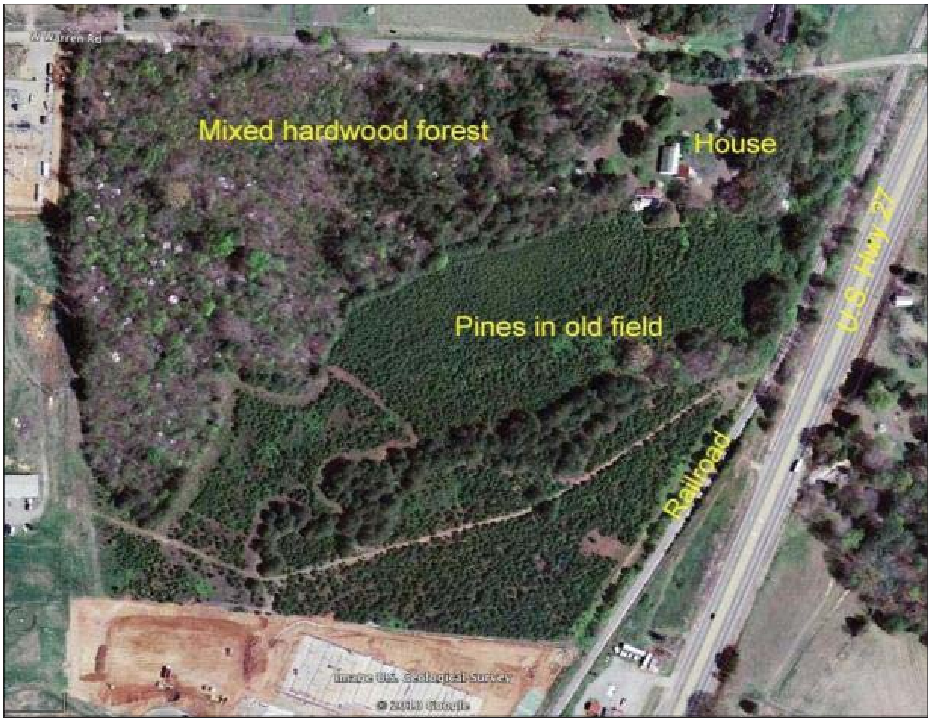
The former farm is actually a small watershed. The west side (pictured on the left side of the aerial image on next page) is a ridge crest, and the land slopes northeastward (to the right) to the lowest spot on the property, below the house. In this northeast corner, all surface drainage exits the property through a single pipe under the railroad and highway, into a natural creek east of the highway.

Questions

1. What characteristics of the farm may factor into how much water is retained or will run off during a rain/storm event?
2. Rainfall runoff is water that doesn't soak into the ground or that gets trapped on plants or in surface puddles. It runs downhill off the land into streams. In the Southeast, one inch of rainfall or more during a day is common. What differences in runoff would you expect between one inch of rain that falls as light rain over a 24-hour period at the farm compared with a one-inch rainfall that occurs during a one-hour storm?

The U.S. Soil Conservation Service (SCS), now named the U.S. Natural Resources Conservation Service (NRCS), developed a widely-used method of determining the volume of storm runoff from different land surfaces. This calculation method is detailed in the Addendum to this case study and is used in Question 3 below.

3. How much water, in cubic feet, would a pond in the northeast corner of the farm property have to hold below its spill point to catch all the runoff from a one-hour storm? Use the U.S. Soil Conservation Service (SCS) method for calculating storm runoff volume to determine the pond size. Assumption: average antecedent soil moisture condition (not wet, not dry).



Part II – If You Build It, They Will Come

Jimmy inherited the old farm in 2006. Like many sons and daughters who have grown up in rural areas and then graduated from college, Jimmy found he had to live in a metropolitan area in order to pursue his career. Jimmy and his wife now lived in Atlanta and had no need for his old home place. They decided that it was in their best interests to sell the property. Who do you think would buy such a place? A residential developer! "Mom would be proud that her dad's old farm would help with our kids' college tuitions," Jimmy told a long-time neighbor.

