Chapter 1

Introduction

Our Planet Earth is unique among other planets of the solar system in the presence of water that has made it possible for the life – in its millions of forms - to exist on it. And the water occurs in great abundance – an estimated 1386 million km^3 of which 96.54% resides in the oceans and another about one per cent is also saline (Shiklomanov 1993, Shiklomanov and Rodda 2003; see also Trenberth et al. 2007). Out of the remaining 2.5% that is fresh water, about 69% is frozen in glaciers, polar ice caps, snow and permafrost areas, and 30% is locked in deep aquifers. Lakes account for a total of 91,000 km^3 of water but most of it resides in just a few large lakes. Marshes and wetlands hold about 11,500 km^3 of water and the rivers have only a little more than 2000 km^3.

However, of greatest significance is the fact that water moves continually around, through and above the Earth and as it cycles through ocean, atmosphere, land and biota, continually changes its form between all physical states – liquid (water), gas (water vapour), and solid (snow and ice). It is noteworthy that the hydrological cycle and its importance were described in detail several thousand years ago in Rigveda, Puranas, Mahabharat and other Indian scriptures (see Jain et al. 2007). Estimates of global water budget of the hydrological cycle shows that annually about 45,000 km^3 of water is transported from the oceans to land through the atmosphere (by evaporation from oceans and precipitation over land) and then returned back to the oceans as it flows mostly over the land surface in the rivers. The evaporation from land surface and transpiration from the vegetation together equal the remaining precipitation over land. Although the processes of evaporation from the oceans, atmospheric transport, precipitation over land and return to the oceans vary geographically and during the year, the earth's total water resources have remained unchanged for millions of years and until recently, the global stocks and flows have also not changed significantly.

What is a River?

The above noted purely quantitative perspective of the Earth's water resources shows that the rivers constitute the most important part of the hydrological cycle, and an indispensable link between the land and the oceans. But rivers are far more important features than simply being the 'carriers' of water back to the oceans. Let us see briefly what the rivers are and what do they mean to different people.

Rivers are unique and fascinating systems of natural watercourses. They invariably originate as trickles of glacier or snowmelt or surface runoff of rainwater at higher elevations. Flowing down the slope from different directions, many small creeks or streams, as we call them, merge their identities systematically into a larger river until it meets another river, a lake, an ocean or any other large water body. In some places, particularly the hills with unconsolidated substrata, the precipitation (rain) infiltrates into the ground, flows below the land surface before emerging as a spring and joining the stream.

A few rivers, mostly seasonal, in the dry climatic zones (deserts), do not reach the sea/ oceans. Instead, they flow into a vast flat terrain or shallow depression where they spread all of their flow through many distributaries, thus forming a large marsh and shallow lakes. The most spectacular example is that of River Okavango (Botswana) in southern Africa. In India, River Luni, a seasonally flowing river that arises from the Aravalli ranges (west of Pushkar, Ajmer) discharges into the marshes of the Rann of Kachch, and in some years, it is unable to reach there. Several small seasonal rivers in Rajasthan end up into Lake Sambhar – a salt lake. Also in Ladakh, small seasonal streams carry snow melt into lakes such as Pangong Tso, Tso Moriri and Tso Kar.

Depending upon the topography, geology, soils and climate (especially the amount and intensity of precipitation) of the area along their course, the rivers often display large changes in their character. A river flow gently may also rush and roar, fall down to great depths, and become quiet again. Flowing down the mountains the rivers often turn violent, pushing and crushing large boulders into fine sand, and become gentle and benevolent in the plain. Periodically, the rivers turn furious, breaching their banks and sweeping everything that comes their way.

Although each stream may be given a name for its course from the source (origin) to the confluence with another stream or river water body), these tributaries form only a part of the larger river system which collects water from a large area – the river basin or catchment – and discharges finally into the ocean or sea. The tributaries joining the larger stream/river not only contribute to the increase in downstream flow but also determine the characteristics of the combined river downstream of their confluence (see chapter 2). For example, River Ganga is considered to flow from its source at Gomukh near Gangotri glacier to Sagar where it finally discharges into the Bay of Bengal. However, the river gets its name

Ganga only after the confluence of Bhagirathi (arising at Gomukh) and Alaknanda rivers at Devprayag, Alaknanda is longer than Bhagirathi, and both of them are joined by many tributaries along their course up to Devprayag. Similarly River Yamuna, which originates near Yamunotri and is joined by many small and medium rivers, is also a tributary of River Ganga with their confluence near Allahabad. The River Yamuna differs from River Ganga not only in its greater flow but also in the water quality (slightly darker colour) and the difference can be noticed visually for quite some distance after their confluence. Similarly, the River Amazon is influenced by the water characteristics of its largest tributary, Rio Negro, whose dark coloured water does not get thoroughly mixed with that of Rio Solimoes for several kilometers.

