Chapter 2

Watershed Hydrology

Planet Earth's land surface can be divided into watersheds based on the drainage of water - all land within a specified watershed drains to the same point. Taking the mouth of a river basin as lowest point in the watershed, then all lands upstream of that point lie within that watershed. Thus, when Spaniards claimed the mouth of the Mississippi River - and all lands that drain into it - as belonging to their King, they little-realized what a large area that they had in fact acquired.

Some large watersheds have large rivers coming out of them, such as the Mississippi and Amazon Rivers. These watersheds lie in wet regions where abundant rainfall exceeds the rate of evapotranspiration, resulting in surplus water that runs to the sea. Other large watersheds may not have large rivers, such as the Colorado River that flows into the Sea of Cortes. Large watersheds with small rivers are generally located in desert areas where the precipitation is small relative to the evapotranspiration rate.

Each watershed has unique qualities that distinguish it from other, nearby watersheds. Understanding why one river or stream behaves differently from another is linked to understanding the unique qualities of each watershed. Humans alter their watersheds by changing landscape properties, such as by increasing impervious surfaces, and by increasing evapotranspiration rates, such as by irrigation agriculture. These changes can and do change the behavior of the rivers that flow through them - increasing peak discharges, decreasing annual discharges.

In the following sections we discuss some of the many features that describe watersheds, and how water moves through the watershed. We distinguish between terrestrial features associated with areas not covered by water from aquatic features, such as rivers and lakes, that are permanently inundated. We also examine wetlands, which transition between these two between features.

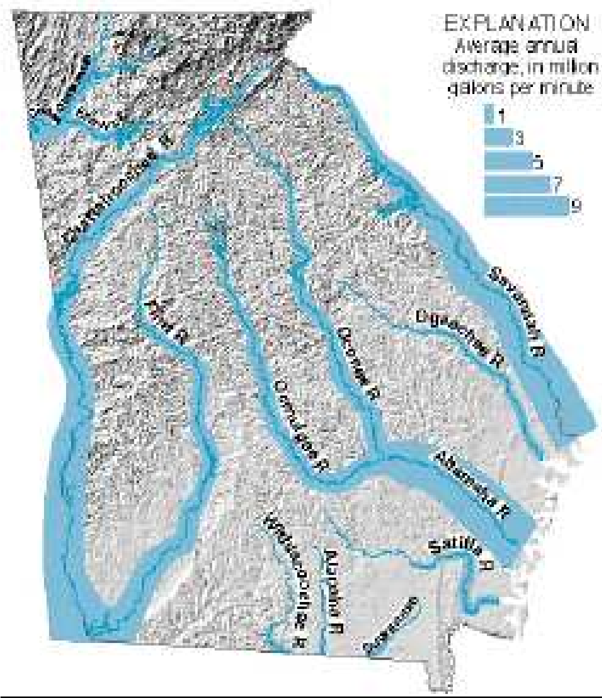

Figure 2.1: River Systems of Georgia.

2.1 Landscape Features

Topographic Characteristics

Topographic features are properties of the earth's terrestrial surface that can be used to describe watershed characteristics. The topography determines the *slope* and *aspect* of the land surface. Steep slopes dominate mountainous areas, rolling hills have moderate slopes, and flat slopes are found in plains and on plateaus. Cooler temperatures and wetter soils are normally found on north- and east-facing aspects in northerly latitudes, and on south- and east-facing aspects in southerly latitudes.

Besides slope and aspect, vegetation and land-use also affect the runoff of water. Water can be applied from natural sources, such as rainfall, or from snowmelt. Water can also be applied artificially, such as by agricultural and residential irrigation or industrial and municipal discharges.

Water flowing across the terrestrial surface is normally intermittent, otherwise it would lie in a specific channel. These flows are called *sheet* or *overland* flow. The flow velocity is usually slow, but can be fast on steeper slopes or where bare soil or rock is exposed.

Contour lines are used to mark points of equal eleva-

Table 2.1: Common landscape features.

Topographic contours - Lines of equal elevation

Slope - Change in elevation per unit distance

Aspect - Direction that a surface faces

Streamlines - Lines perpendicular to topographic contours

Concave slopes, hollows - Zones of converging streamlines

Convex slopes, ridges - Zones of diverging streamlines

Watershed Length - Distance from outlet to most distant point

Watershed Slope - Elevation change divided by distance

Maximum Elevation - Highest point on watershed

Area-Elevation Relationship - Plot of elevation vs amount of land in the elevation class

tion. *Streamlines* are perpendicular to contour lines, and point in the downhill direction. Contour lines are closed (forming a continuous line) around peaks and within depressions. Contour lines are *convex* if the streamlines are diverging (separating), and *concave* if they are converging.