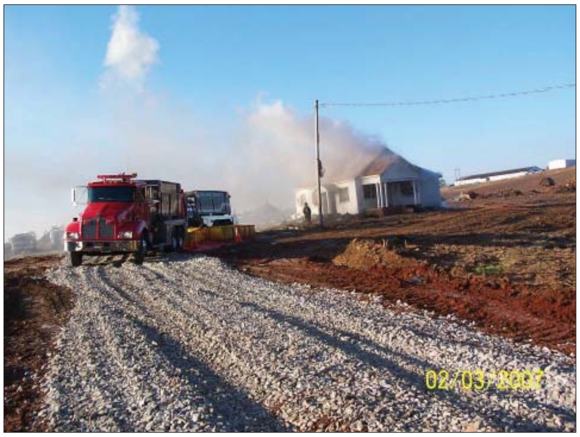
The developer had county-approved plans to pack the acreage with 128 small "affordable" single-family homes on 1/8 acre lots with small common areas, a project called Legacy Cove.

Questions

1. After Legacy Cove is completed with nice green lawns, what characteristics of the landscape, with respect to runoff, will be different from that of the original farm? Do you predict that the runoff from a storm event will be greater from the residential development or the original farm? How will the residential development influence the curve number as compared with that of the farm?
2. After the subdivision is built with houses, streets, and lawns, how would the volume of runoff from a similar 1-inch rain event compare with that which you calculated for the farm? What might be some consequences of this change downstream from the development?
3. What is a practical way to mitigate this change in runoff expected when Legacy Cove is completed?

Part III – Legacy Cove

Legacy Cove started in early 2007. How do you make a subdivision out of an old 30-acre farm? Completely clear all 30 acres and remove all vegetation. The larger trees were cut and sold for lumber while the smaller pines and shrubs were scraped into piles and burned. “When we’re done, it’ll look nice,” Alvin, the dozer operator, said to a concerned neighbor.

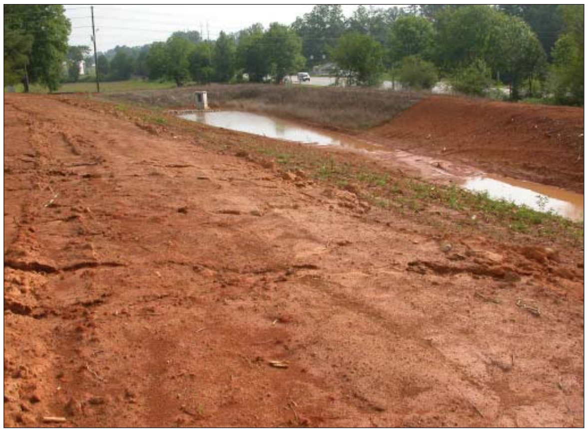


There was no place in Legacy Cove for the house that Jake had built out of the old schoolhouse. It had to go. The developer gave the home to the local fire department to burn as a fire rescue training exercise. The site of cheerful holidays came down quickly with billowing gray smoke. None of the family was there to watch; only disappointed friends.

By the end of 2007, all 30 acres lay naked on the side of a ridge. Red and brown dirt had been skillfully shaped into parcels where new homes and streets would be. As seen in a Google Earth image, the once green spot is now totally barren.

After the land was cleared and reshaped at the end of 2007, the developer never came back. The farm with its soil, forest, and field ecosystems had been destroyed for an expected profit and then abandoned. No homes, no streets, no lawns would be built. The legacy of Legacy Cove had changed. Alvin finally removed his equipment when it became obvious that he was not going to be paid by the developer.

As required by construction practices, Alvin had originally built a storm water catch basin in the northeast corner of the development to catch storm runoff from future lawns, roofs, and street pavement. This was the location of the hypothetical pond in Question 3 in Part I. A concrete drainage system had been built into the catch basin to allow storm water to drain out of the basin gradually. It was important not to overwhelm the natural creek into which the farm had drained.



