CHAPTER 1

OVERVIEW AND RUNOFF PROCESSES

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An important question in hydrology is how much stream flow occurs in a river in response to a given amount of rainfall. To answer this question we need to know where water goes when it rains, how long does water reside in a watershed, and what pathway does water take to the stream channel. These are the questions addressed in the study of rainfall – runoff processes, or more generally surface water input – runoff processes. The term, "surface water input" is used in preference to rainfall or precipitation to be inclusive of snowmelt as a driver for runoff.

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Answering the question of how much runoff is generated from surface water inputs requires partitioning water inputs at the earth surface into components that infiltrate and components that flow overland and directly enter streams. The pathways followed by infiltrated water need to be understood. Infiltrated water can follow subsurface pathways that take it to the stream relatively quickly, in which case it is called interflow or subsurface stormflow. Infiltrated water can also percolate to deep groundwater, which may sustain the steady flow in streams over much longer time scales that is called *baseflow*. Infiltrated water can also remain in the soil to later evaporate or be transpired back to the atmosphere. The paths taken by water determine many of the characteristics of a landscape, the occurrence and size of floods, the uses to which land may be put and the strategies required for wise land management. Understanding and modeling the rainfall – runoff process is therefore important in many flood and water resources problems. Figure 1 illustrates schematically many of the processes involved in the generation of runoff.

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The rainfall – runoff question is also at the heart of the interface linking meteorology and hydrology. Quantifying and forecasting precipitation falls into the realm of meteorology and is part of the mission of the National Weather Service. Meteorological forcing is also a driver of snowmelt surface water inputs. River forecasting involves the use of meteorological variables as driving inputs to the surface hydrology system to obtain streamflow. The temporal and spatial scales associated with surface water inputs, given as output from meteorological processes have profound effects on the hydrological processes that partition water inputs at the earth surface. High intensity short duration rainfall is much more likely to exceed the capacity of the soil to infiltrate water and result in overland flow than a longer less intense rainfall. In arid climates with deep water tables, spatially concentrated rainfall on a small area may generate local runoff that then infiltrates downriver, whereas a more humid area with shallow water tables is less likely to be subject to stream infiltration losses and even gentle rainfall when widespread and accumulated over large areas may lead to large stream flows.

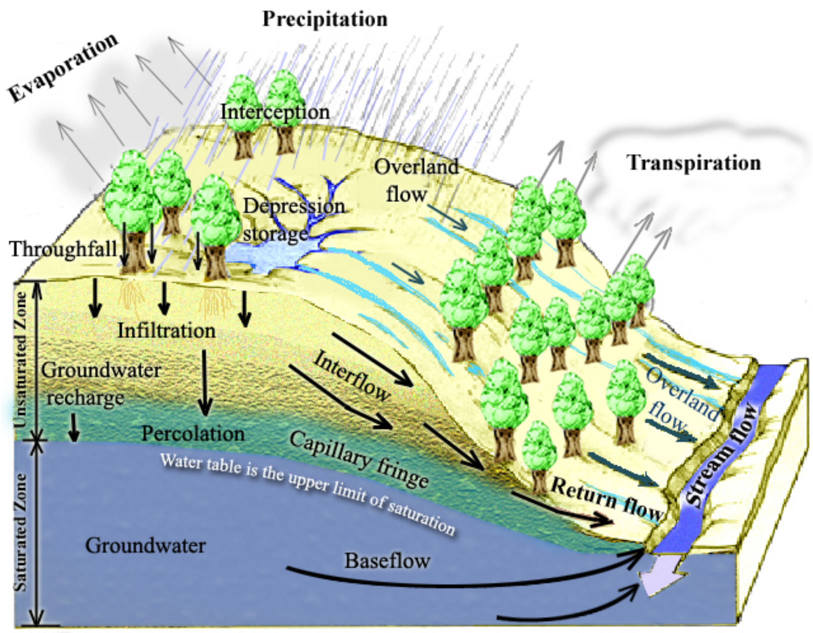

Figure 1. Physical Processes involved in Runoff Generation.