Geographic Information Systems, GIS, are commonly used to describe topographic features of our planet's surface. The surface is digitally stored at various resolutions, and then used to represent the elevations and locations of physical features. Other features can also be inventoried, such as vegetation, land use, and soil type.

Subsurface Characteristics

In addition to surface features, subsurface features are also important from a landscape, or watershed, perspective. Ground, or subsurface, water is important for many reasons - it sustains our rivers and streams during times of dry weather, wells provide us with additional supplies of drinking water, and water for our factories and fields. Areas without ground water are more reliant on the randomness and uncertainties associated with precipitation, and are more prone to droughts.

The *water table* is the elevation of the water surface found in wells. The region below the water table is called the *saturated zone* where all pores are filled with water. The region above the water table, but still below the surface, is called the *vadose*, or *unsaturated*, *zone*. Both the unsaturated and saturated zones are key to understanding why and where water moves in the subsurface.

Groundwater is held mainly in the pore spaces of the saturated unconsolidated sediments. Generally, sandy layers are aquifers and clay rich layers are classified as aquitards or aquicludes. Water flow in the subsurface is not uniform - an *aquifer* is a geologic unit that transmits water rapidly to wells, while *aquitards* (or confining layers) are geologic units that retard the movement of water. Aquifer and confining units are mappable bodies of rock or sediment that transmit sufficient amounts of water or have hydraulic conductivities significantly lower than that of the adjacent aquifer, respectively.

Aquifer and confining zones are informal subdivisions characterized by properties significantly different from the rest of the unit. Hydraulic conductivity, color, chemistry, or lithology may be the establishing feature of a zone. Many geologic formations can be identified in the subsurface as distinct layers with a measurable thickness, usually in the vertical direction. An aquifer system may contain one or more aquifers that transmit groundwater on a regional basis. Confining units that have local but not regional effects may exist within an aquifer system. A confining system is comprised of one or more confining units that impede regional groundwater flow.

The porosity is the volume of water per unit volume of media. Solid rock, such as granite, may have very small porosities, while sands and clays may have much larger porosities. The total porosity is the sum of the interconnected porosity, plus the isolated, or dead end porosity. While some rocks, such as basalt, may have a large total porosity, water may not easily move through these rocks because the pores are not interconnected. Also, sand and clay may have similar porosities, but water does not flow as readily through clay because the pores are much finer.

Problems

1. Describe each of the five physiographic regions of Georgia. How do the Northern and Southern Fall Lines relate to these features?
2. Identify the major types of aquifers in Georgia, and where they are located.
3. How do soils vary across the state?

2.2 Aquatic Features

Rivers and Streams

Mapping stream properties is useful for describing how stream systems behave. A low-order stream has a small discharge and responds quickly to precipitation, while a high-order stream has a larger mean discharge, and responds more slowly.

The stream length is the distance from its source to a confluence with another stream or water body. The length of a meandering stream is much longer than a straight stream because it is often difficult to measure every curve in the stream. We can say that the tortuosity of a stream, $\tau = L_m/L$, is the ratio of the measured straight line distance, L_m to the true length of the stream, Ł:

The stream profile is a plot of the elevation of a stream as a function of the distance of the stream from its source. The slope of the stream profile plot is equivalent to the slope of the stream. The stream profile is useful for describing stream power, which is the product of the discharge and the slope.

Table 2.2: Summary of common subsurface features.

Aquifer - A geologic formation that transmits appreciable quantities of water to a well

Aquitard or Confining Layer - A geologic formation that resists the movement of water between two aquifers.

Aquiclude - A geologic formation in which negligible fluid flow is possible

Surficial Aquifer - An aquifer with a water table, usually the uppermost hydrogeologic unit in the saturated zone.

Water Table - A surface defined where pore fluid pressures equal the atmospheric pressure. Equivalent to the elevation of water in a well penetrating a surficial aquifer.

Saturated Zone - Region of saturated pores below the water table.

Unsaturated, or Vadose, Zone - The region between the soil surface and the water table in which pores are variably saturated with water.

Unconfined Aquifer - An aquifer in which the total head does not rise above the top of the unit.

Confined Aquifer - An aquifer in which the total head rises above the top of the unit.

Porosity - Volume of voids per unit volume of aquifer.

Effective Porosity - Volume of interconnected voids contributing to fluid flow, per unit volume of aquifer.

