RIVERS AND LAKES

Dollar E.S.J.
University of the Witwatersrand, South Africa

Keywords: rivers, lakes, drainage basin, hydrological cycle, hydrograph, sediment transport, climate change, succession, dams, human impact

Contents

Summary

Rivers refer to any natural stream of water that flows in a channel with defined banks. Lakes refer to any large body of water surrounded by land. The basis of understanding rivers and lakes is the hydrological cycle. The hydrological cycle refers to the movement of water from the atmosphere to Earth's surface and thence to the oceans. Regional variations of the relative significance of the various components of the hydrological cycle determine the amount of water available for rivers and lakes. The land surface area that contributes water to a river is known as the drainage basin. Drainage basin lithology and structural fabric determine the type of drainage pattern that a river displays. The ability of a river to transport material also has an impact on river channel pattern. Sediment transport ability is strongly linked to relief; Bloom has calculated that the total energy available for sediment transport is the equivalent of a 7.5 kW engine removing material from 1 km^2 for 24 hours a day, 365 days a year. Rivers are subject to changes in climate and base-level. Floods are shown to be an important part of the normal hydrological, geomorphological, and ecological functioning of a

river. It is argued that rivers should be seen as dynamic systems, and that any impact in one part of the system will be experienced in other parts of the system. Lakes are linked to rivers through the hydrological cycle. Lakes have many origins; major lakes are usually formed by glacial erosion or through tectonic activity. Lakes are dynamic, and evolve through time; young lakes tend to be deep, with limited biological activity, while older lakes tend to be shallow with high levels of biodiversity. Since the middle of the twentieth century, dam building has accelerated to the point where over 60% of the world's rivers are now regulated. The impacts of this regulation are widespread, and include detrimental hydrological, ecological, geomorphological, and socio-economic effects. It is concluded that humans need to develop a reverence for rivers and lakes, and to recognize the interdependence of all creatures and resources.

1. Introduction

A river refers to any natural stream of water that flows in a channel with defined banks. The word river comes from the Latin *ripa*, which means "bank." Central to the definition is the concept of channeled surface flow. The word "stream" is commonly used interchangeably with river. Stream is derived from the Indo-European route *srou*. Smaller, natural watercourses have various names including rivulets, brooks, burns, creeks, and so on. Rivers should not be confused with flows confined in human-made engineering structures such as canals, pipes, or culverts. Rivers make up only a tiny percentage of the world's water. Ninety seven percent of the world's water is held in the oceans, of the remaining three percent which is fresh water, three quarters is stored as land ice (i.e., in glaciers, ice caps), lakes contain half a percent, soil moisture 0.05%, and river channels only 0.025%. Rivers thus represent only one four-thousandth of the planet's total water. Although rivers make up a small percentage of the landscape, their impact on the landscape extends far beyond the channel itself.

From a geomorphologic perspective, rivers have three main functions; to erode, transport, and deposit sediment. In the process of accomplishing these three tasks, rivers destroy old landforms and create new ones. From a hydrological perspective, rivers are an important component of the hydrological cycle. Rivers are also significant in a biological sense, where water bodies can be divided into running (lotic) and standing (lentic) systems. Lotic systems consist of rivers and estuaries, while lentic systems consist of lakes, ponds, coastal lakes, estuaries, and wetlands. This chapter will consist of three major sections, rivers, lakes, and dams. Rivers and lakes are ultimately the major manifestations of the way in which subsurface and surface water move through a landscape. It is impossible to begin to understand how rivers and lakes are formed or how they function without considering the hydrological cycle.

