WATERSHED PROCESSES

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INTRODUCTION

Today, the wildlife management profession faces the challenge of evolving from "population" managers to water managers, land managers, and habitat managers. Successful wildlife managers now must approach their work not only from a classical biologic perspective, but also from a watershed perspective. The recent recognition of riparian areas as critical wildlife and fishery habitats has contributed significantly to this shift in management focus.

A goal of this workshop is to define the abiotic and biotic components of riparian systems and discuss their ecological importance. This paper will present an overview of watershed structure, process and function, emphasizing the contribution of the riparian area to overall watershed condition.

WATERSHED DEFINITION AND CHARACTERIZATION

Simply stated, a watershed is any sloping land surface that sheds water. A somewhat more functional definition would be"all land enclosed by a continuous hydrologic drainage divide and lying upslope from a specified point on a stream". The terms "drainage basin" and "catchment" are often considered synonymous. The Society of American Foresters (1944) defined "watershed management" as:

> "The management of the natural resources of a drainage basin primarily for the production and protection of water supplies and water-based resources, including the control of erosion and floods, and the protection of aesthetic values associated with water."

The key words here are "production and protection of water supplies and water-based resources..." which includes fisheries as well as wildlife. The most important function of a watershed is to produce water. From a water supply standpoint, we are concerned not only with the total quantity of water yielded, but also with the timing of that yield (flow regimen) and its quality. These factors vary among watersheds, dependent primarily upon the climatic, topographic, geologic and vegetative characteristics of the drainage basin.

Climate can be defined as the long-term aggregate atmospheric condition produced by day-to-day weather (Martiner,1986). The climate of an area has direct bearing on both the quantity of water yield and the flow regimen. Measurable factors we typically use to describe climate include air and soil temperatures, freeze dates, precipitation (quantity, type, temporal and spatial distribution), humidity, evaporation, wind speed and direction, solar radiation, and atmospheric pressure. These factors within a watershed are governed by latitude, elevation, proximity to water bodies, and local topographic features.

Geomorphologists have been most responsible for developing quantitative techniques to measure topographic features of drainage basins and to explain their influence on watershed functions and processes (Brown, 1970). Over the past 100 years or so, literally hundreds of topographic measures have been devised to characterize the attributes of the basin as a whole (e.g. basin area, perimeter, length, elevation and relief), the total channel system or network (e.g. total stream length, stream order, drainage density), reaches within the total channel network (e.g. channel pattern, slope, sinuosity), and cross-sections within a channel reach (e.g. channel width, depth, perimeter, width-depth ratio). Within a climatic zone, the area of the watershed dictates the quantity of water yield, while length, shape and relief control the streamflow regimen and the rate of sediment yield.

The geology of a watershed in large measure determines the nature and extent of groundwater storage, the type of material available for erosion and transport, and the chemical quality of the surface water. Groundwater bearing formations sufficiently permeable to transmit and yield water (termed "aquifers") are commonly composed of unconsolidated sands and gravels which occur in river valleys, old stream beds, coastal plains, dunes and glacial deposits. Sandstone also serves as aquifer material, while shale, limestone, granite and gneiss do not unless highly fractured.

Weathering is the physical-chemical process whereby the minerals in rock at or near the earth's surface are altered under normal conditions of temperature and pressure. Weathering proceeds at widely varying rates dependent upon geology, climate, and vegetation. Topography and climate in large measure determine the rate at which the products of weathering, sediments, are removed or solubilized. These rock fragments, ranging in size from large boulders to fine materials, are termed "fluvial" sediments when transported by water. Movement may occur as sheet erosion from land surfaces or as channel erosion once runoff accumulates in streams. Within the stream, fluvial sediments are transported as "bedload" (particles moving within a few particle diameters of the bed) or as "suspended" load in the turbulent water column.

The vegetative character of a watershed is a function of climate, soils, topography, and land use. Vegetation cover plays a dominant role in controlling the timing and amount of water yield from a basin, as well as the quantity of soil available for transport to the stream channel as fluvial sediment. Hence, principles of erosion control focus primarily on rapid re-establishment of the plant community on soils denuded by land use activities. Often a watershed is characterized by the composition of its vegetation (e.g. coniferous forest, deciduous woodland, grassland, shrubland).

