Introduction

- This course will advance the basic geomorphological theories taught and presented in Geomorphology I (Geog 213). The student should be familiar with the concepts of elementary physical and chemical weathering, the role of structure and lithology on landscape expression, basic mass wasting and denudation processes and the interpretation of glacial features.
- The role and impact of many of the processes and concepts mentioned above on the creation and evolution of drainage basins comprises the main focus of this course. Drainage basins or watersheds are one of the most logical geomorphological units of study as they represent a well-defined, meso-scale area bounded by natural divides.
- Chapter 2 (Basic Concepts) should be reviewed thoroughly in order to reinforce many of the basic geomorphological ideas which will be elaborated upon in subsequent sections of this course.
- Chapter 3 (Weathering) also provides important background information which should be well understood. Review the following sections of Chapter 3:
    - Freezing and thawing pp. 16 – 18
    - Thermal expansion and contraction pp. 19 – 20
    - Wetting and drying pp. 20 – 21
    - Chemical weathering pp. 22 – 25 (to the end of **Solution**)
    - Controls of rate and character of weathering pp. 30 – 40 (to the end of **Weathering rates**).
    - Soils pp. 45 – 50
- Before proceeding to an introduction and discussion of drainage basins, a brief overview of the forces responsible for their creation is presented. The effects of internal (endogenic) forces and the influence of climate on drainage basin evolution are reviewed below.
- Much of the discussion below is based on Chapter 2 (Internal Forces and Climate) of Processes Geomorphology 4th ed., Ritter *et al*. (2002) available on reserve at the main library.

Uplift and Tectonics

- Geomorphology as a discipline is concerned primarily with exogenic processes, or the means by which the Earth's surface is denuded or eroded towards a relative base level (i.e. ocean surface). We know that exogenic processes are continuously operating through various mechanisms including weathering, mass wasting, and wind erosion, yet the Earth has not yet been reduced to a flat featureless plain.
- One possible explanation could be that the rate of erosion is slow enough so that the initial mountains and highland areas created during the formation of Earth, several billion years ago are still being worn down today. This however, contradicts what we know about rates of denudation and the age of the oldest known bedrock (around 7 billion years).
- We know that average denudation rates range between 5m/ky to 100m/ky and that the Earth's radius is just over 6,300km so using even the slowest rate, the Earth would have been completely eroded to the size of a marble in only 1.2my!
- What also becomes apparent is that the mechanism resisting or opposing exogenic denudation is operating at a similar rate to that of erosion over a long period of time. We know this because otherwise the radius of the Earth would expand skyward without limits. Endogenic uplift of the Earth's crust is the mechanism opposing exogenic processes.
- This leads to the recognition of a state of equilibrium, or rather quasi- or dynamic equilibrium between exogenic forces of erosion and endogenic forces of uplift.
- The equilibrium is not static or absolute because the driving forces of endogenic and exogenic processes are constantly changing and adjusting resulting in temporary states of equilibrium.
- For example, a sudden and cataclysmic orogenic event will dramatically increase the energy available to processes of erosion as well as the micro-climate of an area. Following an initial period of adjustment a new dynamic equilibrium will be established according to the characteristics of the altered landscape.
- Conversely changes in climate may alter the rates of chemical weathering or the availability of moisture in an area and impose a modified state of equilibrium.

- Data on the frequency and magnitude of events capable of altering conditions of equilibrium suggest that they occur at irregular intervals separated by relatively long periods of constancy.
- As mentioned above, when considered over a long period of time rates of uplift and denudation are similar. This, however masks the reality that exogenic forces are constantly operating, while endogenic events are more sporadic thus the actual rates of uplift are much higher than the average rates of erosion.
- Diastrophism or tectonism refers to the uplift and deformation of the Earth's crust and is manifested through orogenic and epeirogenic processes. The former refers to an intense process of faulting, fracturing and thrusting of rock which culminates in the formation of structural mountains. The latter is a more gradual, regional scale uplift during which the strata are gently tilted rather than crushed or thrusted.
- Isostasy is a major endogenic process and defines the relationship between ocean basins and continents through the vertical motion of the Earth's surface. It is also an important geomorphological concept because it produces potential energy consumed by exogenic processes.
- The rate of and mechanism by which the potential energy is consumed is largely dependent on rock structure, lithology and climate.

Role of Climate on Exogenic Processes

- The prevailing climate will dictate the dominant type of process operating in a region. This relationship is referred to as a climate-process system. This can be converted to a morphogenetic system by identifying the landforms that most commonly result from the dominant processes.
- Climate-process systems are grouped according to differences in mean annual temperatures and precipitation amounts (Fig. 1-1).