Also before the river discharges into the ocean or sea, it may branch out into many channels forming a delta. This normally happens when the gradient in the lower reaches is very small and the river carries a high sediment load. Most of the Asian rivers originating in the Himalaya form large deltas. Usually, each of these channels – called distributaries- are also given separate names. While researchers may treat each of the major or minor tributary and distributary separately for various studies, hydrologically they are inseparable from the main river.

Different Perspectives of Rivers

Humans have been interested in rivers since historical times for their dependence on them for water. The earliest human civilizations developed along the rivers. In recognition of the critical importance of rivers to the human sustenance, several societies consider them to be sacred and hold them in reverence, calling them 'mother' and 'goddess'. Naturally, many social and cultural activities were developed with the main focus on the rivers. Humans have also looked at the rivers as a source of fish. Fishing in the rivers certainly predated agriculture (Forteath 2004, Gartside and Kirkegaard 2004, Lackey 2005).

Over time, the human needs of water have increased enormously and diversified in many ways. Gradually, humans found many uses of rivers and started learning about the rivers. Several disciplines of science and technology have been developed that focus on rivers from different perspectives.

For the hydrologists, rivers are merely channels to carry runoff precipitation which needs to be utilized and not allowed to go 'waste' into the sea. They emphasize upon the volumes of flow (e.g., million cubic meters) and its distribution over time in a year (flow duration curves) so that this flow can be stored and diverted (by constructing dams and barrages) for various uses. For some others, the rivers flowing down steep slopes, even if the total amount of flow is not large, are a huge source of 'clean and green' energy (hydropower) that must be harnessed, often usurping the entire flow and diverting it into large tunnels in the mountains before it is returned to the river downstream after passing through the turbines. The process may be repeated several times so that the river nearly disappears into the mountains.

The urban planners, developers and managers, as well as industries, consider the rivers not only as a source of water for all their needs but more as drains into which they discharge all municipal and industrial wastewaters, immediately below the off-take point and usually with little or no treatment.

Another group of researchers consider the rivers as geomorphic agents which sculpt the Earth's surface by processes of erosion, gullying, incision, and transport of sediments (along with nutrients) which are then redistributed along the river courses and carried to the oceans. These processes create a large variety of habitats for a diversity of organisms (see chapter 2).

Yet others find the rivers to be important waterways for transporting people and goods, even as the channel has to be dredged regularly. Logs of trees felled in the upstream areas of the rivers are often pushed into the rivers which readily transport them downstream, thereby saving energy, time and labour.

Several groups of people, obsessed with land-based activities, consider the rivers as a menace because they regularly flood the land on their both sides which must be reclaimed for urban, commercial or industrial development by creating embankments and landfills. In their view, the river must be 'trained' to flow within the space provided by the humans.

Rivers are considered to be sources for 'mining' gravel and sand used in construction activities and for harvesting different biological resources (besides fish). Rivers are also viewed as site for aquatic sports and recreation which together with the cultural and religious activities are being increasingly driven by commercial interests. For numerous communities, the rivers are simply an important means of their livelihoods.

Despite the interests of so many groups and scientific disciplines in the rivers, a holistic integrative science of rivers did not emerge until about the middle of the last century. Well-known German geographer, Prof. Albrecht Penck had called for a science of rivers, which he named 'potamology' (Penck 1897), somewhat parallel to the science of oceans (oceanography) and the science of lakes (limnology – that had been named only in 1895). Among other topics to be covered by potamology, he included "the rivers as a scene of organic life". It was after several decades that an ecological perspective of the running waters appeared (see Hynes 1970) and the rivers were viewed as ecosystems. It is now well recognised that the rivers are life-support systems and habitats for more than15% of all living organisms on the Earth. The ecosystem attributes of the rivers are discussed in the next two chapters.

Human Impacts on Rivers

Multiple perspectives mean multiple demands on river's water, sediments, space and other resources. Globally, the rivers have been impacted by an array of human activities which directly interfere with their flow, water quality, biota, and space. Numerous activities throughout their drainage basin have indirectly similar impacts. Major kinds of human activities, which affect the rivers, and often threaten their integrity, are highlighted below. The actual impacts – the consequences of these activities for the river ecosystems and in turn for the humans are discussed in later chapters.

