Zekâi Şen

Flood Modeling, Prediction, and Mitigation

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NOAH PHENOMENON — (GREAT FLOOD, WET SPELL)
JOSEPH PHENOMENON — (DROUGHT, DRY SPELL)

There is sensitive balance in nature as a sequence of dry and wet periods, which needs care for their preservations without destroying the balance in the environment. This book is dedicated to those who care for such a balance by logical, rational, scientific and ethical applications for the sake of other living creatures' rights.

Preface

Floods are among the natural extreme events that occur after intensive storm rainfall events as excessive water volumes over the earth surface more than the capacity of surface natural or artificial conveyance systems (stream and river basins, creeks, estuaries, wadis, valleys, canals, channels, culverts, dams, cities). Apart from the rainfall causative floods, there are others as consequences of snowmelt, sea surge and tides, tsunamis, ground water level rise, urban sewer capacity overflow, dam breaks in addition to confined aquifer overflows.

Since the start of human history, societies have been exposed to the danger of natural events such as earthquakes, droughts, and floods that could not be avoided completely even with the modern-day scientific and technological facilities, preparedness, mitigation, and early warning systems. The most hazardous extreme natural event is the flood occurrence not only due to the intensive rainfall effects, but more significantly due to human settlement along flood dangerous areas such as floodplains, adjacent to riverbanks, and valleys. The floods are extremely beneficial events in arid regions, because they are the main source of groundwater recharge along drainage basins (wadis), where there are no human settlements or urban area exposed to flood danger. For this purpose, there are even runoff harvesting works in many arid regions of the world. However, flood beneficial aspects are outside the scope of this book, which is concentrated on floods and flash floods.

In order to achieve successful works to reduce flood danger and hazard, it is necessary to know scientific fundamental aspects of flood definition and generation processes, which pave way for methodological procedures to predict their future behaviors and to take precautions by means of hardware through the engineering water structures and software by means of early warning systems and also public awareness through educative training.

The main purpose of this book is to bring together all the layman, technicians', engineers', and scientists' methodological procedures that have been developed for flood peak discharge prediction during the last 150 years. Early approaches are rather logical and empirical, but later on, more systematic and analytical approaches are developed on the basis of rational, probabilistic, statistical, and stochastic uncertain methodologies in a better objective manner. Empirical formulations are location dependent and cannot be applied to other parts of the world with satisfaction. Their old versions, prior to the rainfall recording, are dependent on the drainage basin area, but later versions include the rainfall amount or intensity. Today, the evolution of the flood peak discharge calculation methodology has reached to the employment of remote sensing and satellite image procedures coupled with digital elevation model (DEM) in the electronic media as for the surface morphological feature description, which is an essential ingredient in flood discharge prediction.

This book after the introductory chapter explaining the flood definition, types, physical causes, relationship to the overall hydrological cycle, and hazard types enters the domain of methodological procedures starting with the precipitation characteristics that take role in flood occurrence in addition to the surface features of drainage basin in terms of geomorphological variables. In two of the chapters, the hydrographs and flood discharge estimation empirical methodologies are presented with basic and fundamental explanations. The uncertainty aspects are presented through the probabilistic and statistical procedures including risk concept and return periods, which correspond to life of an engineering water structure. In the mean time, the sedimentation and debris expositions of various engineering structures are presented with some innovative recommendations for the first time in this book. In the last two chapters, climate change impact relationship to floods and also the flood hazard and mitigation procedures and approaches are exposed with the latest developments. In each chapter, some criticism and new suggestions are proposed for future better methodological advancements.

The content of this book is based on the vast experience of the author especially in arid region of the Arabian Peninsula through his academic work at the King Abdulaziz University, Faculty of Earth Sciences, Kingdom of Saudi Arabia; at the application establishment of the Saudi Geological Survey, Jeddah; and also at the Meteorology and Civil Engineering Faculties at the Istanbul Technical University, Istanbul, Turkey.

I hope that this book will support to those interested in flood discharge estimation with risk attachments, climate change relationships, hazard and mitigation aspects, and their applications in flood prevention works. I thank my colleagues who have encouraged me to write a book on floods and especially my wife Mr. Fatma Şen, who had kept silence, endurance, and patience during my extensive hourly, daily, monthly, and yearly works for the preparation of this book.

Çubuklu, Istanbul, Turkey Zekâi Şen
2016

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Chapter 1
Introduction

Abstract Floods are among the major natural extreme and dangerous events that cause loss of life and property, and they are the most frequent extreme occurrences in different parts of the world. A broad definition of floods and their types are explained with meteorological and hydrological causative triggers and the consequences. Ordinary and flash flood features are presented in a comparative manner so that the reader can appreciate the difference between them. Flood hazards are exposed with recommendations and human pre-flood preparation procedures. It is emphasized that the floods are although natural phenomenon, but skewed settlements especially along the main watercourse such as the flood plain are also effective in the flood losses.

Keywords Definition · Flash · Flood · Hydrology · Hazard · Meteorology Ordinary · Plain

1.1 General

In many places, excess water may become a disaster rather than a temporary inconvenience, especially if there are not early warning flood plans and the basic flood inundation maps, which are very essential for flood-prone region short-term and long-term protections. If there are limited communication facilities in a society, then any prolonged and widespread flooding may become a disaster more than ordinary event. On the other hand, it must be kept in mind that if there are no flood dangers in drainage basins, then floods provide rich groundwater recharge possibilities, especially in arid and semiarid regions, which should be considered as benefit. Any society must be prepared for flood awareness and at least for the preparation of flood inundation maps based on the fundamental flood estimation methodologies, which are the topics of this book.