Isolated Porosity - Volume of dead-end or isolated voids that do not contribute to fluid flow, per unit volume of aquifer.

Dual Porosity - An aquifer with two porosity types, such as small, microscopic pores with a larger set of voids, such as fractures and macropores.

Macroporosity Visible pores, such as fractures, voids or vugs

Microporosity, or matrix porosity - Pores too small to see, such as voids between mineral grains or clay platelets.

Table 2.3: Great Rivers of the World

River	Length (km)
Nile	6,685
Amazon	6,275
Mississippi	6,267
Yangtze	4,988
Congo	4,666
Amur	4,409
Yellow	4,344
Lena	4,256
Mekong	4,183
Niger	4,183
Mackenzie	4,039
Ob	3,998
Yenisei	3,797

Table 2.4: Common stream features.

Stream Order - Smallest streams are given order (1). Larger streams are given order (2), etc.

Stream Length - Distance of stream from its confluence to its source.

Stream Profile - Slope of stream along length of stream

Drainage Density - Sum of all stream lengths divided by total area

Stream Order Density - Sum of stream lengths in each stream order divided by sum of all lengths

Spring Magnitude - Largest springs are given magnitude (1). Smaller streams are given order (2), etc.

Longitudinal features - Pools, Riffles, Steps, Glides

Latitudinal features - Point Bars, Cut Banks

Thalveg - Main channel

Flood Plain - Overbank flows

Terrace - Abandoned flood plain

Lakes and Inland Seas.

These water bodies generally have negligible water velocities and a lack of shade on the water surface. The primary cause of water movement is wind energy, which causes mixing in the surface layer, as well as lake-wide water circulation and seiches.

Lakes and ponds are water bodies composed of fresh water, while inland seas (and salt lakes) have substantial salinity. Lakes and inland seas form by natural geologic processes, such as by glaciation, landslides, and tectonic or geologic subsidence, while reservoirs and ponds are normally constructed by humans, or by other dam-building animals such as beaver.

Because of slow water velocities and the lack of shading of the water surface, solar radiation tends to heat the near-surface water in the photic zone. As the water warms, it becomes more buoyant than the underlying, cooler water, resulting in stratification.

Stratification of a water column is normally greatest in summer, and breaks up in fall as the water surface cools. If the water body is covered with ice, then an additional

Table 2.5: Fractals: Self-Similar Geometric Scaling

Shorelines - length of land-ocean boundary increases as ruler length decreases

River Densities - number and length of waterways increases as map scale becomes finer

Soil Physics - scaling of particles shifts soil-moisture characteristic curves to common shape

Geophysical Measurements - Bulk resistivity is not just product of resistivity and porosity

Fractured Media - Fracture density changes as the scale of measurement changes

Let $L_1 = \lambda \ L_2$ **-** where L_1, L_2 are model and original length scales, and λ is a scaling factor

Table 2.6: Major Lakes and Inland Seas

Water Body	Area ($10^3\ km^2$)
Caspian Sea	424.06
Lake Superior	82.33
Lake Victoria	69.38
Aral Sea	63.69
Lake Huron	59.54
Lake Michigan	58.00
Lake Tanganyika	32.88
Lake Baikal	31.58
Great Bear Lake	31.07
Great Slave Lake	29.00
Lake Nyasa	28.48
Lake Eire	25.63
Lake Chad	20.71

period of winter stratification may occur, resulting to two periods within the year that the water-body is stratified (dimictic).

Discharge from lakes and inland seas is normally from the epilimnion, begin warmer in the summer, and perhaps colder in the winter, than the average water temperature. Discharges from ponds and reservoirs depends upon the outlet structure. If the discharge is from an overflow structure on the water surface, then the outflows will mimic natural discharges. On the other hand, discharge intake structures located deeper in the water column will be cooler than natural discharges during the summer.

Discharge from inland seas is usually absent, so that there is no outlet. Any water entering these water bodies is lost to evaporation, concentrating any salts contained in the inflows. Inland seas are often located in desert areas where precipitation is much less than evaportranspiration. These water bodies are extremely vulnerable because human diversion of inflow waters for agricultural irrigation often has dramatic adverse effects.

Some water-bodies are permanently stratified. The Dead Sea, located between Jordan and Palestine, was stratified for thousands of years due to the accumulation of heavier, salt-rich waters in the deeper sections of the waterbody. As upstream inflows of freshwater were diverted by Israel, the upper layer disappeared, resulting in mixing and a large release of CO_2 and H_2S which had been trapped in the deeper layer.