Abstraction of Water

Human impacts on the rivers started with the abstraction of water only after the advent of agriculture. Cultivation of food, mostly cereals, which started some 7000 years ago on the floodplains of Trigris-Euphrates river system in Mesopotamia, relied on seasonal flooding from the rivers. People moved down to the floodplain from nearby uplands after the floods receded, grew crops from the seeds collected in the wild and sprayed in the fields. After several crops were domesticated, human learned to divert river flows into a system of irrigation channels. The irrigation system was perfected in the Indus Valley around Harappa and Mohanjodaro more than 5000 years ago (Singh 2005). Much later, during the period of Mauryan Empire, most of the irrigation in the Indian subcontinent was done by constructing large tanks to impound the surface runoff during the rainy season. It was only during the Moghul period that canal irrigation was promoted but these were inundation canals into which the water supply depended upon river discharge and the maintenance of canals (Singh 2005). Modern canal system with large scale diversion of river flows was started by Feroze Shah Tughlaq who constructed the 240-km canal from River Yamuna to his fort in Hisar, and four other canals. Similar canals were later built to divert the flows of rivers Ghaghar, Beas, Sutlej, Ravi, etc. (Singh 2005). The development of canals picked up pace during the late 19th century when the British constructed extensive network of canals on River Yamuna, River Ganga and several south Indian rivers. The diversion of river flow into these canals required the construction of barrages only with relatively very little impoundment. In case of River Ganga, after protests from several religious groups, an opening was left on one side of the Bhimgoda barrage to allow uninterrupted flow at Haridwar. During the past few decades, the flows of practically all rivers in India, as well as in neighbouring countries, have been extensively exploited by storage and diversion.

The amounts of abstraction of water (by storage and diversion) for agriculture alone has increased enormously with the increasing demand for agricultural production and intensive agricultural practices. In India as also in most other countries 75-80% of all the available water resources are used for irrigation. Further abstraction is required for domestic supplies (including sanitation) and for industrial use. In many cases, almost all of the flow in the river is abstracted leaving practically no water in the downstream reaches except during the rainy season or until another stream brings water into it. Such is the situation in River Yamuna downstream of Dak Patthar, and particularly after Hathnikund barrage in Yamunanagar. Until 1950 there were only 42 large reservoirs in India. The pace of constructing more large storages accelerated after independence and a peak was reached in the last decade of the 20th century.

Further diversion of flows occurs, usually in the hilly areas, for generating hydropower. The so-called run-of-the-river hydroelectric power (HEP) projects utilise the entire flow (except for a brief period during the rainy season) by diverting it into tunnels. In most cases the HEPs result in a large storage behind dams constructed on the river to ensure a greater ‘head’ and enough volumes of water. The impacts of such diversions get multiplied and become severe when a cascade of HEPs is constructed on the same river and/or its tributaries.

Channelization of Rivers (Embankments)

As mentioned earlier, humans have always encroached upon the space required by the rivers to carry their water. Humans first utilized this space (floodplain) along the river banks by realising the importance of annual flooding to the replenishment of soil fertility and prolonged availability of soil moisture. However, it was soon forgotten and with the human settlements and agricultural fields becoming permanent on the floodplains, periodic flooding of the encroached area was perceived to be harmful, Hence, embankments were constructed to restrict the river to flow within confined spaces. Detailed analysis of floods and embankments has shown that the embankments have failed to mitigate the intensity and impact of floods (Agarwal and Chak 1991) and the recent flooding by River Kosi in north Bihar due to failed embankment bears testimony to it (Mishra 2001, 2007a,b).

Encroachments continue on the river's space between the embankments not only through agriculture but also by dumping urban solid wastes, debris from the construction of roads (usually along the river courses) in the hills, the tunnels for HEPs, and even construction of residential and commercial buildings on the river banks (natural levees). Recent flood disaster in Kedarnath (in the headwater area of River Ganga) exposed the magnitude of such encroachments even on the river bed (channel) which remained dry for most part of the year. Further encroachments occur for the so-called 'river-front development' with recreational and or cultural activities.

Sand / Gravel Mining

Human activities extend right into the river bed which is used for 'mining' gravel and sand for various uses particularly in the construction industry. The quality and quantity of the sediments transported by the river depends upon several characteristics of the catchment (geology, climate, land use) and the river (e.g., gradient and flow), and in turn they affect the morphology, biota and functioning of the rivers. Whereas the removal of some of the sediments may be required to prevent aggradation (rise) of the river bed (inability of the river to spread them laterally over the floodplain), it often turns into a mining activity on the river bed. The construction of flow storage and diversion structures as well as the altered flows also affect the sediment distribution in the river.

