Chapter 1
A Global Review of Large Dam Construction

1.1 History and Distribution of Large Dams in the World

The history of dam construction is as old as human civilization. In ancient Chinese mythology, the legendary tribal leader, Yao, assigned one of his subordinates, Gun, to lead the people to fight a great flood. Gun built dams to block the flood, but they broke and caused an even larger disaster. As punishment, Yao's successor, Shun, killed Gun, and then assigned Gun's son, Yu, to lead the fight against the flood. Yu removed the dams and other barriers blocking the river, allowing the water to flow freely to the ocean, and finally overcame the flood. This story shows the long history of the impacts of dam construction on attempts to control the flow of rivers.

The remains of dams dating back to 6000 BP have been found in Mesopotamia; and irrigation and water supply dams became widespread in many parts of the world by 2000 BP (WCD 2000). The oldest continuously functioning dam is likely one associated with the Dujiangyan Irrigation Project in Sichuan Province, China, which was built in 256 BP and is still providing irrigation water for a large area of farmland on the Chengdu Plain (Zhang and Jin 2008). The first hydropower dam in the world was built about 1890 in the United States (WCD 2000).

Before 1900, there were only about 700 large dams worldwide (Fig. 1.1). Most of the large dams currently in existence were built during the twentieth century. About 5,000 large dams were built during the first half of the century, three-quarters of them in developed countries. Dam construction rapidly increased globally after the Second World War, with the peak occurring between 1970 and 1975, when nearly 5,000 large dams were built worldwide. The rate declined after the 1980s in most parts of the world, especially in North America and Europe (Shah and Kumar 2008; WCD 2000).

According to the World Bank, countries represented by the Organization for Economic Co-operation and Development (OECD) have already developed 70 % of their economically feasible dam potentials, while developing countries are only using 30 % of their potentials. Strikingly, less than 10 % of the potential has been exploited in Africa (World Bank 2009). Since developed countries have built dams on most of

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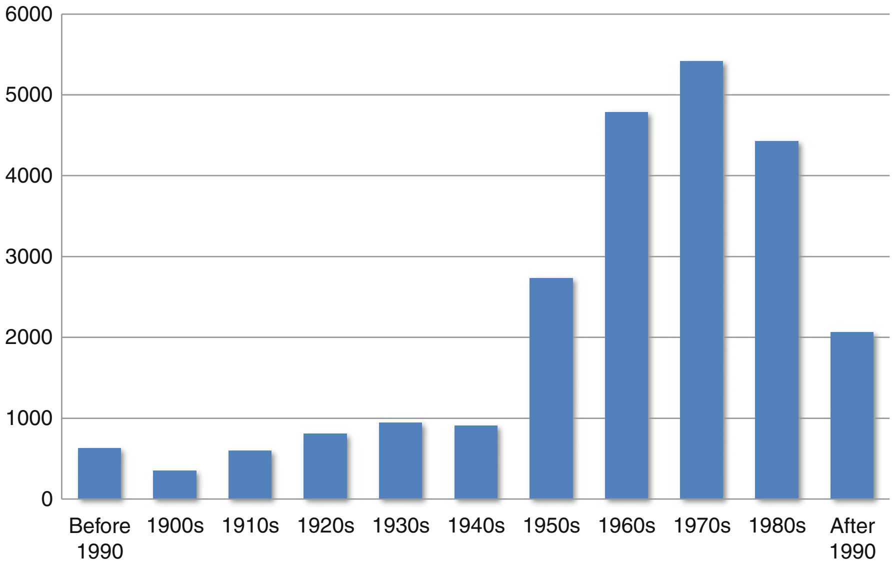

Fig. 1.1 Construction of dams by decade (Data from WCD (2000); *Source*: ICOLD, 1998, excluding over 90 % of large dams in China)

their rivers, they now mainly focus on managing and improving the efficiency of existing dams. But for developing countries, dam construction is considered a promising development opportunity. Therefore, the future of the large dam construction worldwide largely depends on the rate of development activities in these countries.

By the end of twentieth century, more than 45,000 large dams had been built around the world (WCD 2000). Fig. 1.2 shows the worldwide distribution of large dams. Five regions, East Asia, South Asia, North America, Europe, and Southern Africa, have the highest density of large dams.