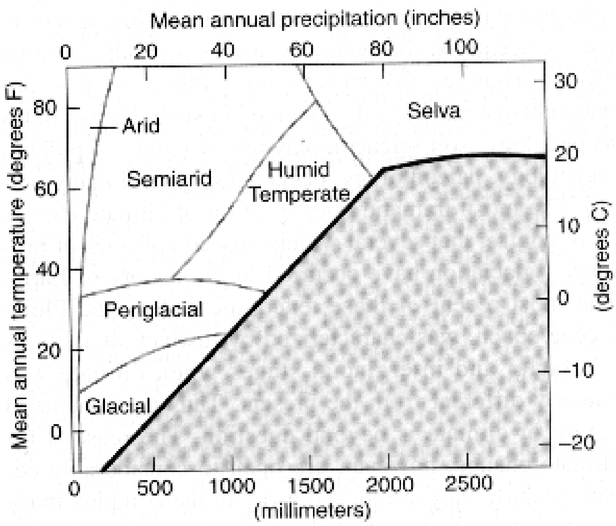


Figure 1-1. Six possible climate-process systems as suggested by Wilson (1968). Each set of temperature-precipitation values tends to drive processes that function most efficiently under those climatic conditions (From L. Wilson in *Encyclopedia of Geomorphology*, ed. By R. W. Fairbridge, copyright 1968 by Dowden, Hutchinson & Ross, Inc. Used by permission of Professor Rhodes W. Fairbridge *in* Process Geomorphology, Ritter *et al*., 2002).

- Geologic variations, seasonal changes in climate, the presence of relict landforms created under different precipitation and temperature regimes may alter the expected topographic outcome under a given climatic type.
- Beyond the identification and classification of landforms developed under certain climatic conditions is the need to assess what impacts climate *change* may have on surficial environments. By using well-established relationships between climate and the activity of dominant exogenic processes, the geomorphologist is capable of modeling or predicting how a landscape will respond to climate change.
- Geomorphologists are more concerned with how changes in climatic variables (i.e. temperature and precipitation) affect the surficial system than with the exact causes of climate change. More precisely the concept of geomorphic thresholds plays a big role in attempting to assess the impact of climate change on the landscape.
- The issue is further complicated by the fact that climatic changes do not directly drive changes in landscape. Rather they alter the environmental factors which in turn drive

the exogenic processes which are then reflected in the landscape. This leads to a lag in response of the landscape to climatic changes, the frequency of which may be longer than the response time of the surficial system.

- Sea-level fluctuations provide an example of the effects of climate change on the potential energy available to a surficial system. Renewed down-cutting by a river near its mouth is a response to a drop in sea-level due, for example, to the expansion of glaciers as a result of atmospheric cooling.
- The river will continue to adjust its channel shape by vertically eroding into the existing channel in a headwater direction. The geomorphic expression of this adjustment are terraces along one or both sides of the river channel.
- However it is important to realize that river terraces and other geomorphic features can be created through a variety of processes and do not necessarily represent a single event or response.
- Climatic changes also alter the vegetal cover and thus the rate of erosion. An increase in precipitation will not automatically result in increased surface erosion because under certain temperature and soil regimes, the response will be a denser and more stable vegetation cover, which will serve to stabilize the slopes (Fig. 1-2).

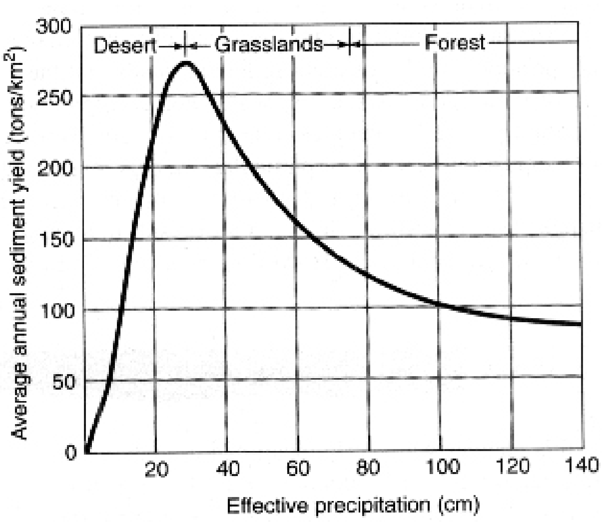


Figure 1-2. Average annual sediment yield as it varies with effective precipitation and vegetation. (Langbein and S. A. Schumm, *Transactions of the American Geophysical Union*, vol. 39, p. 1077, 1958 copyright by the American Geophysical Union *in* Ritter *et al*. 2002).

- To cloud matters further, research shows that quantifying the magnitude of climate change (in terms of precipitation and temperature) may not be enough to predict what the effects will be on a landscape or region. Antecedent temperature and precipitation values appear to be at least as important if not more so than changes in magnitude. That is, the response of a system to a given change in precipitation and/or temperature is heavily dependent on the preexisting conditions of that system.
- In addition there is a lack of reliable data on how quickly exogenic processes react to climatic changes and on the effects of lag time on the expression of these changes in the landscape (Fig. 1-3).