Abundance of water is referred to as floods after intensive storm rainfall events (frontal or convective types) over the earth surface more than the capacity of surface natural or artificial conveyance systems (stream and river basins, creeks, estuaries,

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wadis, valleys, canals, channels, culverts, dams, cities). Apart from the rainfall causative floods, they can be triggered also as a result of snowmelt, sea surge and tides, tsunamis, ground water level rise, urban sewer capacity overflow, dam breaks, and confined aquifer overflows. Floods have depth, areal extent, speed, and debris leading to unwanted sedimentation problems (Chap. 7). They may have threats in cases of intensively developed settlement or human activity concentrated catchments as a result of land use otherwise they do not cause any risk and danger in natural flood plains.

Impact of water-related phenomenon can be categorized into three groups according to their end consequences. In general terms, these groups are water scarcity, water availability, and excessive water occurrences (Şen 2005). Water availability is the most demanding aspect of water activities, and therefore, other two extreme cases must be rendered to support this domain through the application of scientific and technological facilities at large. Although, water is the most fundamental material for life sustenance on the earth, its occurrence and distribution are rather haphazard with temporal and spatial irregularities. For the maximum benefit from such irregularly variable water amounts, it is of prime importance to control and manage water according to certain basic scientific and technological developments. Water resources development scale is an indicator of prosperity for any country. Under the light of above classification, the management and control practices and approaches vary, and their applications in the field are the end products that help to sustainable development for the society.

The main causes of flood are the total amount and distribution of precipitation in the drainage area. Three natural factors that give rise to flood occurrence are the rainfall type and intensity (Chap. 2), drainage basin surficial features (Chap. 3), and subsurface soil and geological composition. Hence, assessment of a flood requires knowledge from meteorology, surface water hydrology, and hydrogeology disciplines.

Floods are initially more conspicuous, because they can occur over days or weeks instead of months or years. Floods arise from conditions that are somehow different than the established norms. Climate may not turn out to be a smooth continuum of meteorological possibilities after all, but rather the summation of multiple processes operations have additional significance both regionally and globally on differing time scales. Floods occur within local and global context of climate. It is necessary to understand the geography and meteorological response of a given watershed. One should also look beyond basin boundaries to appreciate the coherent patterns that influence weather regionally.

A flood is an overflowing of water from rivers onto adjacent land leading to inundations. Flash floods can explode suddenly out of a single summer thunderstorm. Flooding, however, can also be caused by a month-long buildup of moisture, such as the fast melting of a heavy winter's accumulation of mountain snow or soil saturated by high seasonal rainfall. All floods are shaped by the basin through which they flow. Spatial and temporal scales of floods are generally linked to the corresponding time and space scales of the flood -generating rainfall combined with weather and climate change conditions (Chap. 8).

Natural flood disasters related to the atmospheric origin are costly and their cost increases steadily due to social activities, industrial developments, and to a certain extent climate change. In many countries, most of the population lives in major cities, which are highly populated urban areas without sufficient infrastructure and also along the coastal areas. As a result, most of the commercial, trade, and industrial activities are prone to water disasters. On the contrary, human activities also affect the natural events as a result of not only climate change and global warning, but also local increase of impervious surfaces due to construction and asphalt roads and squares as well as the heat islands. Storm and flood losses have increased steadily in the last 30 years all over the world. Historical and conventional studies concerning the climate and floods do not provide reliable prediction for future behaviors of these events. Consequently, there may appear estimation errors in large percentage limits. The reduction of the estimation error will require not only the refinement of the basic knowledge and methodologies but also network design and monitoring system development. Any model has many restrictions, assumptions, local requirements, and time specifications. Therefore, a model that is developed for a specific country or region cannot be useful directly with the quantitative data for some other region. For the success of such a model, the necessary initial and boundary conditions must be identified for the area concerned. For instance, the risk levels of flood plains and inundation risks of coastal areas must be prepared at least approximately on a qualitative basis. However, there are objective quantitative techniques for proper digital description of the risks level (Chaps. 6 and 9). It is necessary to prepare risk maps for any natural disaster including flood risks also. Depths of floods in risky cross sections should also be identified for the establishment of assessment problems (Chap. 4).

The model for flood predication and assessment should require the flood discharges and their occurrence dates for proper investigation. In this book, especially, the statistical properties of each site flood records are conventionally desired as model inputs, but another necessity is their regionalization for proper spatial and regional interpretations. On the other hand, there might not be available data for the area of interest, and therefore, possible flood consequences could be carried from the record-known sites to the area of interest. Even the models that are used in practice cannot be capable of producing the resolutions that are needed by the planners, and therefore, downscaling procedures should be applied for attaining desired information. Model results may not be reliable especially for the tropical and mid-latitude regions. Besides, the models are average parameter producers, and therefore, possible deviations from these averages must also be accounted for. Even though the standard deviation around the mean does not change, this does not mean that the changes will be in a linear fashion, but unfortunately, the extreme events such as floods appear in a nonlinear manner. This point should be taken into consideration in future predictions.

When rainfall covers any area, the water evaporates and infiltrates, and runoff may occur on the surface as flood. The process of generating floods depends on many factors; the most important one is the character of rainfall including intensity, time, and depth intensity–duration–frequency (IDF) curves, (see Chap. 2), the climatic conditions of the area, and the soil characters of the stream. The flood water moves in different directions according to the topography and the slope of the ground toward the mainstream. Flood usually starts with/after rainfall and continues to a time interval after falling (Viessman et al. 1989).