HYDROLOGIC PROCESSES ON WATERSHEDS

The circulation of water from the oceans to the atmosphere, to the land, and back to the oceans is referred to as the "hydrologic cycle". This cycle can be considered as system of water storage compartments and the flows within and between them, (Figure 1). Water is stored in the atmosphere and the oceans as well as in the soil, stream channels, lakes, ponds, groundwater, and vegetation. These individual storages and flows, termed "hydrologic processes", are defined in Table 1. Another way to consider the hydrologic cycle is in terms of the disposition of precipitation. This relationship can be expressed for a given time interval as the water balance equation,

$$P = R + ET + \Delta S$$

where:

- P = precipitation,
- R = streamflow or total water yield,
- ET = evapotranspiration,
- ΔS = change in water storage.

Rearranging this equation, controlling variables which a watershed manager has to work with to increase water yield can be identified,

$$R = P - ET - \Delta S$$

The variables in the water balance equation are typically expressed as "inches of water". This contrasts somewhat with the measures of water normally applied by water users ("acre feet") and stream habitat biologists ("cubic feet per second" or cfs). To relate these units, consider a 1000-acre watershed which receives 48 inches of precipitation annually. If 50 percent of this total becomes streamflow, the water yield is 24 inches. The total volume of water yielded for the year would be 2000 acre-feet (24 inches x 1000 acres x 1 ft/12 inches). The average discharge for the stream draining this watershed during the year would be 2.76 cfs (2000 acre-feet/year x 43,560 cubic ft/acre-ft x 1 year/365 days x 1 day/ 86,400 seconds).

The proportion of precipitation which results in streamflow is highly variable between geographic regions and vegetation zones. Water yield-precipitation relations from several locations in the United States are summarized in Table 2. These data also indicate that in general, the percent of precipitation resulting in streamflow increases with increasing precipitation. This is because evapotranspiration is the most constant variable in the water balance equation. Once the ET requirement is met, remaining precipitation is available for runoff.

Often, water supply problems are not problems of absolute water yield, but rather are related to the timing of that yield. The "hydrograph" is a basic tool of watershed managers used to describe the flow regimen of a river as well as the total runoff volume (Figure 2).

Hydrographs vary within and between watersheds, dependent upon the climatic, geomorphic, geologic and vegetative factors already discussed. For example, Figure 3 compares annual hydrographs from two midwest streams and a mountain stream from the Central Rockies. River A exhibits a flashy response to both precipitation and snowmelt runoff, indicating poor storage due to impermeable or shallow soil layers. The River B hydrograph shows little variation throughout the water year, despite a precipitation regime similar to River A, due to deep, permeable sandy soils having good infiltration and storage capability. The mountain stream hydrograph reflects the dominance of snowmelt runoff in our region, where approximately 75 to 80 percent of our annual water yield results from snowpack.

Sediment is a major product of watersheds which results in part from the hydrologic cycle. Sediment yield can be defined as the sediment transported past the drainage basin outlet from all fluvial erosion processes. It is typically measured in tons per unit land area per unit time. From a watershed management perspective, sediment yield is important because 1) it is estimated that 80 percent of water quality degradation results from erosion, 2) sediment interacts strongly with other water quality components, and 3) it is directly affected by land use activities (Anderson et al, 1976).

Erosion and sedimentation are the two phases of the process of detaching, transporting, and depositing particulate material from one location to another. Erosion refers to the removal and transport of material while sedimentation refers to its deposition and compaction. Within a watershed there are three types of erosion; surface, mass movement, and channel cutting. Each can contribute significantly to the total sediment yield.

Surface erosion is the detachment and removal of individual soil particles from the land surface and includes sheet erosion, rill formation, and gullying. Two hydrologic processes are primarily involved, raindrop splash and overland flow. Raindrops striking bare soil cause minor explosions that dislodge soil particles. These particles can be forced upward into suspension and moved downslope in overland flow. Overland flow itself may entrain additional particles, as can channelized flow in rills and gullies.