2. The Hydrological Cycle

The abundance of water on the earth, and its occurrence in different forms (solid, liquid, and gaseous), is unique in the solar system. It is the ability of water to change from one phase to another that allows life as we know it on Earth to exist. Water in the form of rain and other precipitation (snow, hail, and sleet) falls on the continents and oceans. The water can then be evaporated directly back to the atmosphere. Water that is not evaporated directly back into the atmosphere has a number of pathways. It may infiltrate directly into the soil, where it will be stored as soil moisture or ground water. Over time, under the influence of gravity, the soil water will eventually make its way to the river as subsurface runoff. Water may also move back up to the soil surface through capillary action and then be evaporated back to the atmosphere. In addition, water may be utilized by vegetation and returned to the atmosphere through the process of transpiration. Water that runs off over the slope directly into the channel is known as surface runoff. It is important to note that runoff refers to all water that leaves the slope, drainage basin, soils, and river channel. The final path that precipitation may take is to fall directly into a river or lake, this is known as direct runoff. Precipitation in the form of snow or ice may also be stored in hollows or other places of accumulation. This movement of water from the atmosphere to the earth's surface and thence on to the oceans is known as the hydrological cycle, and is important in understanding how rivers and lakes operate (Figure 1).

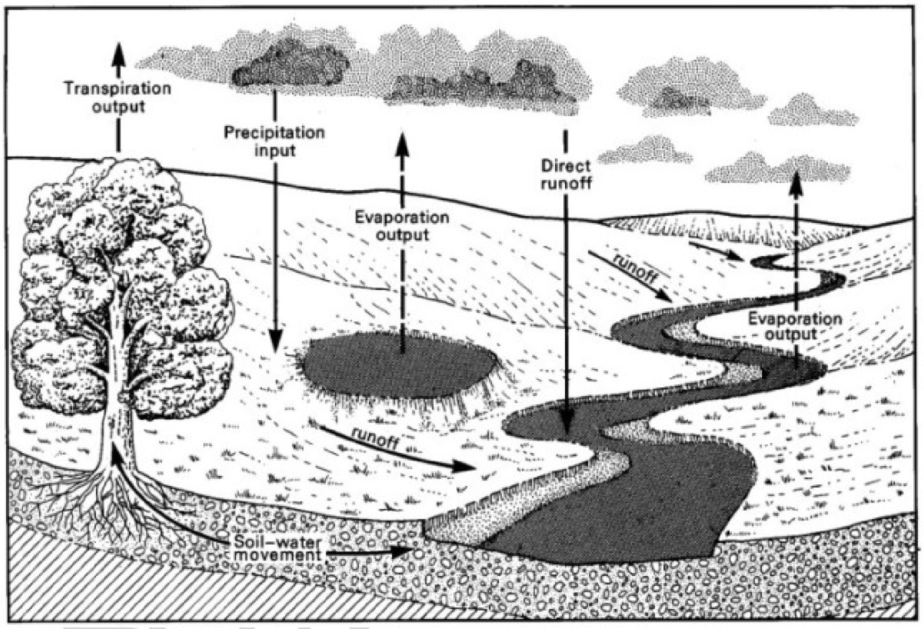

Figure 1. The hydrological cycle

The annual evaporation from the oceans is equivalent to a 1.4 m thick layer of water over the surface of the earth. Ninety percent of this is returned directly to the oceans via precipitation, the remainder falls on the continents. Of the remaining 10%, 35% is returned back to the oceans as runoff, the rest is lost to the atmosphere via evapotranspiration. The regional variations of the relative significance of the various components of the hydrological cycle determine the amount of water available for rivers and lakes. The rivers of the world reflect the global distribution of precipitation. The geographical variation of mean annual precipitation shows it to be highest in tropical areas where convective thunderstorms occur, but also between 35° and 60°N and S atmospheric instability and associated storms are common.

The chemistry of the water in the hydrosphere is of major significance, as it partly determines the nutrient supply and therefore also impacts strongly on the biosphere. The chemistry of the water is determined by reactions taking place with plant material, marine salt particles, and decomposing organic matter, as well as the rocks and soil. Water on Earth's surface is also diluted or concentrated by the addition of precipitation or removal via evaporation. However, the most important factor in determining the chemical composition of the water in all forms on Earth's surface is the input from the weathering of rock. Rivers draining different igneous, metamorphic, and sedimentary rock types, for example, have a varied chemical composition and particulate loads.