Runoff assessment requires sufficient data about climate conditions such as rainfall, infiltration, and evaporation. In addition, geomorphological and geological settings are needed as well as data with regard to surface water stage heights, if available, and water quantity and velocity.

In any flood study, satellite images, digital elevation model (DEM) data and aerial photographs are utilized to delineate drainage boundaries, while control sections of wadi channels are measureable in the field by leveling instruments (Chap. 3). Also observations of the highest flood level marks in the field are gathered and other relevant information is obtained from local inhabitants (Chap. 8). This preliminary information is used to construct rating curves in the control sections by using empirical formula (Chap. 3). The infiltration rates through the alluvium surface can be determined by the use of double ring infiltrometers in the drainage basins, which are referred to as wadis in arid and semiarid regions (Şen 2008a). There are a set of empirical and rational flood peak calculation methodologies among which the most suitable one can be selected for a preliminary assessment (Chap. 5). Hydrological parameters for the rational methods are presented in detail by Maidment (1993).

Only engineering structural protections cannot serve the community, but more significantly the pre-flood warning through the flood inundation maps are very helpful for future planning by local and central authorities. Furthermore, past experience has shown that the engineering structures fail in many cases due to either insufficient calculation or construction or the record breaking behavior of natural events. The main rule considered in this book is that rather than the trust to an engineering structure and expansion of the activity within the flood plain, it is wiser to depend on the flood inundation maps and especially on the risk calculations in planning for future developments in a potential flood-prone area (Chaps. 6 and 9).

According to a report by the U.S. Congress's Office of Technology Assessment, "despite recent efforts, vulnerability to flood damages is likely to continue to grow." The factors cited include the following points.

(1) Growing populations in and near flood-prone regions,
(2) The loss of flood-moderating wetlands,
(3) Increased runoff from paving over soil,
(4) New development in areas insufficiently mapped for flood risk,
(5) The deterioration of decades-old dams and levees,
(6) Policies such as subsidies that encourage development in flood plains.

A very significant factor that should be added to this list is the anthropogenic climate change impacts (Chap. 8). Although a number of water balance studies have been conducted for a variety of watersheds throughout the world, the rainfall–runoff studies in addition to the water balance of the arid and semiarid lands present some interesting challenges (Flerchinger and Cooley 2000; Scanlin 1994; Kattelmann and Elder 1997; Mather 1979). These watersheds, which are dominated by precipitation and evaporation, exhibit a high degree of variability in vegetation communities on scales much smaller than addressed by most hydrological modeling. Thus, arid region wadis (catchments) pose a unique set of problems for hydrological modeling.

Extreme situations are rather uncontrollable due to hazard potentiality, but their impacts can be reduced significantly provided that a certain risk level is accepted in water structure designs such as dams, culverts, land use, industrial area development, agricultural land allocation, and similar activities, last but not the least, also the impact of present climate change should be taken into consideration in all future projects (Chaps. 8 and 9). The risks are more serious in arid and semiarid regions, because of the potential flash flood occurrences, which cannot be pre-warned easily (Chap. 5). It is, therefore, preferable to prepare flood hazard maps that guide any development level and areas in a flood-prone drainage basin. This book also provides effective field and office works in addition to reliable models for flood hazard map preparation (Chap. 6).

1.2 Flood and Hazard Definition

Floods are the common name for extreme runoff volumes after an intensive storm rainfall event over a drainage basin. This definition indicates two components for flood occurrences, which are the rainfall intensity and the drainage area features. It does not imply that intensive rainfall events will lead to floods. For flood occurrence, certain features of the drainage basin are important and without them even though the rainfall might be very intensive, but there might not be any flood event. Among the most significant drainage basin features are drainage basin areal extend, slope and especially cross-sectional area variations along the main channel course.

A flood is an overflowing of water from rivers, streams, main channels, wadis onto land that do not experience usually inundations. Floods also occur when water levels of lakes, ponds, reservoirs, aquifers, and estuaries exceed some critical value and inundate the adjacent land, or when the sea surges on coastal lands are much above the mean sea level. Nevertheless, floods are natural phenomena important to the life cycle of many biotas, not the least of which is mankind. Floods are the most destructive of natural disasters and cause the greatest number of deaths. Spatial and temporal flood scales are generally linked with the corresponding scales of the flood-generating thunder storm events.

A flood is defined also as any relatively high flow that overtops the natural or artificial banks in any reach of a stream. When banks are overtopped, water spreads over the floodplain and generally comes into conflict with man. It is important that floods should be controlled so that the damage caused by them does not exceed an acceptable amount. Man must acquaint himself/herself with the characteristics of floods if he/she is to control them. Although floods vary from year to year, their measurements should be carried out regularly. Analysis of flood records provides a better understanding of the phenomenon (Linsley et al. 1982).

The most flood-prone environments are presented in Fig. 1.1 including five areas in general irrespective of hydrological regime.

Low-lying areas suffer the most from the flooding and inundation hazards. Many thousands of populations live in these areas due to the groundwater availability and transportation facilities. In small basins, flash floods occur more frequently, because during an intensive storm rainfall the basin receives more than it could transfer as surface water in a short time of period.

Floods may also result from dam failures, which give destruction and damage to downstream-located activity centers such as urban areas, industrial plants, agricultural lands. Shoreline flooding due to sea level rise is also possible in some countries. Alluvium fans are attractive for urban development with their groundwater potentiality, but in the same time especially in arid regions, they create special type of flash flood treats. Alluvial fans are risk-prone environments, because the drainage channels can meander unpredictably across the relatively steep slopes, bringing high velocity flows (5–10 m/s), which are highly loaded with sediment.