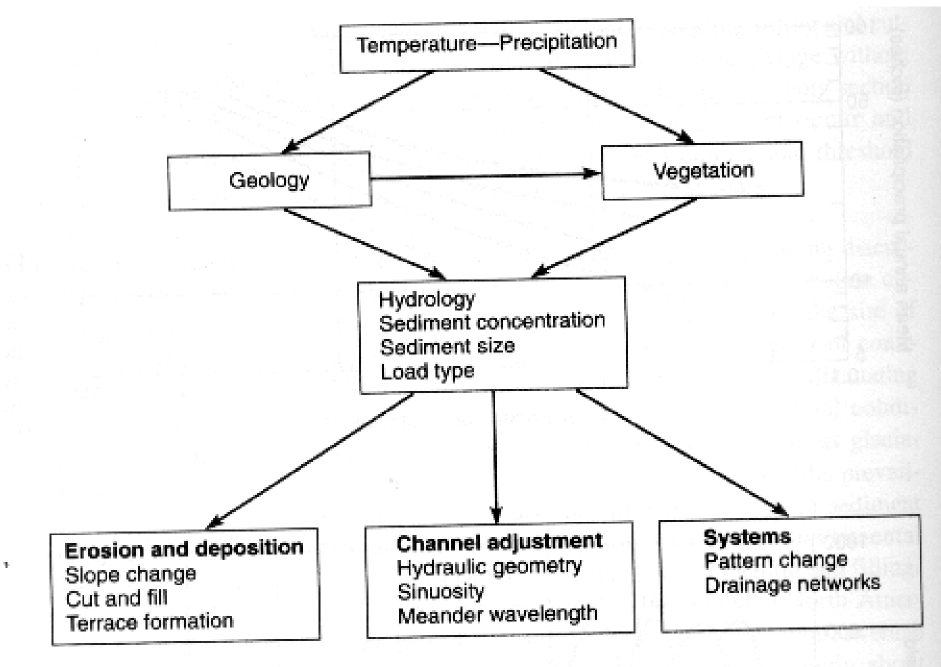
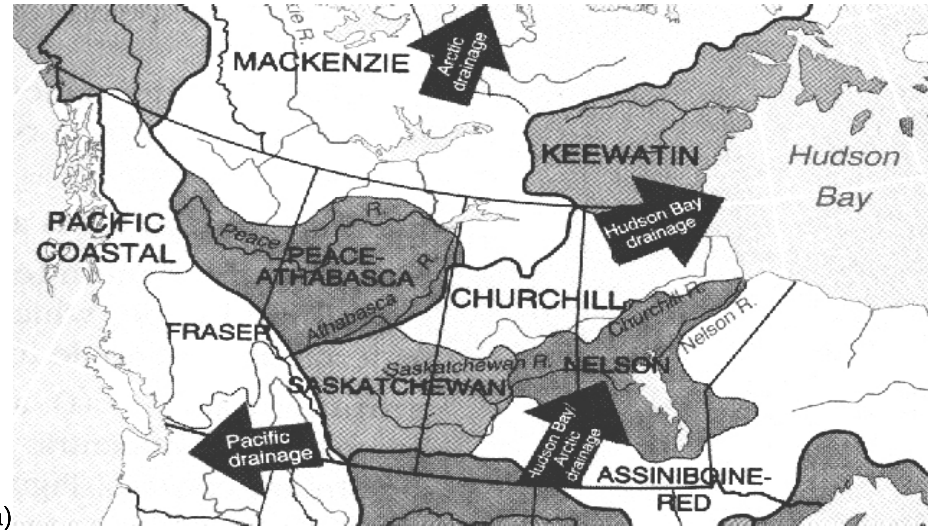


Figure 1-3. Hypothetical flow chart showing how climatic variables exert an influence on rivers. A change in climate alters sediment concentration, sediment size, or load type, requiring a response by the river system. Responses vary depending on local conditions (Ritter *et al.* 2002).

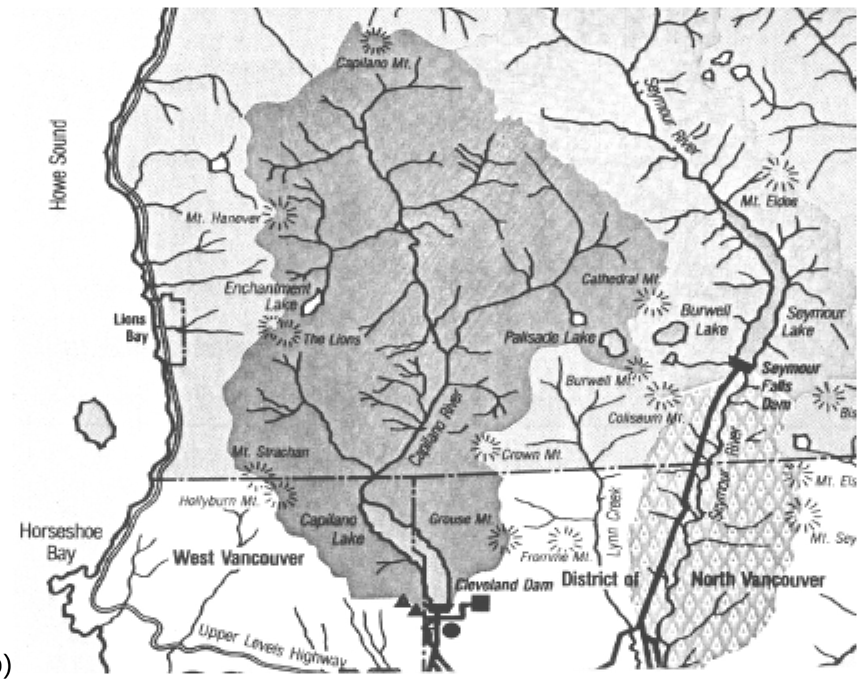
- With this brief overview of the endogenic and exogenic forces which create and modify, respectively, the Earth's surface forms, let us now turn to the definition of a watershed as the basic unit study of the detailed effects of these forces.