This module will provide an elementary quantitative understanding of the processes involved in the transformation of surface water input to runoff at the earth surface. We will review the mechanisms involved in runoff generation and the pathways water takes moving to streams in different settings. Much of this review will provide the language and terminology used by hydrologists as a basis for qualitative understanding and description of the runoff processes. We will then consider the physical factors at the land surface that affect runoff, and present in depth the current understanding of runoff processes. Soils and soil properties are fundamental to the partitioning of water inputs at the earth surface, so we focus on quantification of soil attributes important for understanding infiltration and runoff generation processes. Quantifiable soil properties serve as the basis for a variety of mathematical models for the calculation of infiltration given surface water inputs, and for the partitioning of surface water input into runoff components. A section of this module focuses on these at a point infiltration models. Soil properties and at a point infiltration models are the most quantitative part of this module and the equations and exercises are provided for the implementation and reinforcement of these concepts. Practical hydrologic models can rarely represent the at a point detail of rainfall – runoff processes, and tend to average or lump hydrologic response over large areas or watersheds. This lumping is at the heart of the scale problem that has received much attention in hydrologic research recently. Averaging is necessary for computational reasons as well as because it is difficult to measure and quantify the full spatial heterogeneity of soil properties involved in runoff generation. In practice rainfall runoff models rely on numerical and conceptual representations of the physical rainfall – runoff processes to achieve continuous runoff generation simulations. This module ends with a brief review of the simulation of runoff generation in hydrologic models using TOPMODEL (Beven et al., 1995) and the National Weather Service River Forecast System (NWSRFS) as examples.

The student needs to recognize that rainfall – runoff processes in hydrology are an active and deep area of research with continually emerging new understanding. Entire books (e.g. Kirkby, 1978; Anderson and Burt, 1990) have been devoted to the subject, as well as recent conferences (AGU Chapman conference on Hillslope Hydrology, 2001, Sun River, Oregon, http://www.agu.org/meetings/cc01ecall.html) and journals (Uhlenbrook et al., 2003). The student is referred to good texts that include sections on rainfall – runoff processes for a deeper understanding (Dunne and Leopold, 1978; Linsley et al., 1982; Chow et al., 1988; Bras, 1990; Beven, 2000; Dingman, 2002).

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Further Study

Runoff Processes

The paths water can take in moving to a stream are illustrated in Figure 1. Precipitation may be in the form of rain or snow. Vegetation may *intercept* some fraction of precipitation. Precipitation that penetrates the vegetation is referred to as *throughfall* and may consist of both precipitation that does not contact the vegetation, or that drops or drains off the vegetation after being intercepted. A large fraction of intercepted water is commonly evaporated back to the atmosphere. There is also flux of water to the atmosphere through transpiration of the vegetation and evaporation from soil and water bodies. The surface water input available for the generation of runoff consists of throughfall and snowmelt. This

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Runoff Process Puzzle

surface water input may accumulate on the surface in *depression storage*, or flow overland towards the streams as *overland flow*, or *infiltrate* into the soil, where it may flow laterally towards the stream contributing to *interflow*. Infiltrated water may also *percolate* through deeper soil and rock layers into the *groundwater*. The *water table* is the surface below which the soil and rock is saturated and at pressure greater than atmospheric. This serves as the boundary between the saturated zone containing groundwater and unsaturated zone. Water added to the groundwater is referred to as *groundwater recharge*. Immediately above the water table is a region of soil that is close to saturation, due to water being held by capillary forces. This is referred to as the *capillary fringe*. Lateral drainage of the groundwater into streams is referred to as *baseflow*, because it sustains streamflow during rainless periods. Subsurface water, either from interflow or from groundwater may flow back across the land surface to add to overland flow. This is referred to as *return flow*. Overland flow and shallower interflow processes that transport water to the stream within the time scale of approximately a day or so are classified as *runoff*. Water that percolates to the groundwater moves at much lower velocities and reaches the stream over longer periods of time such as weeks, months or even years. The terms quick flow and delayed flow are also used to describe and distinguish between runoff and baseflow. Runoff includes *surface runoff* (overland flow) and *subsurface runoff* or *subsurface stormflow* (interflow).