On the contrary to the natural cases, there are also artificial flood occurrences due to human activities. The closer the urban land use to the main channel stream, the more prone is to inundation, and consequently, drainage cross sections that have not been prone to flood hazard before, may become under the threat of flood danger. Hence, it is possible to divide the flood hazards into two complementary sections as natural and artificial flood hazards as shown in Fig. 1.2.

There are not enough floods studies in arid regions. In these water stricken regions, flood waters can be stored in the form of surface or subsurface reservoirs. In addition, most of the engineering structures across watercourses are under designed and in small intensity floods they may be subjected to damage or even complete washout. This damage might extend to agricultural lands and to other human properties. Furthermore, the sediments transported during floods may result in the filling of hand-dug wells and ditches. Most of the alluvium aquifers in arid

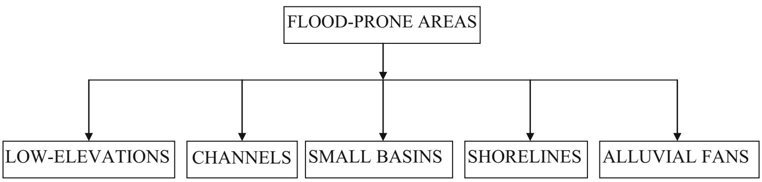

Fig. 1.1 Flood environments

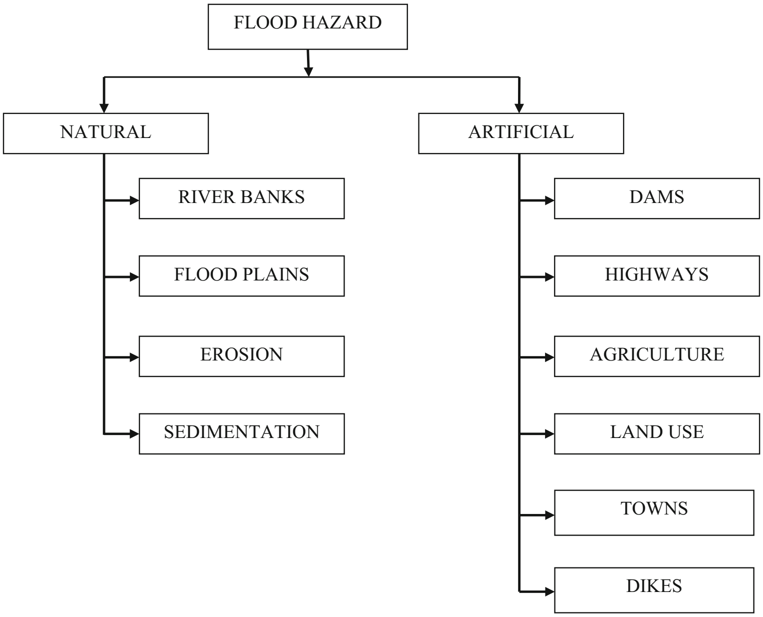

Fig. 1.2 Flood hazards

regions occur in the wadis (dry valleys), which provide depressions for deposition and occasional surface runoff occurrences. The groundwater reservoirs in these wadis are directly related to flash floods. Groundwater resources in arid region aquifers are depleted through pumping or by natural subsurface flow into the sea. However, it is replenished during floods following adequate rainfalls. These replenishments of groundwater depend on the local climatological and geomorphological conditions, in addition to the geological composition of the area (Şen 2008a).

The absence of detailed records on major floods is noticeable in most basins. In general, comparatively more recorded data exist on normal rainfall. The set of available rainfall data together with the drainage basin characteristics facilitate the use of empirical equations to estimate relevant flood discharges. As explained by Parks and Sultcliffe (1987), the problem of flood measurement is more acute in arid areas than elsewhere.

Apart from the flood hazards there are also a variety of benefits provided that the flood management planning is based on local experience, expertise, scientific methodologies, and technologies. For instance, flood plain inundation provides groundwater recharge possibilities, which may support round-the-year water supply through surface and subsurface water structures. Floods also carry nutrients in addition to sediments, which help to enrich soil.

1.3 Hydro-meteorological Events

Water-related problems cannot be solved only by consideration of the measurements, but the physical mechanisms should be also thought for the integrated flood estimation methodologies. The trend for integrated water resources management (IWRM) also includes integration of flood management for sustainable development and human security. Any successful IWRM should be based on the flood hazards vulnerability and society that are under the effects of flood risks. Although the rainfall is the triggering event for surface flow and its extreme values as floods, its quantitative and qualitative features must be identified in a combined manner. Toward the best solution meteorology, climatology, surface hydrology, and finally, hydraulics principles inter-effectively play common role for flood problem solutions.

The main causes of flood are the amount and distribution of precipitation in the drainage area. Three natural factors that give rise to flood occurrence are the rainfall type and intensity, drainage basin surficial features, and subsurface soil and geological compositions. Assessment of a flood requires knowledge from meteorology, geomorphology, geology, and surface water hydrology and hydraulics principles.