Watershed as a Unit of Study

- A watershed is a convenient unit of study of the effects of endongenic and exogenic forces because it is the fundamental landscape unit concerned with the collection and distribution of water and sediment. That is, the input of water and the production of sediment can be quantified for any portion of the basin.
- The word **drainage** can be defined as the **process** by which **water is transferred**, or drained, from one area to another. Notice we are not merely interested in the movement of water rather we focus on the *process* by which it moves.
- The general definition includes both structural (geological) and topographical (geographical) connotations. For our purposes, the definition of **basin** is **the catchment or watershed** of a **river system**.
- Taken together **drainage basin** (or river basin) refers to the "…basic **spatial geomorphic unit of a river system**; distinguished from a neighboring basin by ridges and highlands that form divides, marking the limits of the catchment area of the drainage basin, or its watershed" (Christopherson, 1997, p. A.16). The ridges themselves are called interfluves (Fig. 1-5).
- The definition offered by Brookes *et al.* (1997) is similar stating that **river basins** "…comprise all the **lands that drain through**…**rivers** and their tributaries **into the ocean**" (p. xiii).
- Figures 1-4 and 1-5 below illustrate the concept of a drainage basin and its catchment areas or watersheds respectively. The term watershed and catchment area can be used interchangeably, as can drainage basin and river basin. In most cases, the former two refer to a smaller portion of the latter.



(a)



(b)

Figure 1-4 Major (a) and minor (b) drainage basin (Christopherson, 1997 (a), Economic and Engineering Services, 1991 (b)).

Figure 1-5. A single catchment area or watershed of a drainage basin. Interfluves are delineated with a black line.

- Figures 1-4 and 1-5 should help to explain why the concept of a river basin and watershed is so attractive to researchers from many different disciplines. They form well-defined natural boundaries between adjacent natural and more recently, human transfer systems. This property allows basins or watersheds to be studied individually as a coherent unit and in many cases drainage divides or watershed boundaries also form political boundaries between districts, regions, provinces/states or countries.
- The reason why watersheds are so well defined and delineated is simple: gravity. Gravity ensures that, in most cases, the transfer of material, energy, and processes is in a downhill direction, from regions of high potential energy to areas of low potential energy, thus continuously working towards equilibrium.
- In this case the material being transferred is water along with organic and inorganic debris produced by exogenic processes such as erosion and mass wasting. The selection of a watershed as a basic unit of study is therefore not an arbitrary or convenient concept rather it is founded on a solid physical basis.

- The downward movement or transfer of material means that input into a section of the watershed must have come from the upstream portion. In other words areas of input, transfer, and output can be clearly defined. This is illustrated in figure 1-6.