A similar disaster occurred in Camaroon in 1983 when a deadly cloud of CO_2 was released from a lake that *turned over* (destratified) when large volumes of colder water flowed into the lake during a rainy period.

Table 2.7: Common lake features.

Photic Zone - Zone near the surface of the lake with sufficient sunlight for photosynthesis.

Thermocline - Point of inflection on temperature curve, separating the well-mixed water near the surface from the poorly mixed water at depth.

Stratification - The separation of a water column into distinct layers.

Epilimnion - Zone of well-mixed water near lake surface above the thermocline

Hypolimnion - Zone of poorly mixed water below the thermocline

Metalimnion - Zone of moderately mixed water near the thermocline

Seiche - A random oscillation of the water surface due to wind, changes in barometric pressure, or earthquakes

Littoral Zone - Shallow water zone along shoreline. Zone where rooted macrophytic vegetation most likely

Open Water Zone - Deeper water away from shoreline. Free-floating plants most likely.

Oceans, Seas, and Estuaries.

The marine environment consists of those interconnected aquatic features which are dominated by the presence of salt water. We previously grouped inland seas with lakes because they are not directly connected to the marine environment. The marine environment dominates Planet Earth, covering most of its surface. Perhaps our planet should be named *Oceanus* instead!

The major oceans include the Pacific, Atlantic, Indian, and Arctic, with countless smaller marine water bodies, such as the Caribbean, Mediterranean, and Bering Seas. While these oceans and seas are interconnected, their circulation and water chemistry may differ in essential ways from each other.

Wetlands

Wetlands have many unique hydrologic attributes. One particularly important attribute is their position as the transition zone between aquatic and terrestrial ecosystems. Wetlands have aspects of both aquatic and terrestrial environments because of this position.

Table 2.8: Major Marine Water Bodies

Water Body	Area 10^6 km^2	% of globe
Pacific Ocean	165.65	32.5
Atlantic Ocean	81.62	16.0
Indian Ocean	73.41	14.4
Arctic Ocean	14.34	2.8
Mediterranean Sea	2.96	0.6
Bering Sea	2.27	0.4
Caribbean Sea	1.94	0.4
Gulf of Mexico	1.81	0.4
Sea of Okhotsk	1.52	0.3
East China Sea	1.25	0.2
Hudson Bay	1.23	0.2
Sea of Japan	1.05	0.2
Total Marine	359	70.4

On one hand, most freshwater and marine aquatic environments, such as lakes, rivers, estuaries, and the oceans, are characterized as having permanent water. On the other hand, terrestrial environments are generally characterized as having drier conditions, with an unsaturated (vadose) zones present for most of the annual cycle. Wetland thus occupy a zone that is the transition between dominantly wet and dry environments.

An additional important defining feature of wetlands is their shallow inundation. The upper extent of the zone of saturation within wetlands extends from quasi-flooded (i.e., water covering the surface) to quasi- dry (i.e., the water table within the root zone). This shallow hydrologic environment creates unique biogeochemical conditions that distinguishes it from freshwater, marine, and terrestrial environments. In freshwater and marine habitats, the water surface lies above the land surface, while in terrestrial environments it lies some distance below the root zone as a water table or zone of saturation.

Wetlands tend to form where surface water and groundwater accumulate within topographic depressions (such as in flood plains, potholes, and behind dunes, levees, and glacial moraines, lime sinks, pocosins, and Carolina Bays), where groundwater discharges on slopes (such as along the shores of streams, lakes, and oceans), and above low-permeability substrates where infiltration is restricted (Novitzki, 1989).

Wetlands are a fundamental hydrologic landscape unit (Winter, 2001) that generally form on flat areas, or on shallow slopes, where perennial water lies at or near the land surface, either above or below. Wetlands may form initially in depressions, but may modify their environment as they mature. Peatlands may develop to substantially modify the original landscape (Daniel, 1981).

Wetlands are normally found in low energy environments, in part, because the land surface is relatively flat in these areas (Orme, 1990). Because wetlands lie in relatively flat landscapes, their surface area expands and contracts as the water stage changes. This large change in area results in the ability to store large volumes of water. Wetlands therefore serve as a moderator of hydrologic variability - storing flood flows during wet weather in particular. In addition, shallow depths and low slopes, consistent with low energy environments, are important for trapping nutrients and sediments.

Problems

1. Delineate a major watershed in Georgia using a map of the rivers and streams. Find the mean annual flow for this watershed using U.S. Geological Survey stream gaging data. Find the water yield for this watershed by dividing the mean annual flow by the watershed area. Find the runoff efficiency by dividing the mean annual flow by the mean annual precipitation.