The hydrological cycle forms the basis of our understanding of the way in which rivers, lakes, and dams operate. Any alteration to one part of the hydrological cycle will have a domino effect in other parts of the cycle, so that in the end, the entire hydrological system may alter its state, and consequently, the impact will also be felt in the rivers, lakes, and dams.

3. Rivers

The drainage basin (or catchment area) is the most convenient unit for the study of rivers. The drainage basin refers to the land surface area that contributes water (and sediment) to the river channel. The study of drainage basin morphology (surface form) is termed morphometric analysis. The American engineer, Robert E. Horton described in mathematical terms the relationship between drainage basin morphometry, hydrology, and landscape evolution. The basis of morphometric analysis is the ordering of the stream network. The most common means of doing this is through a method developed by Strahler. This method involves designating the "finger tip" tributaries, first order streams; where two first order streams join they form a second order stream, when two second order streams join, they form a third order stream and so on (Figure 2). The ordering of the stream network makes it possible to define the relationship between stream order, stream number, stream length, drainage basin area, and stream gradient. All these relationships have a significant impact on the type of river that exists. They also determine how quickly flow (or a flood) moves through the drainage system.

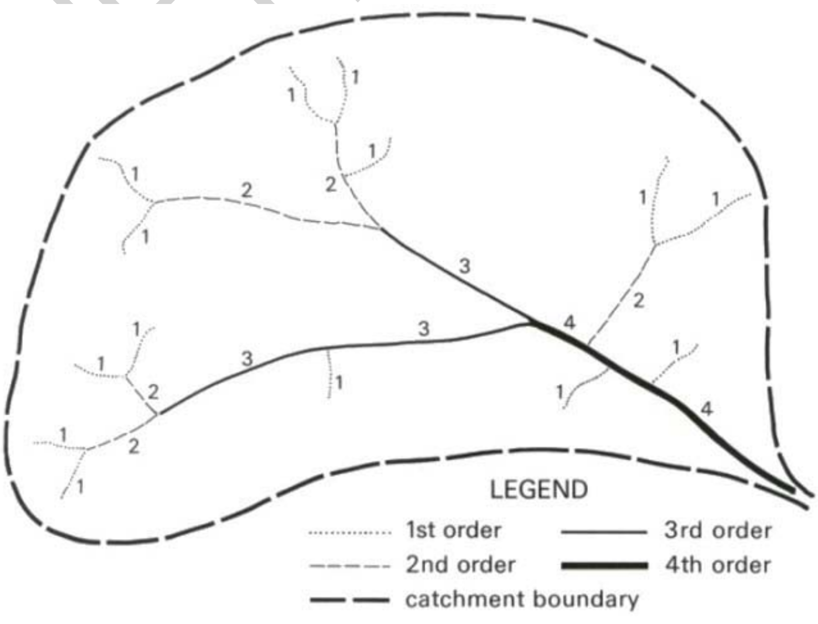

Figure 2. Stream ordering

The drainage basin lithology and structural fabric (the orientation and spacing of folds, faults, and joints) plays a very important role in the type of drainage pattern that a river displays. Where the drainage basin consists of a uniform rock type (and therefore uniform resistance to erosion), the drainage pattern is usually dendritic. Dendritic drainage patterns are usually found on horizontally bedded homogenous sedimentary rocks (Figure 3a). Where the drainage basin is strongly influenced by zones of weakness such as faults and joints, the river follows these lines of weakness and they develop a parallel pattern (Figure 3b). In drainage basins that are strongly affected by the folding of sediments, the drainage pattern is usually a trellis pattern, with short tributary streams along the flanks of the folds and the longer tributary streams flowing down the dip slopes (Figure 3c). A rectangular stream pattern (Figure 3d) usually develops in drainage basins when the fault or joint sets intersect at almost 90°. The drainage pattern of a drainage basin thus provides an indication of the lithology of the basin, as well as its tectonic history.