Questions

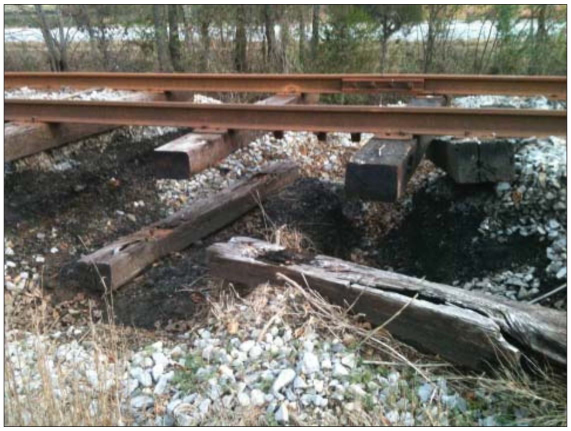
1. What do you predict is going to happen to the 30 acres of cleared dirt that has now been abandoned?
2. Would you predict that runoff from a one-inch storm event would be greater from the bare dirt or from the completed residential development?
3. How much runoff from a one-inch storm event will come from the abandoned dirt site?
4. How does your calculation for runoff from bare soil compare with the amount you calculated for Legacy Cove, which would have had grass lawns? Does that difference surprise you? Why is there such a difference?

Part IV – The Legacy of Legacy Cove

During 2008 and through much of 2009, the abandoned site suffered severe erosion. Much of the site lost soil. Gullies up to four-feet deep developed in the steeper slopes where the street beds had been. The catch basin totally filled with sediment, and its discharge plumbing system became overwhelmed and non-functional, totally clogged with sediment. Without any discharge from the basin, as little as 1 inch of rainfall could cause severe runoff and fill the catch basin to capacity.

And then came the night of September 20, 2009. An extraordinary rainfall event occurred in northwest Georgia. Over 9.1 inches of rain fell. The U.S Geological Survey called it a flood of "epic" proportions.

An 88-year-old neighbor said "I don't know if it was the hundred-year-flood, but I know that it was at least the eighty-eight-year flood. I've never seen anything like that here in my lifetime." The 9.1 inches of rain that collected on Legacy Cove's bare dirt washed away the dysfunctional catch basin's dam and then undermined the adjacent railroad bed. Even the highway was flooded and had to be closed for hours. Luckily, no one was injured.



Questions

1. How does the volume of runoff from 9.1 inches of rain compare with your calculation of runoff captured by a 1-in rain on the bare dirt?
2. Calculations for these soil types and soil land uses have been made assuming average, not wet nor dry, antecedent soil moisture. The extraordinary rainfall event actually fell on saturated soils because it had rained the preceding afternoon. How would the curve number of a saturated soil compare with the curve number of the same soil that is not saturated and of average moisture? How would the runoff calculation result be different from the one we have calculated above?

Part V – Stabilization

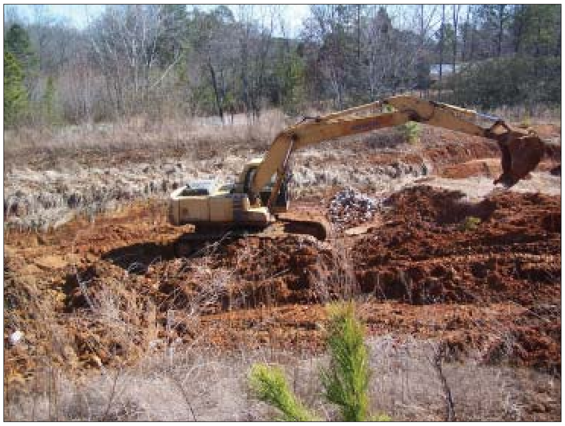
By the end of 2010, the developer's bank had foreclosed and taken possession of the property. Liabilities associated with uncontrolled erosion and sedimentation downstream became the bank's responsibility. The Georgia Division of Environmental Protection (EPD) had been pursuing legal action against the developer for not maintaining the catch basin and erosion control structures. In 2011, five years after the land was cleared, the EPD required the new owner, the bank, to take immediate action to stabilize the entire 30-acre site. The bank hired engineering and environmental consultants to rapidly stabilize the site so they could satisfy the EPD's requirements and put the property on the market.