Watewater Discharge

Rivers are known to have a self-purification property linked to their ability to assimilate organic wastes. However, humans have treated them as drains to discharge all their domestic and industrial wastes. The river stretches along major urban settlements and industrial centres receive enormous quantities of wastewaters with all kinds of pollutants. In the absence of natural freshwater flow, many smaller tributaries have turned permanently into wastewater drains.

Other Activities

Several other human activities in the river and its catchment affect the river in different ways. Agriculture and urban development are major non-point sources of pollution. Excessive withdrawal of groundwater, particularly from the floodplain and adjacent areas affects the river flow by reducing or eliminating the subsurface movement of water into the river channel. Among other activities affecting the rivers include deforestation and clearing of the vegetation on river banks; overgrazing by domestic animals; intensive agriculture on the river bed; over-exploitation of biological resources; and the introduction of exotic plant and animal species.

SCOPE OF THE BOOK AND THE IWRM CONTEXT

The foregoing account shows that since the earliest stages of their evolution, humans have depended upon the rivers and their dependence has grown enormously in recent years. All kinds of human activities depend upon water abstracted mainly from the rivers which in turn are impacted variously by all of them. Humans are only one species among millions of other species of organisms which also depend on water. A large proportion of the Earth's biodiversity resides in the rivers and associated freshwater habitats. Many of these organisms are directly utilised by the humans whereas others provide numerous benefits which humans cannot obtain by simply using water. Excessive manipulation of the rivers through intensive regulation of their flows and other human activities has caused severe degradation of the rivers, loss of their biodiversity and many social, cultural and economic consequences (Postel and Richter 2003, Dudgeon 2000, Dudgeon et al. 2006). It is critically important that we consider these organisms also as stakeholders in the Earth's freshwater resources. Ethics demands that we should abstract only as much water from the rivers as it would not affect the nature's functioning and in turn, our own well being. Recognising the problems and also the needs to conserve and restore the rivers, people are now assessing the amounts of water which need to be left in the rivers or released from storages into them at different times of the year in order to sustain their ecological integrity. These amounts have been named as 'environmental flows'.

The multiple and competing demands on the Earth's limited, unevenly distributed water resources and the growing impacts of diverse human activities on the water quality and aquatic life call for their proper management. Discussions at various global forums since 1977 lead to the concepts of Sustainable Water Management, Integrated River Basin Management (IRBM) and Integrated Water Resources Management (IWRM). The concept of IWRM was elaborated by the Global Water Partnership (GWP 2000) which defined it as "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitabe manner without compromising the sustainability of vital ecosystems*". For a discussion of the concept and its development, see Snellen and Schrevel (2005), Saravanan et al. (2008) and Gopal (2012).

It is in this context that the assessment and provisioning of environmental flows is an important component of integrated water resource management (IWRM) to ensure the sustainability of vital aquatic ecosystems. All development projects requiring storage, diversion and/or abstraction of river flows or those affecting the flows in any other manner should assess the environmental flows requirements and make a provision for them at the planning phase itself. The restoration of degraded river stretches also needs similar assessment of environmental flows.

Following chapter provides a brief history of developments in river ecology during the past century and then an overview of the ecosystem characteristics of the rivers focusing on their morphology and natural flow regimes, water chemistry, biodiversity and ecosystem functions. It is followed by a description of the ecosystem services of rivers in relation to their flow regimes. The next chapter deals with the impacts of flow alteration on the biodiversity, ecosystem functioning and ecosystems services along with its social cultural and economic impacts on river dependent communities. The impacts on estuarine reaches and backwaters are also noted.

These chapters provide the background for Environmental Flows whose concept and history are then elaborated briefly. The next chapter discusses various methods of Environmental Flows assessment and their merits and disadvantages. Relevant examples are used from the Asian region as far as available. The chapter also discusses the methodologies in the context of biophysical, socio-cultural and economic features of the South Asian region. Finally, The developments concerning the study and application of environmental flows in South Asian countries are summarised along with observations on their water policies and legal requirements.

The book concludes with a few observations on the needs for research on stream flow-ecology relationships, development of environmental flows assessment methods appropriate for the South Asian region, and the incorporation of environmental flows requirements in planning, implementation and monitoring of water resources development projects.

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