2. Confirm the reported lengths and find the mean annual discharge for the rivers listed in Table 2.3.

3. Confirm the reported areas and find the total volume of water in the lakes and inland seas listed in Table 2.6.

4. Confirm the reported areas and find the total volume of water in the marine water bodies listed in Table 2.8.

5. Find the area of the largest wetland in Georgia. How does this compare to other wetlands in the United States? In the world?

2.3 Sources of Streamflow

A stream *hydrograph* relates the *discharge* or *stage* of water as a function of time. The stream stage is the elevation of water in the channel, which normally increases as the discharge increases. The relationship between the stream stage and discharge is called the *rating curve*. A staff gage is a scale placed in the stream to measure the stream stage. The stream discharge is estimated by measuring the stream stage and then consulting the rating curve.

Between storms, streams normally decline slowly over time, rising in response to precipitation. The *rising limb* of the hydrograph corresponds to the period of time from when the stream stops declining until it reaches its peak. The *peak discharge*, or *peak stage*, corresponds to the time when the river reaches its highest level. The *falling limb* of the hydrograph corresponds to the period following the peak and lasts until the next storm.

The *time to peak* is the length of time between the peak precipitation and peak discharge. The *time of concentration* is the time required for flow to travel from the most distant point on the watershed. Times to peak are short in urban areas with large impervious surfaces and channels that have been modified to increase stream velocities.

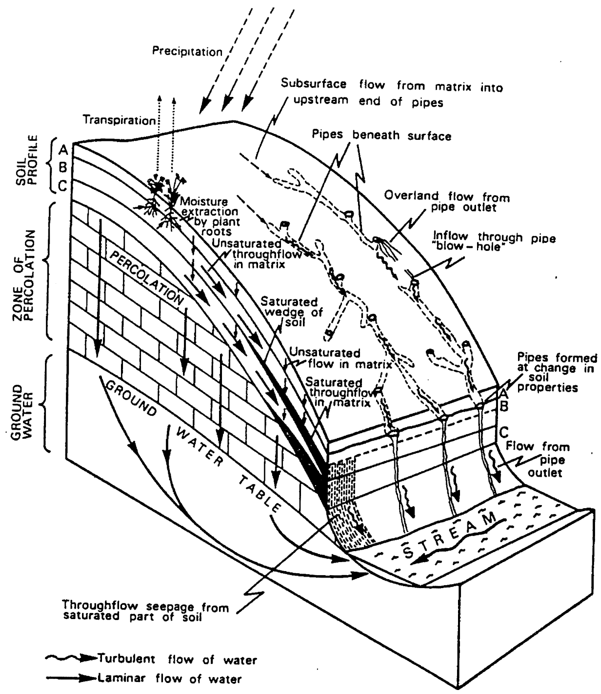

Figure 2.2: Components of flow on a hillslope.

Times to peak are longer in forested areas with few impervious surfaces and channels with many obstructions that slow the passage of water.

Hydrologists divide streamflow into two types of flow, *baseflow* and *stormflow*. Baseflow is that component which provides streamflow during low flow periods, while stormflow refers to streamflow that occurs quickly in response to precipitation events. If a stream was flowing before the rainfall (a typical situation), stormflow is the flow that occurs in addition to the baseflow that would have occurred if it had not rained. There are many ways to separate streamflow into stormflow and baseflow.

The source of water in rivers and streams has been a source of controversy from the dawn of history – many of the greatest scientists and philosophers have argued over this subject. Today we know that some of the water in streams comes from overland flow across impervious surfaces. This is especially the case in landscapes altered by humans, such as in cities and agricultural areas.

There are fewer impervious surfaces in forests and other areas less affected by humans. Streamflow in these areas is dominated by ground-water discharge as exfiltration from subsurface sources. Water infiltrates into the soil, recharging aquifers that then supply flow to streams.

One way of explaining runoff is the concept of the *contributing area*. The contributing area, or *variable source area*, model assumes that only certain areas within a watershed contribute to streamflow. These include saturated areas, such as lakes and ponds, stream channels, wetlands, and other areas of standing water, as well as areas where the soil is saturated at the surface.

Table 2.9: Summary of watershed hydrologic processes.

Precipitation - Atmospheric water falling on the surface of the earth.

Interception - Precipitation that is captured by plant surfaces before reaching the ground.

Throughfall - Precipitation not captured by vegetation and reaches the ground surface.