Question

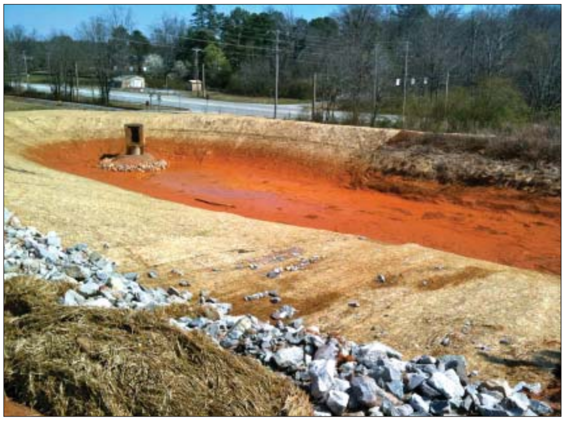
1. Based on what we have learned in this example about land surfaces and runoff relationships, what actions would you recommend to the bank, as their engineering or environmental consultant, in order to quickly stabilize the site as much as possible?

Part VI – The Remedy

In order to stabilize the site from erosion and to prevent sedimentation downstream, the Georgia EPD required the catch basin to be rebuilt and its drainage plumbing repaired. All sediment in the basin had to be removed and drainage piping had to be flushed out. The basin was completely rebuilt during 2011.



Steeper slopes were covered with woven straw mats to slow erosion and then seeded with a grass mixture. Natural drainage courses on steeper slopes were covered with cobbles to slow water flow across the surface.



In addition, the entire 30-acre site was sown with the grass mixture. As of spring 2012, the strategy appeared to be working well except for some erosion in drainages where the planned streets were located. Some soil areas were beginning to recover naturally through ecological succession. Pioneering forbs and shrubs began to grow along with the sown grass.

Question

1. How has the curve number *(CN)* changed as a result of these remedies?

Addendum – The SCS Method of Calculating Storm Runoff from a Land Surface

The U.S. Soil Conservation Service (SCS), now the Natural Resources Conservation Service (NRCS), developed a method of determining the volume of storm runoff from different land surfaces. The method is based on actual empirical field measurements made in various plots of different soil cover types. These experiments started with agricultural land runoff measurements and were later expanded to include other, more urban-type land uses. The SCS method is the most commonly used runoff estimator for engineering and for environmental hydrology projects (Viessman and Lewis, 2002; Ward and Trimble, 2003).

The SCS developed curve numbers *(CN)* which relate to how permeable different soil types are with various land uses:

$$CN = \frac{1000}{S} - 10$$

and

$$S = \frac{1000}{CN} - 10$$

S = potential maximum retention (maximum water that doesn't run off) when runoff begins. This term S is related to soil types and initial soil moisture (antecedent moisture condition AMC) and is included in the curve number determination.

A curve number is therefore dependent on the ability of a soil to infiltrate water and on its surface uses, which also affect the soil's ability to infiltrate and retain water. Curve numbers were established by measuring storm runoff of different soil types and different land uses. These were compared with an impermeable surface in which all precipitation runs off. An impermeable surface is given a maximum curve number of 100. Types of soils in which precipitation can infiltrate have curve numbers less than 100. The lower a curve number of a particular soil type and soil cover type, the more water is retained by the soil and its surface features. The lower a curve number, the lower the runoff to be expected from a single storm rain event. Many curve numbers have been determined by the SCS for various soil types and with different surface land uses or soil cover. Curve numbers range between 25, for woods with very permeable soil covered by litter, and 100 for impervious surfaces. Selected curve numbers useful in this case are given in Table 1.