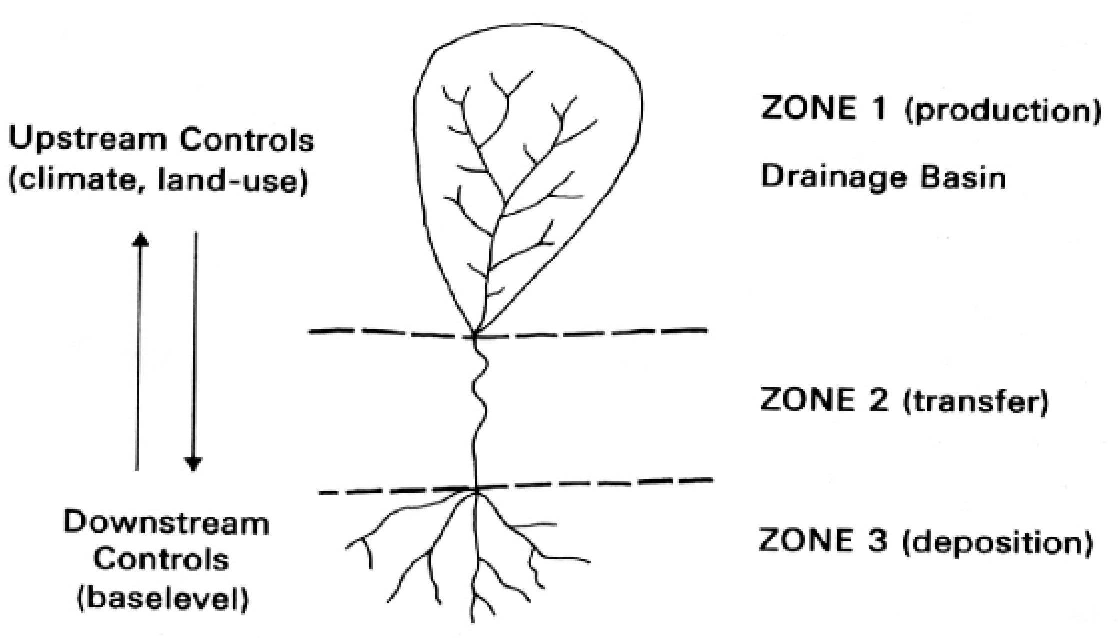


Figure 1-6. Transfer system and controls of a watershed (Newson, 1997).

- The simplistic view shown above, however, is not the only depiction of a watershed although it does capture the essence from a geomorphological point of view.
- The manner in which a watershed is depicted depends mainly on the background of the person or group depicting it. For example, figures 1-7 and 1-8 show how an engineer might draw a watershed. The message in these figures is one of human control or management of a natural resource (i.e. water). On the other hand figure 1-9 is a water managers' view, complete with all the human-related sources of input and abstraction from the river. Note that these illustrations do not explicitly show the watershed boundary, which differs from the geographical point of view.

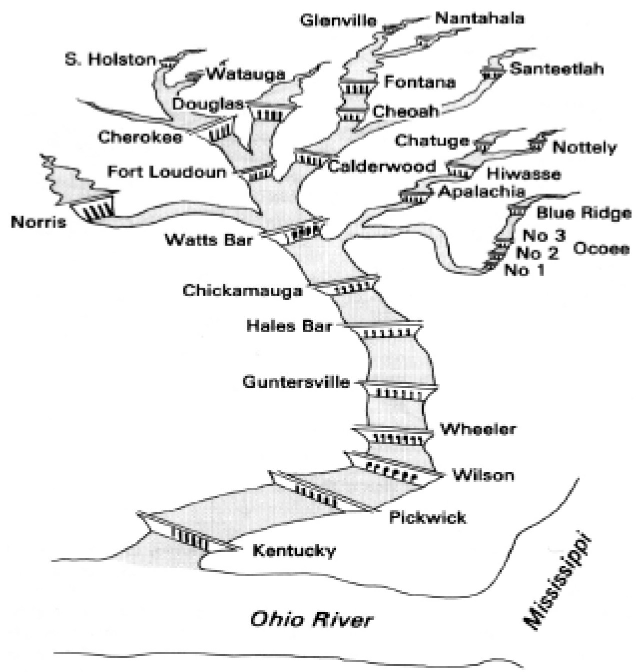


Figure 1-7. Engineering view of a watershed. Total control by human-built dams (Newson, 1997).

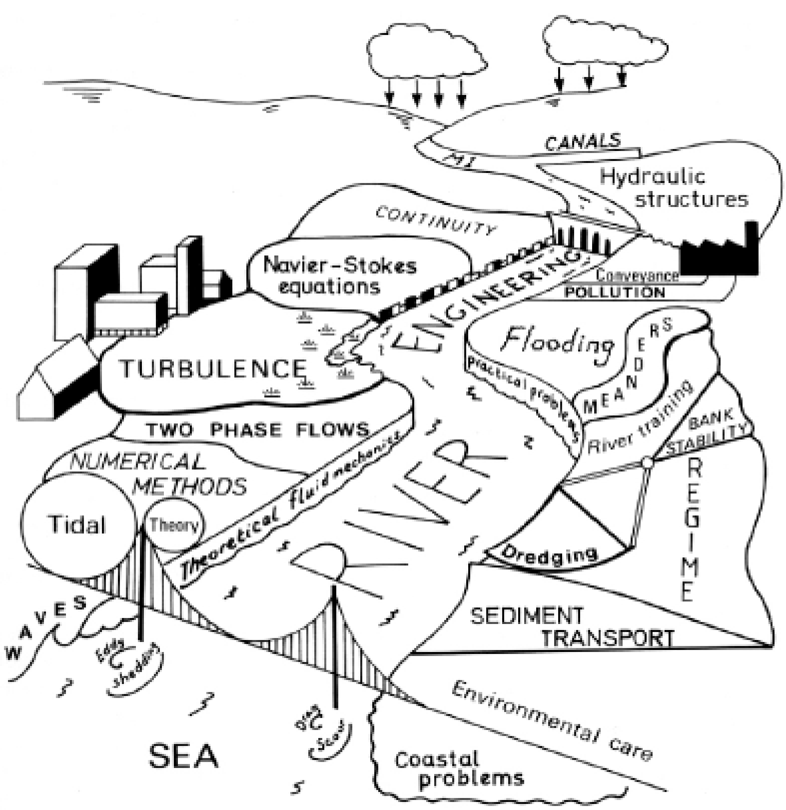


Figure 1-8. Engineering view of a watershed. The river system explained using principles of hydrology (Newson, 1997).