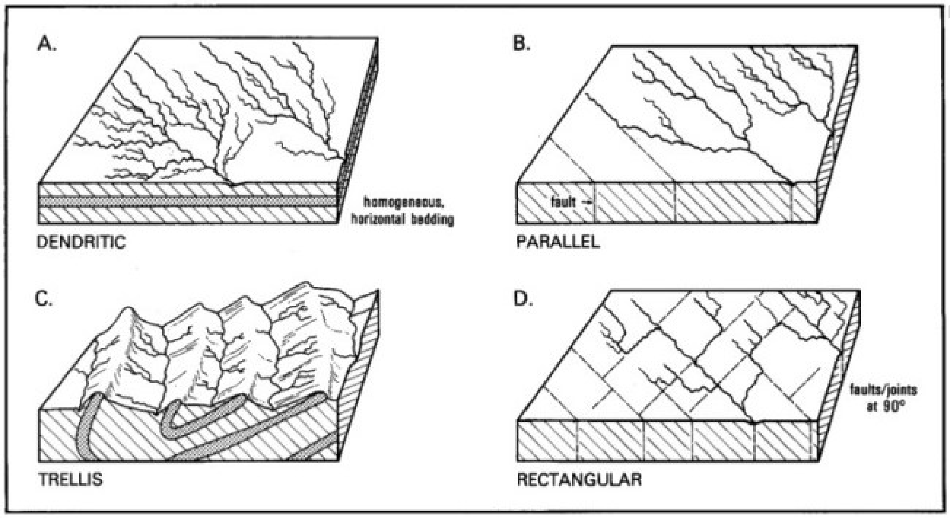

Figure 3. Drainage basin patterns. (a) dendritic drainage, (b) parallel drainage, (c) trellis drainage, (d) rectangular drainage

River	**Average runoff (km^3/yr)**	**Catchment area ($\times 10^3$ km^2)**	**Length (km)**	**Continent**
Amazon	6 930	6 915	6 280	South America
Congo	1 460	3 820	4 370	Africa
Ganges (with Brahmaputra)	1 400	1 730	3 000	Asia
Yangzijiang	995	1 800	5 520	Asia
Orinoco	914	1 000	2 740	South America
Paraná	725	2 970	4 700	South America
Yenisei	610	2 580	3 490	Asia
Mississippi	580	3 220	5 985	North America

Lena	532	2 490	4 400	Asia
Mekong	510	810	4 500	Asia
Irrawaddy	486	410	2 300	Asia
St. Lawrence	439	1 290	3 060	North America
Ob	395	2 990	3 650	Asia
Chutsyan	363	437	2 130	Asia
Amur	355	1 855	2 820	Asia
Mackenzie	350	1 800	4 240	North America
Niger	320	2 090	4 160	Africa
Columbia	267	669	1 950	North America
Magdalena	260	260	1 530	South America
Volga	254	1 360	3 350	Europe
Indus	220	960	3 180	Asia
Danube	214	817	2 860	Europe
Salween	211	325	2 820	Asia
Yukon	207	852	3 000	North America
Nile	202	2 870	6 670	Africa

Table 1. Major rivers of the world

The most obvious means of comparing the world's great rivers is on the basis of the size of the catchment area, length of the main channel, and the average runoff. Table 1 displays the major rivers of the world on the basis of these categories. By far the world's greatest river is the Amazon, both in terms of catchment area and average runoff. The Amazon accounts for approximately 20% of the world's total runoff. The Nile is the world's longest river, but ranks well below much larger rivers in terms of catchment area and runoff such as the Congo, Ganges, and Yangzijiang.

4. Rivers and the Hydrograph

The amount of water flowing in a river is called its discharge. Discharge is usually measured as units of volume per unit time, for example cubic meters per second or cubic feet per second. The flow of water is variable through time. The plot of discharge as a function of time is known as a hydrograph (Figure 4). The time unit can be shown in minutes, hours, days, or years. As a general rule, discharge increases downstream, as more and more water is added to the flow from tributaries joining the main channel and from water entering the channel from the banks or the bed. For most of the time, the water in the channel comes from base flow, that is, water that has entered the channel along its banks or from the bed from soil moisture or ground water. During rainfall events, water that enters the channel directly from the slopes in the form of runoff is known as quick-flow. The hydrograph serves as a useful tool in managing rivers. In

Section 9, reference will be made to the hydrograph and how it can be used in managing floods.