Asia has not only the most existing dams compared to all other regions, but is also currently experiencing the highest construction rates. China and India, the two most populous countries in the world, are building most of these new large dams. Rapid economic development in these two countries not only demands more energy and water, but also provides the financial resources for major construction projects, such as the building of large dams (Bawa et al. 2010; Liu and Diamond 2005). The top five countries with most of the dams currently under construction are all in Asia: India, with 700–900 new dams under construction; China, with 280; Turkey, with 209; South Korea, with 132; and Japan, with 90 (WCD 2000).

The United States has built the greatest number of large dams in North America, about 8,000. However, by the end of the twentieth century, a new trend was evident as old and poorly functioning dams were decommissioned across the United States. About 15 years ago, the top official at the US Bureau of Reclamation, which had been responsible for building massive dams throughout the American West, declared that the “era of big dams is over” (Longman 2008). In 1998, the speed of decommissioning exceeded that of construction for the first time (WCD 2000).

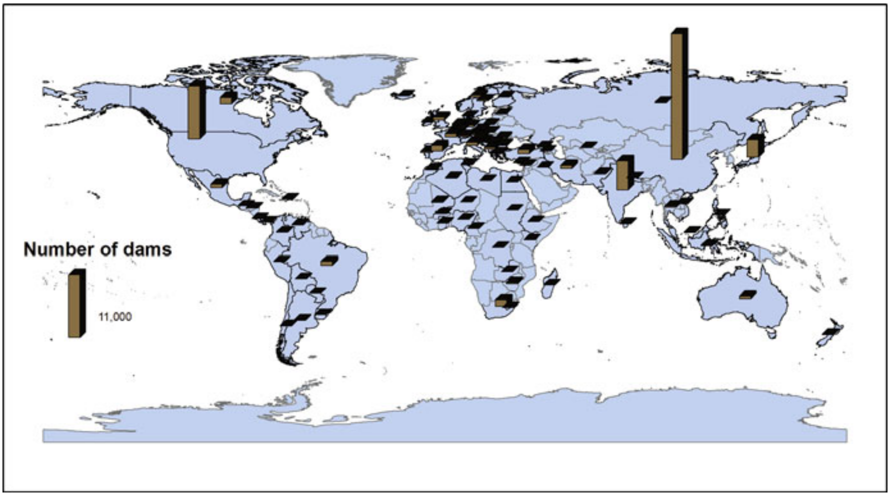

Fig. 1.2 Distribution of large dams in the world (Synthesized from data on ICOLD website: http://www.icold-cigb.org/)

Decommissioning old dams has many benefits for the restoration of riparian systems. However, some studies have shown that the removal of old dams may also cause negative impacts on associated ecosystems as they are forced to readapt to new hydraulic regimes (Poff and Hart 2002; Bednarek 2001) .

Currently, there are about 6,000 large dams in Europe. The pattern of construction of dams and reservoirs in Europe can be illustrated using the United Kingdom and Spain as examples. In the UK, the number of large dams grew rapidly during the nineteenth century, from fewer than 10–175, a rate of 1.7 per year. By 1950, the rate had almost doubled. After 1950, construction took place at a rate of 5.4 dams per year before dropping to zero by the late 1990s. Today, the UK has a total of 486 dams. In contrast, Spain saw the number of reservoirs grow at the rate exceeding 4 per year between 1900 and 1950, before almost doubling and reaching 741 facilities by 1975. By 1990, this figure had more than doubled again (19.5 per year), and today there are 1,172 large dams in Spain, the most in Europe (European Environmental Agency 2010). With suitable sites becoming fewer and environmental concerns becoming greater, the total number of dams in Europe is now growing very slowly.

1.2 Multiple Functions of Large Dams

1.2.1 Irrigation

Large dams have made significant contributions to rapid increases in yields associated with modern agriculture. About one fifth of the world's agricultural land is irrigated, and irrigated agriculture accounts for about 40 % of the agricultural production globally. Half of the world's large dams were built exclusively or primarily for irrigation, and an estimated 30–40 % of the 268 million hectares of irrigated lands worldwide rely on dams (WCD 2000).

The heights of large dams can range from 15 to several hundred meters. But generally, dams used for irrigation are relatively low compared to those constructed for flood control and hydropower. In North China, where precipitation is often inadequate for irrigation and the flow of rivers is generally low, many dams have been built to meet the water needs of cropland (Nickum 1998).