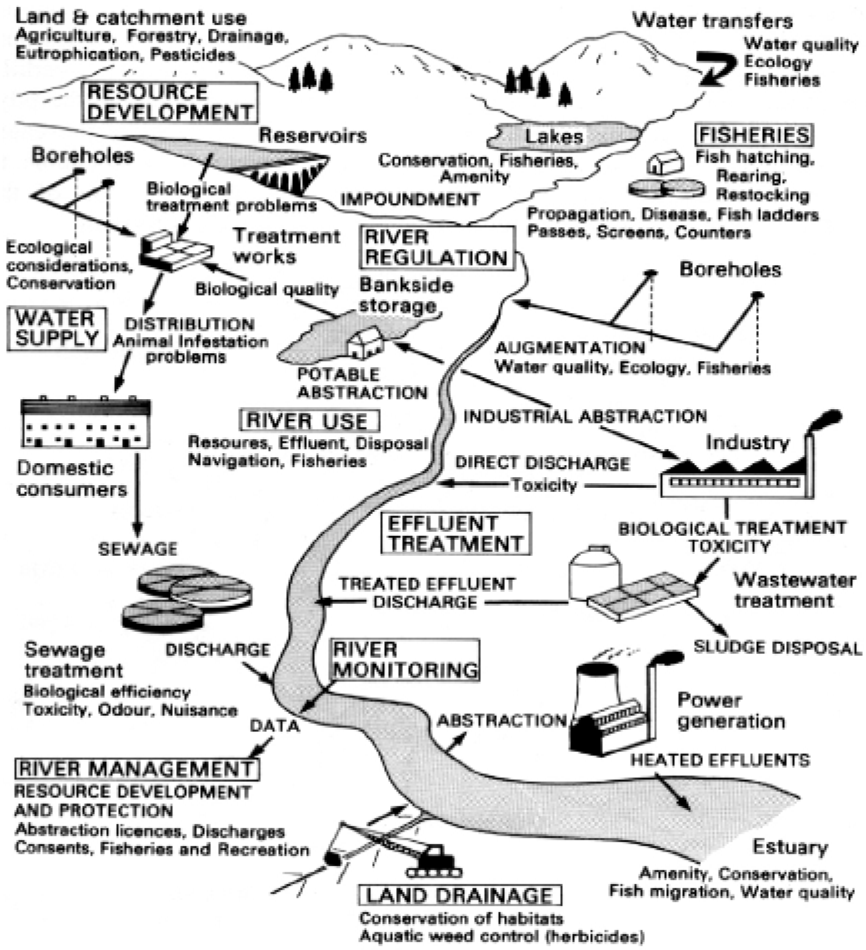


Figure 1-9. A water managers' view of a watershed. An attempt to compartmentalize the river system into input and output (Newson, 1997).

Slope Hydrologic Cycle

- The ultimate source of river flow is precipitation through either rain or snow. The path of precipitation from the impact on a slope through the drainage basin and into the river channel is known as the slope hydrological cycle (Fig. 1-10).

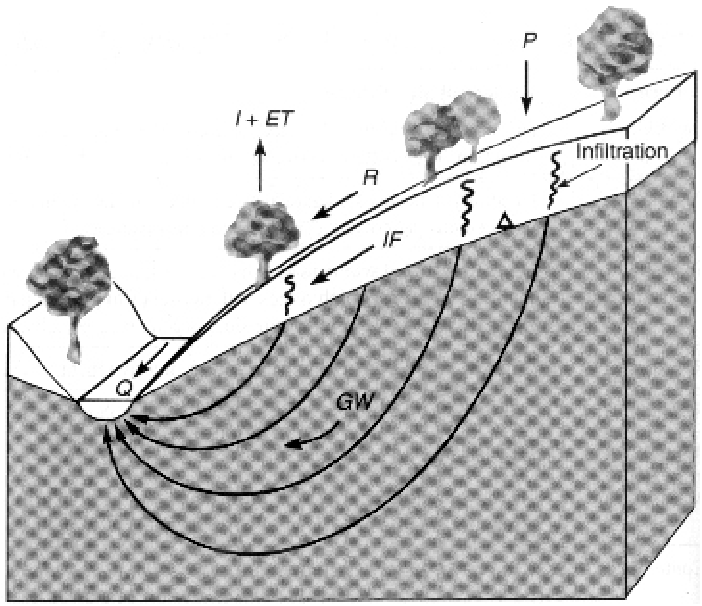


Figure 1-10. Slope hydrologic cycle. Some of the precipitation (*P*) is intercepted by vegetation (*I*) or lost by evapotranspiration (*ET*). Upon reaching the ground surface, it becomes part of stream discharge (*Q*) by direct runoff (*R*), interflow (*IF*), or groundwater (*GW*) after it reaches the water table (?) (Ritter *et al*. 2002)