Stemflow - Interception that reaches the ground surface.

Infiltration - Water passing across the earth's surface into the subsurface.

Percolation - Water moving through the unsaturated zone.

Deep Percolation - Water moving past the root zone in the unsaturated zone.

Recharge - Water moving across the water table from the unsaturated zone into the saturated zone

Exfiltration or Groundwater Discharge - Water moving from the subsurface to the surface across the earth's surface.

The variable source area approach assumes that all rainfall infiltrates in some areas, while rainfall does not infiltrate in other areas because the soil is already saturated in these areas and runs off the surface. The observed runoff only comes from these contributing areas.

Precipitation on Channels

Some rainfall lands directly on the surfaces of streams, rivers, wetlands, and lakes, and obviously becomes stormflow immediately. This is usually a small percentage of the stormflow, however, because surface waters usually cover a small part of the landscape. This is not true in swamps, however, such as the Okefenokee, where large areas are covered with water.

Precipitation on Saturated Areas

Some parts of the landscape tend to stay wetter than others because water continually drains toward these areas between storms or because saturated soils lie near the surface. Hillslope hollows, low areas around streams and rivers, wetlands, and the margins of wetlands are examples of these areas.

During rainfall, soils in these areas may become completely saturated, and their *infiltration* rates may fall to zero. When this occurs, overland flow occurs on these saturated areas. This runoff generation process is also called the *variable source area* concept, because these saturated areas expand during rainstorms or during wet seasons because larger areas becomes saturated.

If the rate of rainfall exceeds the soil infiltration rate (the rate at which soil absorbs water), then water ponds on the soil surface. If the soil surface is sloped, the ponded water flows downhill toward the channel system. This is referred to as *overland* flow, *sheet* flow, or *surface runoff*. It is also called *Hortonian flow* after B.F. Horton, the hydrologist who first described this process in the 1930s.

The most obvious example of Hortonian flow is on streets and parking lots. In Georgia, Hortonian flow is also common on plowed fields and bare soils, but it rarely occurs in forests unless it rains hard, such as during a hurricane. Even then, however, forest runoff is more likely to occur due to saturation of the underlying soils, rather than due to low infiltration rates across the soil surface. The difference between the rainfall rate and the infiltration rate is the amount of rain that runs off the landscape.

Potential infiltration rates tend to decrease over time. When rainfall begins, the relatively dry soils near the soil surface absorb water faster than it can be carried by gravity alone. This uptake (also called *imbibition*) of water is the result of *capillary* forces (like how a paper towel absorbs water) in the soils.

As soil moisture contents become uniform with depth near the surface, the infiltration rate becomes equal to the soil's *hydraulic conductivity* (the permeability of the soil) for that moisture content. As infiltration occurs, there is typically a sharp moisture difference between the newly wetted soils and the drier soils below them. This sharp break in the moisture contents is called the *wetting front*, and it moves downward during the storm.

Because of the change in potential infiltration rates during rainfall, the occurrence of surface runoff depends not only on the intensity of the rainfall, but also on the timing of the intensity. For example, a rainfall rate of ten cm/hr is much more likely to cause surface runoff if it occurs after two days of light rain than if it occurs at the beginning of a storm.

Interflow

Interflow is lateral, shallow, subsurface flow that occurs on hillslopes with shallow permeable soil layers overlying low permeability layers. Interflow can occur as either *saturated* (soil pores are filled with water) or *unsaturated* (soil pores are only partially filled with water) flow. Interflow begins in a soil layer as soon as the wetting front crosses that layer and reaches the surface of the layer below.

Obviously, interflow does not reach stream channels as quickly as surface flow, but interflow is fast enough to generate part of the stormflow response. In some forested areas, interflow dominates stormflow response. Interflow continues between storms, transporting soil water from higher portions of the landscape to lower portions of the landscape. Interflow is of the processes that create *variable source areas* (saturated areas near streams).

Interflow does not occur in all landscapes. Interflow is more important when soil layers are thin and when slopes are relatively large. The Bt horizon can cause interflow because of its low permeability.

Baseflow

Streamflow between storms comes from *ground water discharge* (water stored in underground aquifers), *interflow* (hillslope drainage), and the draining of water stored in lakes and wetlands. Baseflow is not constant. It steadily but slowly decreases between rainfall events as water drains from the watershed (like how a bathtub drains more slowly as it empties). Baseflow is a critical determinant of habitat conditions in streams and rivers.