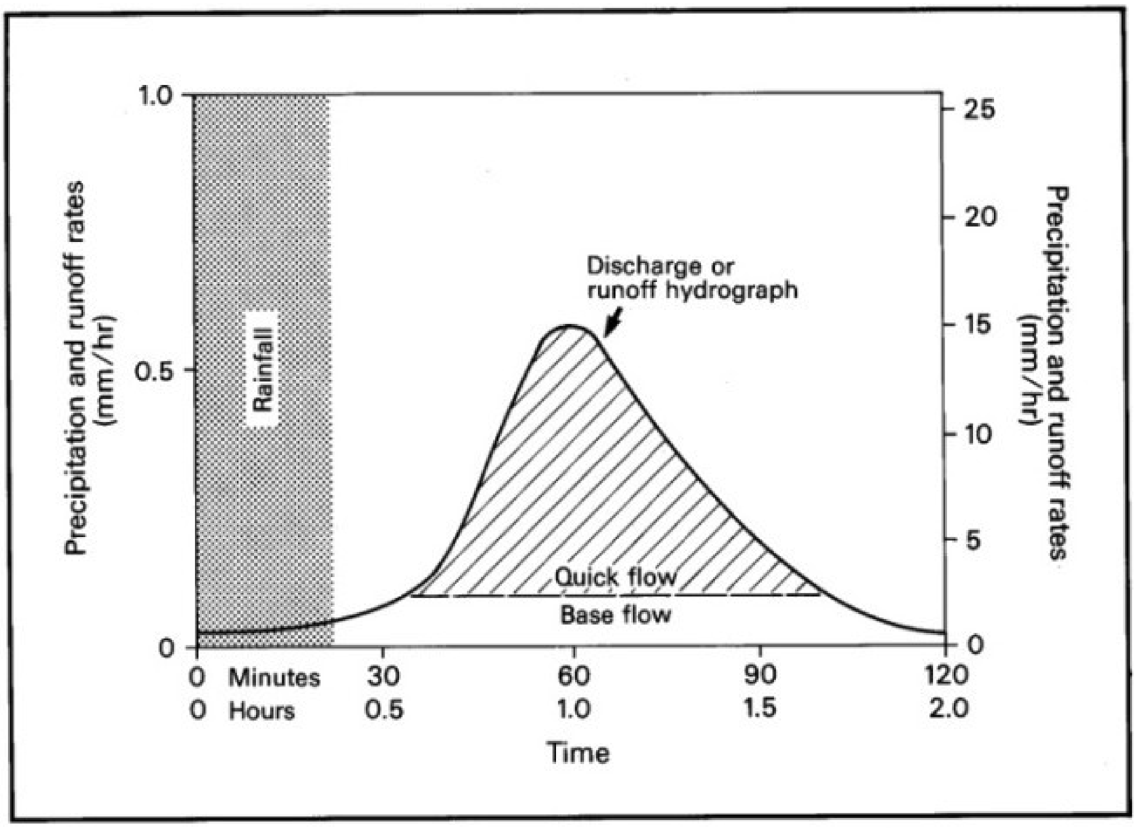

Figure 4. Hypothetical hydrograph relating rainfall to runoff

5. Rivers and Time Scales

Our understanding of how rivers function is dependent on the temporal and spatial scale within which we discuss them. In the long term (usually called geological time), variables such as lithology, tectonic history, and long-term climatic change are important. However, if one considers a river in a shorter time frame (usually called engineering time), variables such as the observed discharge of water and sediment are significant. At this time scale, factors such as lithology and tectonic history are constants (or independent variables), and as such, will have little impact on the river system. What is clear is that rivers are dynamic, responding to a variety of energy inputs. Depending on the nature of the system, these changes in energy inputs may be absorbed by the system without any significant change to form or process—this is called negative feedback. Alternately, a river may alter its form or process in response to a change in energy (positive feedback). What is clear, however, is that fluvial systems are constantly evolving.