Table 1. Runoff curve numbers *(CN)* for selected soil cover types and soil groups of average antecedent soil moisture.

Curve Numbers *(CN)* for Hydrologic Soil Groups

Runoff greater →

Soil Cover	*Ave. % impervious surface*	*Soil Group A*	*Soil Group B*	*Soil Group C*	*Soil Group D*
Cultivated with conventional tillage		72	81	88	91
Woods (soil covered with litter)		25	55	70	77
Meadow (continuous grass protected from grazing)		30	58	71	78
Residential developments by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
Newly graded areas (little to no vegetation)		77	86	91	94

Maximum CN = 100 for impermeable surfaces such as smooth concrete or roofing.

The SCS method consists of selecting a precipitation amount and determining the runoff amount expected from curve numbers representing different types of soil cover combinations. To determine the runoff expected from a storm event, you need to know the type of soil cover (land use), characteristics of the soil (hydrologic soil groups A, B, C, or D, discussed below), and an estimate of the antecedent soil moisture conditions, or AMC (how wet the soil already was before a storm event). Wet soil will infiltrate less rain and, therefore, runoff will be greater. Wet soil (high antecedent soil moisture) will have higher curve numbers than dry soil. The curve numbers presented in this exercise are those determined by the SCS for "average" antecedent soil moisture. Corresponding *CN's* for wet or dry soil can be found in SCS (1973).

Hydrologic Soil Groups

The SCS classified soils into four hydrologic groups according to the following criteria (Source: NRCS, 1986):

Group A. Soils with high infiltration and water transmission rates such as deep draining sand and gravel. These soils have low runoff potential.

Group B. Soils of moderate infiltration rate when they are thoroughly wet. These are moderately-to-well-drained soils with fine-to-coarse textures.

Group C. Soils of low infiltration rates when thoroughly wet and consisting of soils with a layer that impedes downward movement of water. These soils usually have a fine texture.

Group D. Soils of high runoff potential. These soils have very low infiltration rates because they consist chiefly of clay or they are shallow soils overlying an impervious layer.

Calculating Volume of Runoff

The SCS method determines the volume of runoff per acre using the following equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

Where

Q = excess rainfall (runoff) in inches of depth per acre

P = rainfall depth in inches

I_a = initial abstraction (all losses from precipitation that don't participate in runoff including surface depression storage, interception by vegetation, infiltration, and evaporation)

Through measurements of actual watersheds, the SCS determined empirically that I_a approximated $0.2S$ and that

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

This equation gives the storm runoff as depth of water in inches per acre and considers soil types, land cover uses, and precipitation amounts.

Usually one wants to know the total volume of runoff from land in cubic feet instead of depth. Therefore, after calculating Q in inches of depth/acre, convert the inches of depth to feet of depth by dividing the inches by 12. To obtain the volume of runoff per acre in cubic feet, multiply the depth of runoff in feet by the number of square feet in an acre (43,560).

References

Soil Conservation Service. 1973. A method for estimating volume and rate of runoff in small watersheds, SCS Technical Paper 149.

Viessman, Warren, Jr., and Gary L. Lewis. 2002. *Introduction to Hydrology*, Fifth Ed. Upper Saddle River, NJ: Prentice Hall.

Ward, Andy, and Stanley W. Trimble. 2003. *Environmental Hydrology*, Second Ed., Boca Raton, FL: CRC Press,

NRCS. 1986. Urban hydrology for small watersheds, Technical Report 55. United States Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division.

Credits

Photographs appearing in this case study were taken by the author, except as noted below.

The photos of the burning house (p. 4) and the catch basin reconstruction (p. 8) were taken by Mell Price.

The aerial image of the forested farm (p. 2) was taken by the US Geological Survey on December 31, 2006 and © Google 2010 as displayed on Google Earth™ mapping service. The image is displayed under the "Fair Use" permission guideline for educational uses. Yellow lettering was added by the author.

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