Mass movement of slopes is caused by gravity. When the cohesive and frictional strength of an earth mass fails, such movement occurs. If the rate of movement is perceptible to the eye, the term "landslide" is used. "Creep" occurs at a rate slower than the eye can perceive. Mass movement can result from either an increase in shear stress, a decrease in resistance, or both. Shear stress is the sum of all forces acting to displace the earth mass on the slope. While the weight of the soil itself is generally the primary stress component, water, vegetation, wind, vibration, downcutting and soil creep may also contribute.

Channel cutting refers to the detachment and movement of material from stream channels by flowing water. While much of the suspended sediment load transported by a stream is the product of erosion processes on the land surface of the watershed, the bulk of the sediment transported as bedload is the result of channel erosion. Channel erosion, like runoff, is highly variable over space and time. Sediment transport is a function of the availability of material to be eroded and the sediment transporting ability of the flow. Each stream has a fixed sediment carrying capacity, based upon its channel dimensions and hydraulic characteristics (Leopold and Maddock, 1953). A concept fundamental to sediment transport is that of stream power, the rate at which a stream does work and a measure of sediment transport capability. Stream power, expressed as pounds per foot of channel width per second, is the product of the specific weight of water, mean depth of flow, mean water velocity, and stream slope. As discharge changes, stream power and consequently sediment carrying capacity change at a particular stream location. Natural stream channels are seldom uniform from one site to another. Therefore, even though discharge may be constant at two stream locations, depth, velocity and slope will differ, resulting in varying patterns of sediment mobilization and deposition.

As a result of this temporal and spatial variation, stable streams may be characterized by a dynamic equilibrium. Sediment is eroded and transported primarily on the rising limb and deposited on the receding limb. At any given time, sediment is moved from one channel location and stored in another. Pools may be scoured at high flows while riffles are filled. The opposite may occur at lower discharges. The net result is that sediment moves downstream in a "wave" pattern, responding to the changing hydrograph and hydraulic characteristics of the channel.

RIPARIAN-WATERSHED INTERACTIONS

Within a watershed, riparian areas serve as the transition zone between the uplands and the stream channel network. Throughout the early settlement of the western U.S., these areas provided much of the food, shelter and fuel necessary for pioneer survival. Today, riparian zones are recognized not only as transportation corridors and high producers of timber and forage, but also as key habitats for a diversity of wildlife, a major component of fisheries habitat, prime recreation areas, and perhaps most importantly, a critical element in the overall management of any watershed. It is not surprising then, given this array of uses, that increasing attention is being given riparian areas by user groups and management agencies (Skinner, 1986).

The availability of water distinguishes riparian areas from the uplands. Riparian zones exist because water is more available to plants during their growing season,thereby promoting the dominance of species requiring a water table continually near their root zone. If the water table is lowered, hydrophilic species may be replaced by plants better adapted to more xeric conditions. Current research is exploring the magnitude and duration of such hydrologic flux in relation to changes in plant species composition. While the late summer "green" corridor along a stream in a semiarid region clearly indicates the water dependence of riparian vegetation, little difference may be observed between the upland and riparian areas along a mountain stream where moisture is abundant.

Riparian areas serve several important functions from a watershed perspective. Streamside vegetation plays a critical role in controlling channel morphology and geometry. Not only does root biomass serve to stabilize otherwise erosion prone streambank soils, but when overbank flooding occurs, the vegetative portions of the plants increase flow resistance on the floodplain, thereby slowing the water and promoting infiltration and recharge to the alluvial aquifer. Instantaneous water yield from a particular hydrologic event may be reduced in this manner. At least a portion of this water may then be released later from shallow groundwater storage to improve and stabilize baseflow conditions. Sediment transported by the overbank flow is deposited due to the stilling effects of the vegetation, thereby reducing sediment yield from the watershed. Plant nutrients, especially phosphorous and to some extent nitrogen, are often attached to sediment particles. Through increased sediment storage, nutrient loadings to the aquatic system can also be reduced by the riparian zone (Karr and Schlosser, 1978). This in turn encourages enhanced vegetation growth, streambank development and stabilization, and control of nonpoint source pollution through filtration of sediments delivered via overland flow from the uplands. Through the processes described, riparian areas function to modify flood peaks, enhance base flows, reduce sediment yields, improve water quality, stabilize stream channels, and benefit wildlife/fisheries habitat. Past studies have qualitatively defined these important functions. A focus of recent and current research is to quantify relations between riparian health, watershed type and condition, and land use effects, with emphasis on the creation and restoration of streamside zones. Several references are provided at the end of this paper for recent publications which describe the state-of-the-art.