1.3.1 Global Environment and Cycle

Hydrological cycle is the combination of all possible waterways among the atmosphere, lithosphere, biosphere, hydrosphere, and cryosphere in addition to specific ways within each one of these spheres. Human beings, animals, and plants are dependent on some gases, water, nutrients, and solids that are available in nature quite abundantly in sensitive balances and almost freely for their survival. The most precious ones are the air in the atmosphere that is essential for living organisms to breathe and the water that is available in the hydrosphere. The atmosphere has evolved over geological time history, and the development of life on earth has been closely related to the composition of the atmosphere, hydrosphere, and lithosphere. From the geological records, it seems that about 1.5 billion years ago free oxygen first appeared in the atmosphere in appreciable quantities, (Harvey 1982). The appearance of life was very dependent on the availability of oxygen, but once sufficient amount was accumulated for green plants to develop, then photosynthesis was able to liberate more into the atmosphere. The various spheres and their interactions for human survival on the earth are shown in Fig. 1.3 (Şen 1995). Hydrosphere consists of oceans, lakes, and rivers, whereas lithosphere forms the continental crust, and biosphere includes the living kingdom of continents and oceans. Although these natural systems are very different in their composition, physical properties, structure, and behavior, they are interlinked to each other by exchanging fluxes of mass, energy, momentum, and hydrological cycle (Şen 2008b).

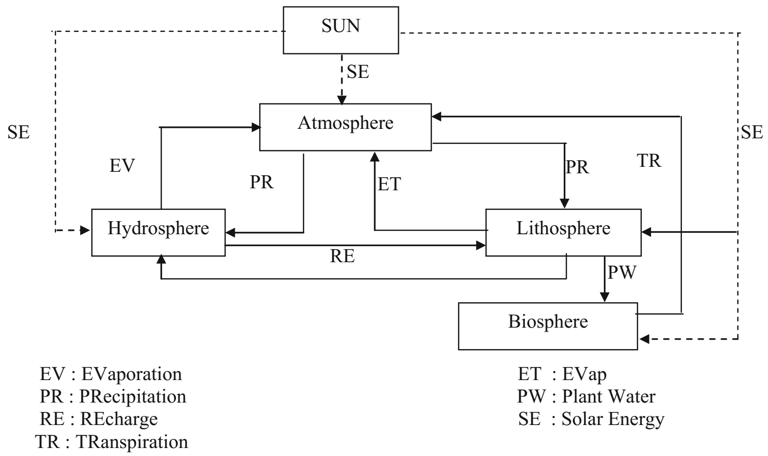

Fig. 1.3 Spheres and their environments

In any part of the world, the hydrological cycle functions fully or partially, and especially in arid and semiarid regions functioning is not continuous, but depends on the season of the year. Rainfall phenomena are the major hydrological events, which subsequently cause other hydrological events such as the depression, interception, evaporation, infiltration, runoff, and flood. These are the vital hydrological elements for the existence of life in a region.

1.4 Hydrological Cycle

Hydrology is the science of water occurrence, movement, and transport. Furthermore, it is concerned with local circulations through the atmosphere, lithosphere, biosphere, and hydrosphere dealing with water movement, distribution, quality and environmental aspects. In general, it deals with natural events such as rainfall, runoff, drought, flood, and groundwater occurrences.

The hydrological cycle of rainfall, runoff, and evaporation does not exist in isolation. The interaction at various time scales between the hydrological cycle and the cycle of erosion and sedimentation has long been recognized. More recently, the study of the earth–chemical cycles of carbon, nitrogen, and sulfur has revealed the importance of their linkage to the hydrological cycle. These three cycles (hydrological, erosion, geochemical) can be considered as part of a general earth system, which interacts in turn with the regional socioeconomic system. Population growth and economic development combine to increase the demand for good quality water. At the same time, these two factors also combine to impact the geo-system in such a way so as to reduce the supply of clean water. The continuation of these two tendencies in the future is expected to produce water crises of unprecedented magnitude.

Human beings try to benefit from different ways of water movements to their advantage for the prosperity of society. It is, therefore, necessary to develop different and convenient techniques for the assessment of these movements, and if possible to delay or speed up their sequences such that right water demands are met at right times and places. Hence, temporal and spatial variations of hydrological components play a definite role in human activities so as to control and use the potentials provided by the hydrological cycle.

On the application side, hydrology provides basic laws, equations, algorithms, procedures, and modeling of earth-system events for the practical use of the humanity. It is most concerned with the practical and field applications for water resources identification, simple rational calculations leading toward the proper management (Fig. 1.4).

Hydrological cycle is the sole vital indicator of water existence with its distribution, movement, physical properties, and quality related to atmosphere, lithosphere, biosphere, and hydrosphere environments. Each environment includes water in different phases (gas, liquid, or solid) and these are related both temporally and spatially to each other by the hydrological cycle. The classical form of hydrological cycle is presented in many textbooks with its full components.

This general cycle works completely or partially depending on the geographical location. For instance, in arid regions, the component of infiltration or deep percolation may not function properly, and consequently, groundwater resources cannot be replenished sufficiently. Hydrological cycle works since millions of years, but even during such time span, it has worked in some parts completely in the past, but today it functions partially at the same locations. At great depths of sedimentary geological successions are the groundwater reservoirs as fossil water that cannot be replenished with the present day hydrological cycle. The effective domain of hydrological cycle does not change with geographical location only, but also temporally and leaves trace in different forms.