- Precipitation rarely falls on the slope surface itself and even more seldom drains directly into a stream channel. In arid regions such as Arizona, for example, 95% of precipitation is lost through *ET* while the value for the entire United States is 70% (Grey 1997).
- The influx of precipitation into a drainage basin can, of course, be quantified using a network of well-placed rain gauges. How much of that precipitation actually makes its way into the river and when is more difficult to establish.
- The type, extent, and condition of vegetation greatly influences the pattern of deposition and amount of precipitation reaching the soil surface. Interception is generally highest in areas of dense forest cover but can account for 10 to 20% of gross precipitation in shrublands and on the prairies when maximum growth has been attained.
- The remainder of the precipitation that has made its way to the ground surface now begins to get absorbed by the soil or regolith overlying the slope. Following initial absorption, the moisture will infiltrate at a rate governed by soil thickness, texture, and

structure, vegetation, and the antecedent condition of the soil moisture. If the soil is already saturated or the rate of infiltration is slower than the rate of precipitation, overland flow, or runoff, will occur.

- Direct precipitation into the channel and overland flow contribute the greatest volume of water into a stream channel and produce the initial response in a flood hydrograph (Fig. 1-11 and 1-12).

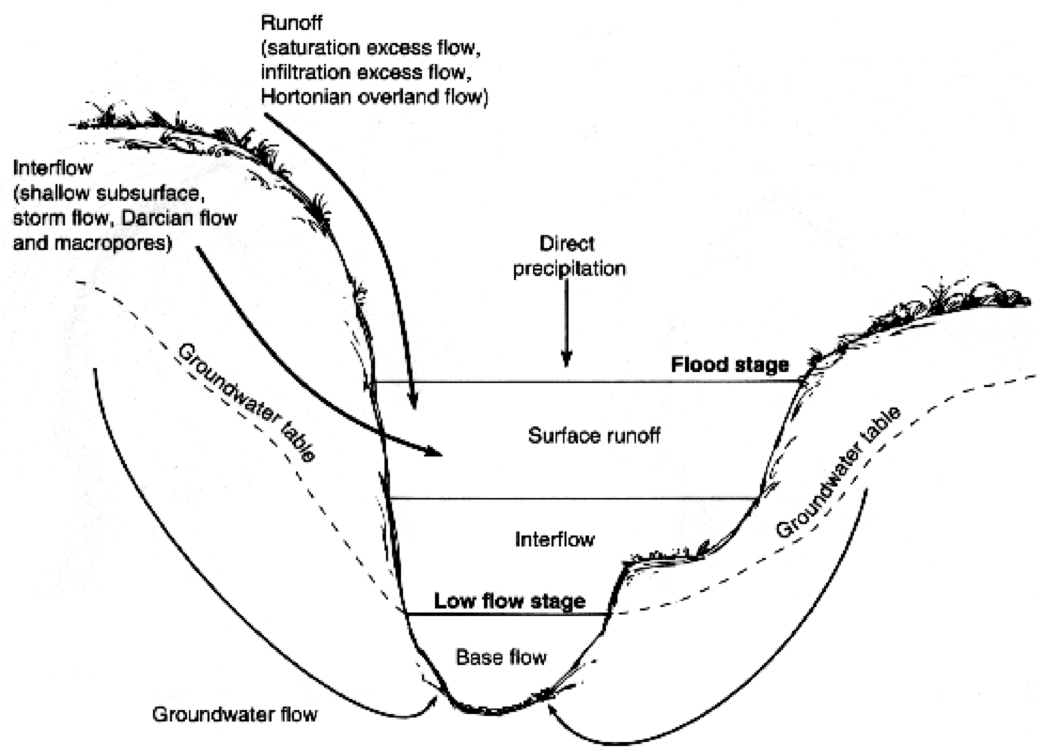


Figure 1-11. Schematic of stream channel showing major kinds of water contributions. Arrival of water from any given precipitation event is progressively delayed from runoff to interflow to groundwater flow (Ritter *et al*. 2002).