Exercises

1. Label the Rainfall-Runoff processes depicted in the figure

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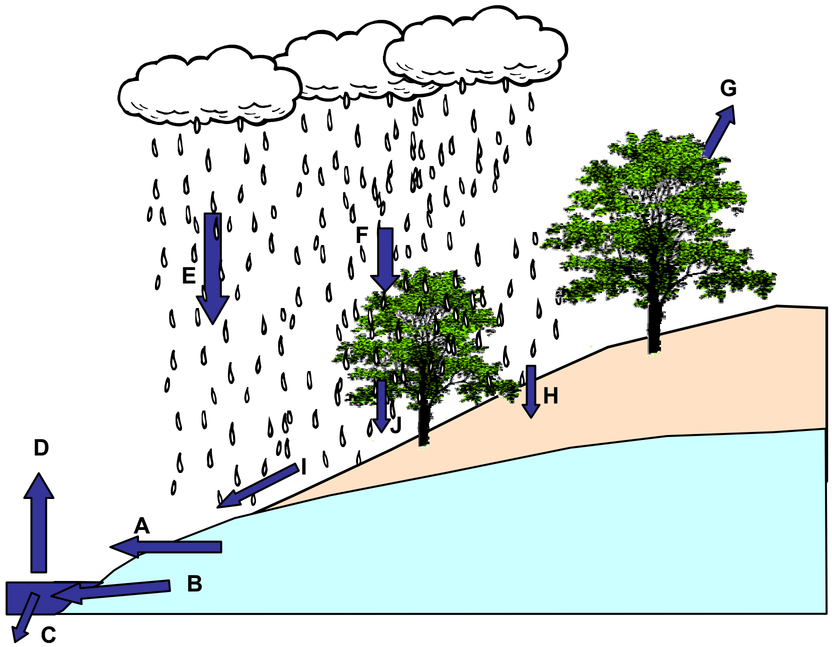
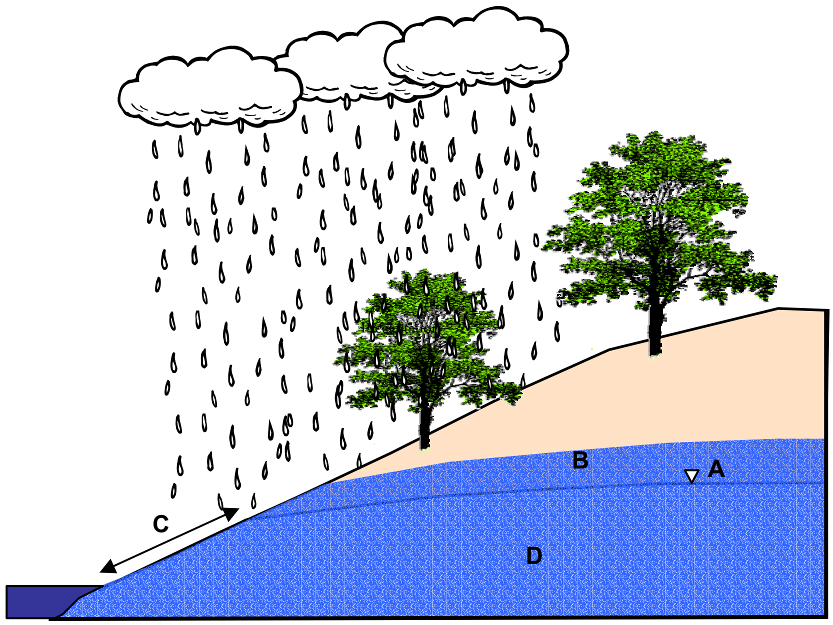
Do the Chapter 1 quiz



Infiltration	
Return flow	
Overland flow	
Base flow	
Interception	
Throughfall	
Precipitation	
Evaporation	
Transpiration	
Streamflow	

2. Label the locations depicted in the figure associated with runoff generation processes



Water Table	
Groundwater	
Capillary Fringe	
Variable Source Area for saturation excess overland flow	

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