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Table 1. Definition of hydrologic processes (from Rechard et al., 1978).

Hydrologic Process	Definition
Precipitation	The discharge of water, in liquid or solid state, from the atmosphere onto a land or water surface.
Throughfall	In a vegetated area, the precipitation which falls directly to the ground, including streamflow, canopy drip and windblown snow.
Interception Loss	That portion of the precipitation caught and held by vegetation and lost by evaporation, never reaching the ground.
Overland Flow	The flow of rainwater or snowmelt over the land surface toward stream channels. Upon entering a stream, it becomes runoff.
Infiltration	The flow of liquid water into the soil above the water table.
Subsurface Flow	Water which infiltrates the soil surface and moves laterally through the upper soil layers until it enters a channel.
Streamflow	The discharge that occurs in a natural channel.
Seepage	The slow movement of water from soil-water storage to groundwater storage.
Transpiration	The process by which water vapor escapes from the liquid or solid state into the vapor state.
Evapotranspiration	The volume of water evaporated and transpired from soil and plant surfaces per unit land area.
Water Yield	The total runoff from a drainage basin through surface channels and aquifers.

Table 2. Precipitation-water yield relations for different watersheds (Anderson et al., 1976; Wesche, 1982).

Location	Vegetation Type	Mid-Area Elevation (Ft)	Precipitation (In)	Streamflow (In)	% Water Yield
New Hampshire	Northern hardwoods	2,050	48	27	56
West Virginia	Central Appalachian hardwoods	2,500	58	24	41
North Carolina	Southern Appalachian hardwoods	2,700	72	36	50
Minnesota	Bog black spruce	1,385	31	7	23
Colorado	Lodgepole pine, spruce-fir	10,400	22	12	54
Arizona	Ponderosa pine, white fir	7,150	32	3	9
Arizona	Chaparral	4,250	27	2	7
Oregon	Douglas fir	2,500	94	61	65
Wyoming	Alpine	11,000	50	38	76