6. River Energy

The ability of a river to transport material and modify the landscape is determined by the energy of the river. The energy of a river is defined by its potential energy. The potential energy of a river system is determined by gravitational forces, translated into mass and energy. The total potential energy of the world's rivers has been estimated from the average elevation of the continents and the mass of water discharged from the continents. This has been calculated by Bloom in 1967 as being around 3.2×10^9 kW. This is the equivalent of a 7.5 kW machine removing material from a 1-km^2 area 24 hours a day, 365 days a year. The cumulative effect of this energy is to reduce the land surface to flat plains. It has been estimated that the total rate of sediment delivery to the oceans is the equivalent of an average lowering of all the continents by 0.30 m every 9000 years. In fact, if it were not for tectonic and volcanic activity that constantly uplifts the surface and supplies new material for the crust, all the relief of the world would be removed in 25 000 000 years. Australia, a continent with no modern volcanic activity and very little uplift, has very little relief, and illustrates this point well. Work on drainage basins has shown that relief plays a primary control on the rate of denudation. Summerfield and Hulton have shown that the highest rate of removal of sediment from a drainage basin is the Brahmaputra River in India, which has 6700 m of relief and a mean denudation rate of 688 mm per thousand years.

As rivers flow downstream, so potential energy is converted into motion (kinetic energy). The velocity of the water in rivers is largely determined by its gradient and the resistance to flow (roughness). The gradient of a river refers to the change in altitude, as a ratio to its change in longitudinal distance. In many rivers, steeper gradients are usually associated with the upper, mountainous source area of the river. The gradient decreases with distance from the source so that near the river's exit to the ocean the gradient is normally very flat, and consequently the river is often wide and shallow. The gradient of a river can be seen through plotting a long profile of a channel. The long profile of a river can help point to the tectonic history of the river, and often the dominant processes that have shaped it over time. For example, arid and semiarid rivers often have a convex shaped profile. Similarly, rivers that have undergone tectonic uplift, or have carved through various types of rocks with different abilities to resist erosion, might show a nonsmooth profile, indicating adjustment. The ultimate level to which a river can erode its bed is termed base level. For most rivers, the sea is the ultimate base level. In some instances, a river may discharge into an inland sea, or large lake, the local base level.

-
-
-

Bibliography

Bloom A.L. (1967). Pleistocene shorelines: a new test of isostasy. *Bulletin of the Geological Society of America* **78**, 1477–1494.[This is a paper concerning the low sea stand.]

Davies B. and Day J. (1996). *Vanishing Waters*, 487 pp. Cape Town, South Africa: University of Cape Town Press. [This is a basic environmental monograph.]

Mulder T. and Syvitski J.P.M. (1996). Climatic and morphologic relationships of rivers: implications of sea-level fluctuations on river loads. *Journal of Geology* **104**, 509–523. [This is an important paper on sea-level fluctuations.]

Summerfield M.A. and Hulton N.J. (1994). Natural controls of fluvial denudation in major world drainage basins. *Journal of Geophysical Research* **99**(B7), 13871–13883. [The paper deals with fluvial denudation.]

Biographical Sketch

Dr Evan Dollar was born in Zimbabwe and educated at Rhodes University in South Africa as a fluvial geomorphologist. His research interests are primarily in the field of fluvial geomorphology, hydrology, and environmental change. He has been involved in research and as a consultant on numerous rivers and dams in southern Africa, and has lectured and presented papers around the world. At present, he is employed at the Centre for Water in the Environment, School of Civil and Environmental Engineering, at the University of the Witwatersrand, Johannesburg, where he is conducting research on the rivers of the Kruger National Park.