In arid regions, the hydrological cycle behavior becomes independent from the general atmospheric circulations, which are significant for humid regions. However, the hydrological cycle is more dependent on local conditions and distance from the

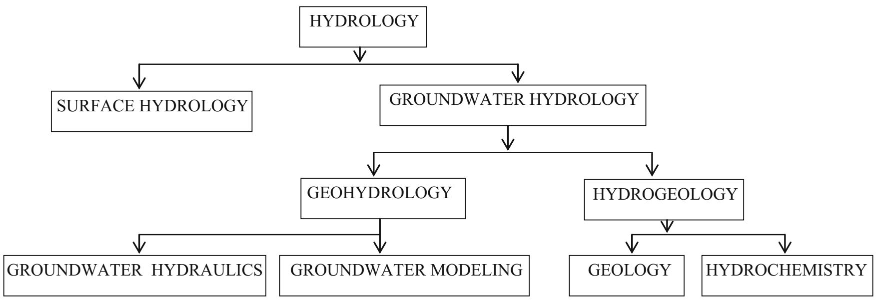

Fig. 1.4 Hydrology-related topics

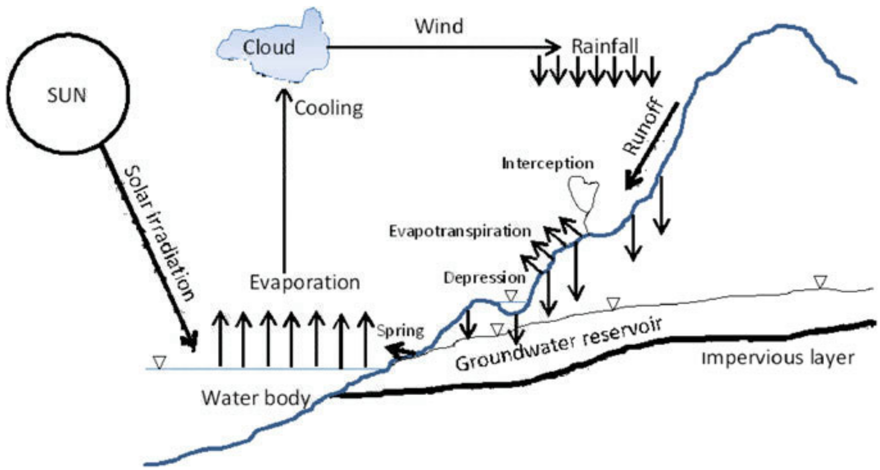

Fig. 1.5 Hydrological cycle components (Şen 2015)

coastal areas. It is possible to say that the arid region hydrological cycle works rather in small scales at the sea coastal regions and nearby inland areas, but with the penetration of moist air to far inland areas, hydrological cycle components either become very weak or nonexistent for some reasons.

In nature the hydrological cycle starts from the evaporation and ends after stages of cloud formation, rainfall, runoff and groundwater recharge. Along this path, there are the oceanic, atmospheric, hydrospheric, and lithologic domains, each of which impacts on the occurrence, movement, and distribution of the natural water phase (gas, fluid, and solid) and water resources occurrences. Hydrosphere includes environments of sole water such as lakes, rivers, and oceans. The water of the earth circulates among these environments from the hydrosphere (oceans) to atmosphere then to the lithosphere. The circulation including complex and dependent processes such as evaporation, precipitation, runoff, infiltration, groundwater flow is called "the hydrological cycle" (see Fig. 1.5).

1.5 Flood Definition

Naturally, there are two flood types as ordinary floods, which are common in many parts of the world and flash floods that are sudden and in huge quantities that are coupled with recent climate change impact, especially in arid and semiarid regions of the world. However, as for the triggering mechanism of floods there are also many different types.

1.5.1 Ordinary Floods

Coupled with the meteorological conditions hydrological circumstances might not be sufficient for the flood occurrence. Still further the surface features (geomorphology) of the area play a significant role in the generation of the harmful floods. Geomorphological characteristics are the guide features of the precipitation water that reaches the earth surface. According to the water divide and collection (streams and rivers), this water is distributed and divided into various shares within each catchment and in its sub-catchments. Geomorphological features provide basis for the flood velocity, and subsequently, the damage increases. Due to high velocity in areas where there are not sufficient vegetation covers, flash floods endanger further the human life and property (Chap. 3).

In addition to the above causes, there are social factors, which bring at times, unconsciously, some human settlement areas under the threat of future floods. This might be due to misplanning and mismanagement. For instance, if urban areas are selected right in the upstream areas, where there are not flood risks, then they will not be exposed to flood danger. For such a task, necessary meteorological, hydrological, and social planning projects, constructions, and administration works must be studied carefully with the aim to reduce the flood damage. Most often, these studies do not care flood exposed sites such as industrial and settlement locations, where all of sudden floods may appear with their destructive property and life claiming consequences. Especially, river flooding is caused in a flash manner mainly by sudden precipitation increase, which leads to intensive rainfalls within short time durations. Long duration precipitations, say for few weeks, replenish the soil moisture and after the saturation, the surface flow starts to appear in an increasing rate and velocity leading steadily to floods. These might not be as harmful as the flash floods, which might appear even in desert areas, because due to the high rainfall intensity there is not enough time for the seepage, and therefore, suddenly all the water contributes to the surface flow and consequently to the floods. The sequential flood blocks are presented in Fig. 1.6 which should be considered in any flood assessment study.

Meteorological data do not provide reliable regional study possibilities, and therefore, insufficient studies must be supplemented by the expert views and additional local information and experience from the society and administrations.

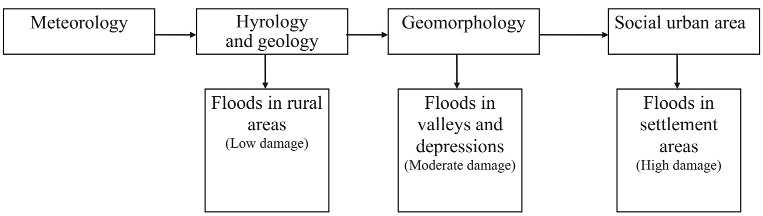

Fig. 1.6 Flood causes

For instance, the insurance companies would like to know the risk levels during different return periods so as to guide and properly design their insurance policies (Chap. 9). Especially, in flood studies, real-time predictions are not necessary but interval estimates, i.e., return period-based estimates are the basic knowledge that is required by the planners and administrators in addition to the private companies such as the insurance units. On the other hand, not only quantitative digital data, but additionally verbal expert views are most important in taking final decisions. Any model has many restrictions, assumptions, local requirements in addition to time specifications. Point risk levels on the site basis are useful (Chap. 6) but more effectively, it is desirable to have regional risk level maps, which may be in the form of equal risk level lines for different return periods such as 5-year, 10-year, 20-year, 25-year, 50-year, and 100-year. Unfortunately, these have not been prepared for many parts of the world.