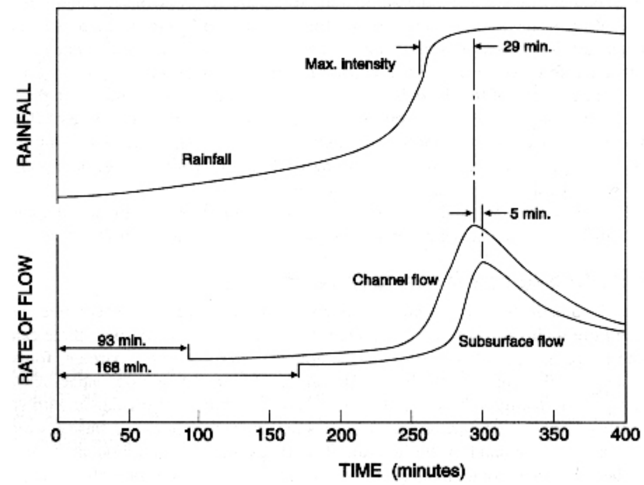


Figure 1-12. Relationship between timing of rainfall and corresponding subsurface flow and channel flow responses averaged for 36 storms for hillslopes in Mississippi (Beasley 1976, as presented by Troendle 1985 *in* Brookes *et al*. 1997).

- In addition to a time lag in response between peak storm intensity and peak channel discharge, there is a spatial lag in the area of the basin that actually contributes to the peak flow. This is known as the variable source concept and is explained by the upslope expansion of areas where the soil is saturated from the channel banks (Fig. 1-13).
- Soils immediately adjacent to stream banks are always at or very near the saturation point because of contact with the groundwater table. The surface of the groundwater table rises with the ground surface but at a slower rate meaning its depth beneath the ground increases upslope (see Fig. 1-11).
- So as the saturated area expands so does the area which contributes moisture into the channel through the most direct mechanism of runoff (apart from direct precipitation into the channel). A secondary mechanism, interflow, is also accelerated over time during a precipitation event.

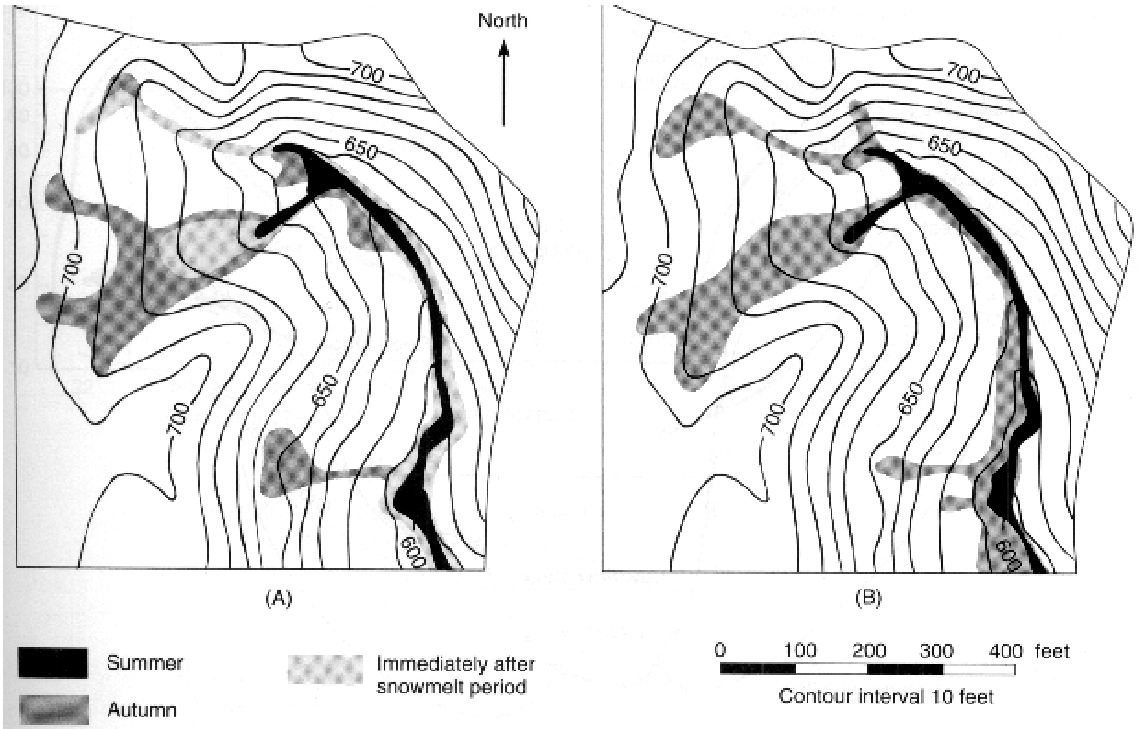


Figure 1-13. Variations in saturated areas on well-drained hillslopes near Danville, Vt. (A) Seasonal changes of prestorm saturated area. (B) Expansion of saturated area during a single 46mm rainstorm. Solid black line represents beginning of storm. Light shade represents saturated area at the end of a storm where water table has risen to the surface (Dunne and Leopold 1978, *in* Ritter *et al.* 2002).

- Consider the implications of the variable area concept on slope stability. How can we use this knowledge of an expanding contributing area to explain the type and magnitude of erosion processes operating on the hillslopes of a given drainage basin or watershed?
- This basic review of the movement of water through a drainage basin sets the stage for a more detailed examination of the morphological expressions of the action of water on hillslopes.