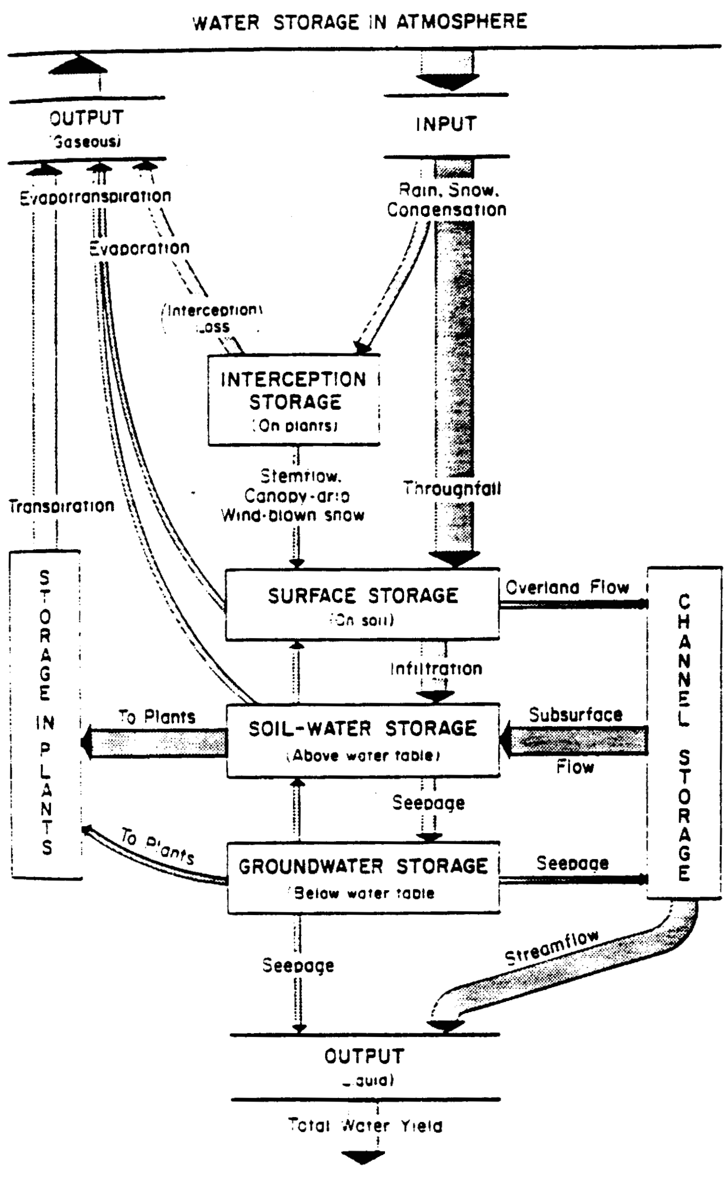

Figure 1. The hydrologic cycle. (Anderson et al., 1976).

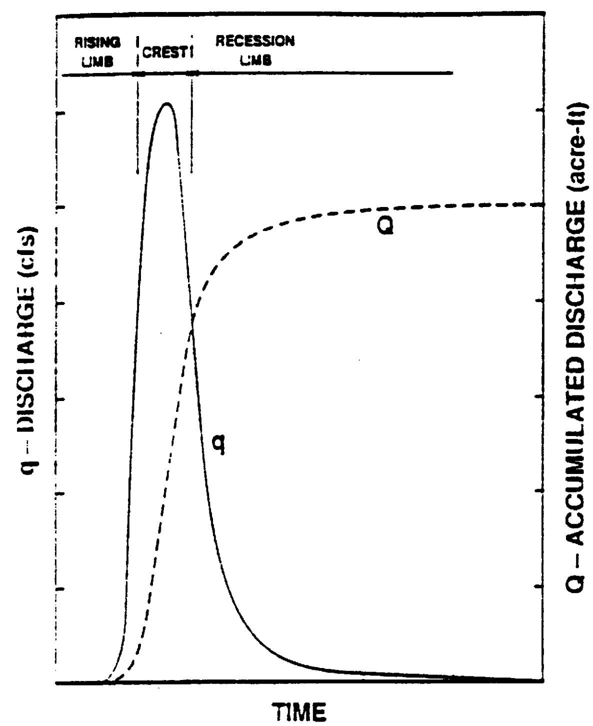

Figure 2. Component parts of a simple hydrograph. Q is the volume of runoff as related to time and q is the discharge rate at any point in time.

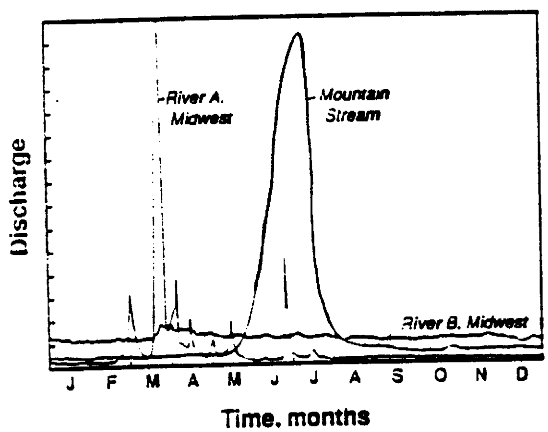

Figure 3. Annual hydrographs for two streams in the midwest compared to a typical mountain stream in the central Rocky Mountains. (Adapted from Hewlett and Nutter, 1969.)