When flows are lower, there is less dilution of pollutant inputs resulting in higher concentrations of contaminants during low flow periods. Also, there is less *buffering* (attenuation) against solar and atmospheric heating of the water. Thus, stream temperatures can be a problem for fish during summer low flow periods. The ground water characteristics of a basin largely control the quantity, quality, and temperature of baseflow.

Problems

1. Select the letter in Figure 2.3 that best describes each of the following terms.

   ___ Precipitation
   ___ Interception
   ___ Transpiration
   ___ Stemflow
   ___ Throughfall
   ___ Overland flow
   ___ Depression storage
   ___ Infiltration
   ___ Evaporation
   ___ Percolation
   ___ Deep percolation
   ___ Unsaturated zone
   ___ Recharge
   ___ Water table
   ___ Saturated zone
   ___ Unconfined aquifer
   ___ Confining layer
   ___ Confined aquifer
   ___ Artesian well
   ___ Seepage, exfiltration
   ___ Groundwater discharge to stream
   ___ Water table well
   ___ Perched water
   ___ Plant roots
   ___ Wetland

2. Identify which landscape position indicated on the right side of the figure corresponds to:

   ___ Backslope
   ___ Floodplain/Terrace
   ___ Toeslope
   ___ Upland

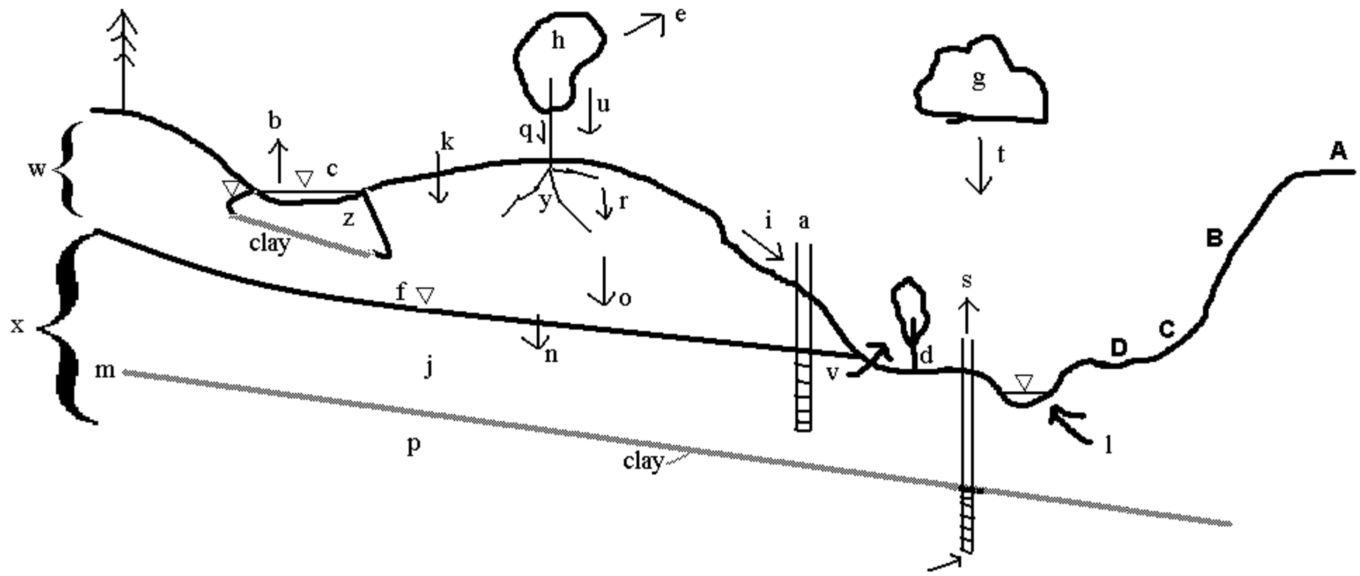

Figure 2.3: Definition sketch for Problem 1.

2.4 Hydrologic Alteration

Hydrologic systems responds to disturbance - whether natural or artificial - by changing the rates and magnitudes of flows, as well as the transport of materials by those flows. Natural disturbances, such as volcanos and earthquakes, can alter the topography of the landscape, as well as alter the soil and channel characteristics, thus strongly influencing the watershed hydrology.

Man also causes disturbance. The Southeastern United States has benefited by unbridled economic and population growth in the last half-century. Yet continued success is threatened by climatic extremes, including severe droughts and hurricanes. Trying to sustain regional growth in the face of these climatic uncertainties is a major challenge for water resource managers.