Flooding can occur quickly in the mountain head-water areas in large river basins as well as in the rivers draining to the coast. The rivers are steeper and flow quickly with flooding sometimes lasting only for one or two days. These floods can be potentially much damaging and pose a greater risk to loss of life and property. This is because there is generally much less time to take preventative actions against dangerous water flows. This type of flooding can affect major towns and cities.

Flooding studies concerned with life protection depend on estimating the maximum rate of flooding in the area (Chaps. 5, 6, 7, and 9). The processes of developing and distribution of flooding movement are affected by many climatic and topographic factors. Accordingly, the estimation of flooding hazards needs detailed examination of climatic studies (including rainfall data and evaporation process), geological, topographic and morphologic studies (including basin area and their drainage system patterns), engineering geologic studies (including the characteristics and behavior of wadi soils), and hydrological studies.

The absence of detailed records on major floods is noticeable in most drainage basins. In general, comparatively sufficiently recorded data exist on normal rainfall. The set of available rainfall data together with the drainage basin characteristics facilitate the use of empirical equations to estimate relevant flood discharges (Chap. 5). As explained by Parks and Sultcliffe (1987), the problem of flood measurement is more acute in arid areas than elsewhere. In general, floods are flashy, and hence, the problem of the peak discharge level determination by the maximum water level record is aggravated by siltation of inlet pipes (Farquhason et al. 1992).

1.5.2 Flash Floods

A flash flood is a specific type of flood that appears and moves quickly across the land with little warning. Many parameters can cause a flash flood including heavy rainfall concentrated over an area, thunderstorms, hurricanes, and/or tropical storms. Dam failures can also cause flash flood events. When a dam or levee breaks, a gigantic quantity of water is suddenly discharged downstream destroying anything in its path.

These are events that occur in many parts of the world including arid regions, and they may cause sudden potential hazards to human life and property. Especially, in arid and semiarid regions, these floods may rise rapidly due to impervious hard rock catchments and move along the sand and gravel filed wadis, which are normally very dry. The flood speeds are usually faster than a person can escape from the rough channels. Flash floods normally reach the sea or are lost in the inland deserts. However, they also help to fill the wadi alluviums that later provide groundwater recharge for local agricultural lands or partially for the nearby city water supply.

Flash floods are short-term inundations of small areas such as a town or parts of a city, usually by tributaries and creeks. Heavy rain in a few hours can produce flash flooding even in places, where little rain has fallen for weeks, months, and years. If heavy rainfall occurs repeatedly over a wide area, then river or mainstream flooding becomes more likely, in which the main rivers of a region swell and inundate large areas, sometimes well after rainfall end. If the intense convectional cells coincide with small drainage basins, then catastrophic flash floods can result and they occur mainly in the summer season, especially in the inlands. They produce large volumes of flood water with rapid concentrations in time and space leading to great damage potentials.

Although flash floods are among the most catastrophic phenomena, the volume of the infiltration from floods is a major source of groundwater replenishment to aquifers that are hydraulically connected with watercourses on the surface. Moreover, this volume of water could be increased significantly by impounding the floods with surface dams or successive dykes (Şen 2014). Importance of flood studies, other than dealing with surface and subsurface water interactions includes flood influences on engineering structures, such as dams, bridges, culverts, and spillways.

From the hydrological point of view, the following variables are important in any flash flood calculation (Chaps. 3 and 4).

(1) Rainfall intensity,
(2) Rainfall duration,
(3) Topography,
(4) Soil conditions,
(5) Coverage of the terrain.

Topographic conditions such as high-exposure (steeply sloping) high land terrains, narrow valleys, or ravines hasten the runoff and increase the likelihood of flash flood occurrence. Saturated soil or shallow watertight geological layers increase surface runoff. Urbanization processes and affiliated construction with watertight materials are thought to make runoff 2–6 times greater in comparison to terrains with natural coverage (fields, meadows, forests).

Flash floods are not uncommon in arid regions and present a potential hazard to life, personal property, and structures such as small dams, bridges, culverts, wells, and dykes along the wadi courses. After a short period of intensive rainfall, flash floods are formed rapidly and they flow down over extremely dry or nearly dry watercourses at speeds more than 1. 5 m/s faster than a person can escape from the rough and sandy wadi channels (Dein 1985).

In arid/semiarid regions, flash floods constitute the majority of casualties of all natural hazards, and these areas occasionally confront a higher risk of damage by flooding than their counterparts in more humid environments. This is usually because of the longer return periods or rarity of extreme rainfall, in addition, prediction of flash floods is extremely difficult due to their short duration and the small geographical region over which they occur. However, in a warmer world, the frequency of these intense storms in semiarid and arid regions may increase (Smith 1996; Smith and Handmer 1996; Smith and Ward 1998).

Flash floods normally strike the urban areas and roads at the downstream part of any drainage basin, because they are uncontrollable and difficult to predict. Therefore, the subject requires special attention by researchers especially in arid climates to estimate the magnitude, volume, time to peak flood discharge and areas, which are prone to flood hazards. The most frequent areas that are affected by flash floods are those in low-lying areas surrounded by high mountains in and around the mainstreams of wadis and in adjacent flood plains. The risks are more serious in these regions, due to the potential flash flood occurrences, which cannot be warned earlier. It is, therefore, required to prepare flood hazard maps that may help to indicate safe and unsafe areas along the basin.