Land Uses

As we humans exploit our Planet Earth for our own benefit, we continually alter hydrologic systems, either intentionally or unintentionally. Urban areas increase impervious surfaces, and stormwater conveyance system route this water to nearby rivers and streams. Agricultural areas can alter the soil surface, exposing bare mineral soil and causing increased overland flow and sediment transport.

Forest road-building and harvesting can also decrease infiltration rates, thus altering the natural timing and quality of flows in streams. Grazing can alter the types of vegetation and soil properties, as well as disturbing channel banks and beds, resulting in increased stormwater flows and poorer water quality.

In addition to water shortages during droughts, coastal and upland flooding from tropical systems threatens the economic vitality in these areas. New insurance rates that better reflect long-term risks are compromising the financial ability of landowners and businesses to sustain development. Infrastructure costs to sustain coastal development are largely borne by the national government, yet these subsidies are likely to be less generous in the future. Competition for scarce coastal development funds is increasing as Florida and other states re-trench during the current economic downturn.

Mapping land uses and land covers is an integral part of water management. Each land use has a distinctive impact on aquatic systems. An obvious impact is the degree to which stormflows are generated. Managing stormwater runoff requires understanding the hydrologic behavior of the various land uses.

Water Storage, Withdrawals, and Return Flows

Humans need water for their modern way of life. In cities, water is used indoor for drinking, washing, bathing, and waste disposal. Agriculture uses water for irrigation. Power companies need water for thermoelectric cooling. Industries need water for manufacturing.

Water can come from a range of sources, including surface water, rivers and lakes, or ground water. Municipal and industrial water is commonly treated prior to use, to make the quality acceptable to the application.

Some of the water is used consumptively. That is, the water is diverted and then lost to evaporation or transpiration. Other water is non-consumpitve - it is returned to the hydrologic system. In the home, most indoor water is a non-consumptive use, i.e., it is returned to the river through a regional wastewater treatment facility, or to local groundwater through an onsite waste disposal (septic) system.

As water becomes limiting during droughts, competing interests vie for preference in water allocations. Agricultural water demand has increased as modern farming methods have triumphed over historic pests such as the Bowl Weevil, and as irrigation technology has improved. Industrial water use has changed as historic fiber-production declines have been offset by water uses in technology-based industries. Municipal water demand has increased, both due to burgeoning Sunbelt populations, as well as increased per capita water demand for modern conveniences. The perceived need to safeguard local water supplies means that other water users are viewed as competitors.

Channel Modification

A major cause of stream degradation is the alteration of the channel and associated flood plains. Straightening a river, building levees that disconnect a river from its floodplain, building culverts or bridges that artificially narrow a stream channel, all contribute to channel modification.

In addition, adding sediments beyond the natural conveyance capacity causes an channel agradation, while adding flows that scour stream bottoms will cause channel degradation.

Juxtaposed against these rapid demographic and economic shifts are the rich ecologic landscapes in the region - from coastal wetlands that support migratory species, to the Blue Ridge rain forests that support some of the most diverse aquatic ecosystems on the planet. Overlaying the modern post-industrial society on these landscapes is fraught with lose-lose opportunities. By dredging coastal wetlands for improved navigation and development, we hasten the impact of coastal storms. By building in mountain floodplains, we exacerbate both local and downstream flooding. Water quality alteration has resulted in cultural eutrophication - which threatens both natural and human systems.

Sustainability

Trying to incorporate principles of sustainability in regional development is (or should be) a major effort of water resources management. As noted by Magnuson in his recent court decision (July 17, 2009), "Too often, state, local, and even national government actors do not consider the long-term consequences of their decisions." While protecting ecosystems for their intrinsic worth is a noble endeavor, important ancillary benefits are the services they render. From plentiful and clean water, to recreational and aesthetic values, these services become more valuable as human systems increase in complexity and sophistication.

How to achieve sustainability is our grand challenge. Decreasing our ecologic footprint while reducing our sensitivity to climatic extremes is an engineering question that remains unsolved. In answering these management questions, the first step is to identify those best able to frame and describe the problem. I posit here that the scientific and technical communities are those best able to assist in upgrading from Growth 1.0 to Growth 2.0. Yet there is firm resistance within the resource management community, due in large part to the need to assuage stakeholders, as well as residual uncertainties in how ecologic systems function and respond to disturbance. As demonstrated many times, only a complete failure is sufficient motivation for change.

Problems

1. Find a map of land uses of Georgia. Where are most of the urban areas located? Forested? Agricultural?

2. Where are the large thermolectric power plants in Georgia located?

3. How do you think Georgia land use and population will change over the next century? Millennium?