During the last few decades, flash floods have developed as one of the most dangerous natural disasters, which may occur almost everywhere in the world. In recent times, great attention is given to flash floods due to several catastrophic events in different countries. Flash floods are one of the most impressive hazardous manifestations of the environment, which directly affect human activities and security. Their origin and development are not yet well enough understood. There are many ways to prevent flash floods, but no matter how well any one method works, its effect is always limited.

1.5.3 Triggering Mechanism Types

As mentioned earlier, flood occurrences take place in different location depending on their triggering mechanisms. These are summarized in the following items.

(1) Winter rainfall floods: Westerly depressions with well-developed warm fronts bring winter precipitation, mainly in Central and Northern Europe. When these precipitations are heavy, continuous, and prolonged, they can lead to soil saturation and consequent high volumes of runoff. As a result, rivers may flow out of banks, causing flooding,

(2) Summer convectional storm-induced floods: Heavy convectional thunderstorms can sometime generate intensive storms and floods. Especially, in Southern European regions, prolonged summer months hot periods can end with sudden storms. If the storm event can be localized they can lead to severe flash floods affecting highly developed sub-areas,
(3) Convective frontal storm-induced floods: Frequent meteorological conditions over Western and Southern Europe are characterized by extended low pressure, associated to cold fronts, which travel from the west Mediterranean Sea toward the continent. In these situations, mesoscale convective systems may develop, resulting in extreme rainfall, lasting more than 24 h. The air mass can be subjected to orographic enhancement upon reaching over the slopes of the mountain chains,
(4) Snowmelt floods: Rapid snowmelt can sometimes cause flooding, especially in the spring when warm southern air streams become influential Alpine or upland areas may generate sudden snowmelt accompanied frequently by heavy rainfall. This phenomenon is usually much localized and in very steep watersheds can produce flash floods, since flood water velocity can be high. The problem affects urban areas at the valley bottoms,
(5) Urban sewage flooding: Inadequate sewage system can lead to serious flooding problems in urban areas, since even normal intensive rainfall events can create abnormal flooding,
(6) Sea surge and tidal flood threat: One of the major problems of flooding that may affect many European coastal areas is related to the sea surge and tidal effects. Moreover, associated with this problem is the phenomenon of coastal erosion, which may consequently lead to flooding,
(7) Dam-break flood risk: Flood problems can also arise from the breaking of dams and dikes.

In many regions, there are various causes of flooding, the most important ones are related to the geological and topographic conditions and the climate features. In addition, the social and economic situation of the population makes them more closely attached to the sources of the hazards. It is possible to classify the floods according to their durations and appearances as follows.

(1) Long-term floods: One week or longer duration,
(2) Short-duration floods (flash floods): About 6 h or less duration.

On the other hand, floods can be classified also according to their appearances into four categories as follows.

(1) Active water collector floods—Streams and rivers,
(2) Dry water collector floods—Mountain sides and slopes,
(3) City floods—Creeks in the urban areas,
(4) Coastal floods—Open pressure effect on the sea surface.

1.6 Physical Causes of Flood

Floods are among the natural disasters that cause property and life losses occasionally with great financial, environmental, and social consequences. The main trigger mechanism of these natural hazardous events is the atmospheric conditions that end up with the convenient meteorological setup for the generation of precipitation. Especially, extreme cases of precipitation give rise to intensive rainfall, which might be calculated from the water expert's point of view, by the concept of "probably maximum precipitation" (see Chap. 2). Meteorological conditions are necessary, but not sufficient for the floods in an area. In the hazardous flood occurrences not only rainfall event the but also hydrological, geomorphological and the geological sub-surface features play significant role to a certain extent. From the hydrological standpoint, floods appear when the soil saturation is complete and, therefore, almost all the precipitation without evapotranspiration and seepage turns to the surface flow. In plane areas, hydrological floods become harmful for the agricultural lands mostly due to water accumulation.

Floods are extreme surface water occurrences corresponding to a high flow of water, which overtops either the natural or the artificial banks of a river. For a hydrologist, the flood is expressed best with its maximum flood discharge, which does not indicate the flood inundation effects. However, for someone working in flood hazard potential, rather than the discharge, its maximum height (stage) is more significant. The stage is the maximum level that surface water reaches. Floods are generated as a combined result of two distinctive physical causes.

(1) Primary Causes: These are due to meteorological and atmospheric conditions related to the climatologic features of the region. The rainfall occurrences, types, intensities, directions, excessive rainfall, etc., are the necessary ingredients among these causes,
(2) Secondary Causes: These are related to the surface features of the drainage basin in terms of geomorphology, geology, vegetation, etc. The necessary ingredients are the catchment area, slope, drainage density, main channel length, time of concentration, etc.

The primary causes are time variables that cannot be predicted reasonably. These can vary from the semi-predictable seasonal rainfalls over wide geographical areas, which give rise to the annual monsoonal floods in tropical areas, to almost random convectional storms giving flash floods over small basins, (Ward 1978).

Climate change is among the physical trigger agents of unusual floods. It causes changes in timing, regional patterns, and intensity of precipitation events, and in particular in the number of days with heavy and intense precipitation occurrences. Floods are now being experienced in areas, where there were no floods in the past. This is mainly due to the global climate change. The recent floods seem to have some effects of global climate change, although they cannot be taken as proof that it