1.2.2 Water Supply

According to research on water supply security, there is a clear positive correlation between the density of dams and security level (Vorosmarty et al. 2010). Many reservoirs were built to provide a reliable supply of water to meet rapidly growing urban and industrial needs, especially in drought-prone regions where natural groundwater sources and existing lakes or rivers were considered inadequate to meet all needs. Globally, about 12 % of all large dams are designated as water supply dams and about 60 % of these are in North America and Europe (WCD 2000). Most metropolitan areas must rely heavily on reservoirs in distant surrounding watersheds for water supply, such as Beijing (Government of Beijing 1981) and New York City (The City of New York 2013).

1.2.3 Electricity Generation

Hydropower provides about 19 % of the world's electricity production, and in some countries, it is the most important power source (WCD 2000). Therefore, dams for hydropower are constructed globally as an important development approach. In addition to the ambitions of many different governments, the World Bank and other development banks also promote large hydropower dams by providing a large number of loans, especially to developing countries (World Bank 2009).

Hydropower is considered to be cleaner than electricity generated by burning fossil fuels. It has almost zero CO_2 emission (if the CO_2 emitted by deteriorating organic matter at the bottom of the reservoirs is not considered), and once completed, no additional inputs are needed other than the maintenance of the power station. In the view of hydraulic engineers, some deep valleys with rapid elevation drops are particularly suitable for building large dams.

The electricity generated from hydropower dams is most often fed into national grids, which benefits people in the whole country. However, local people commonly bear most of the negative impacts from dam construction and the operation of the power station (Magee 2006). This uneven cost-benefit distribution is one of the main equity issues related to large dams.

1.2.4 Flood Control

Worldwide, flooding has caused more deaths than any other natural disasters (WCD 2000). In those countries with monsoonal climates, flood control during the rainy season becomes even more imperative. Generally, flood control projects include not only dams and reservoirs, but also levees, all of which significantly change natural flow regimes.

However, dams constructed for flood control can sometimes make the situation even worse. For some rivers with high sand concentrations, like the Yellow River in China, dams often cause serious sedimentation problems, which lift the riverbed and reduce the water-holding capacity of the original watercourses (Xu 1998; Yang et al. 2008). The case study part in the second chapter will show the failure of Sanmenxia Dam on the Yellow River, which is a good illustration of how a flood control dam can exacerbate flooding disasters.

1.2.5 Navigation

Only a small number of large dams have been constructed specifically for the purpose of navigation. But for some, the need to improve transportation conditions was an important consideration in the decision-making process. One of the most obvious examples is the Three Gorges Dam in China, which was advocated eagerly by provinces on the upper reaches of the Yangtze River, like Chongqing and Sichuan Province. After the dam was finished, the river's water level rose by 175 m, allowing 10,000-t ships to reach Chongqing, which has substantially improved the transportation condition of this major city surrounded by mountains (Jackson and Sleigh 2000).

1.3 Environmental Impacts of Large Dams

Most large dams constructed throughout the world have emphasized the economic and social benefits to society while largely ignoring any long-term environmental impacts (McCartney et al. 2001). More recently, however, the environmental impacts of large dams on river ecosystems have received considerable attention and the cost of dams to human society has become a major concern. Dams are designed to alter the natural flow regime of rivers and, as such, they have profound impacts on natural river processes both upstream and downstream from the dam. The impacts of dams on river ecosystems are numerous, complex, and varied, some obvious and others more subtle, but all mostly have negative consequences.

The environmental impacts of dams on river ecosystems can be viewed within a hierarchical framework of first-, second-, and third-order impacts with upstream and downstream effects considered separately (Table 1.1) (Bergkamp et al. 2000;

Table 1.1 A hierarchical framework of upstream and downstream impacts of dams on river ecosystems (From Bergkamp et al. 2000; McCartney et al. 2001)

Location in relation to dam	Category of impact	Impact
Upstream	First-order impacts	Modification of thermal regime
		Accumulation of sediment in reservoir
		Changes in water quality
		Evaporation and greenhouse gases
	Second-order impacts	Changes in channel configuration
		Increased growth of plankton and periphyton
		Increased growth of aquatic macrophytes
		Reduced biomass and diversity of riparian vegetation
	Third-order impacts	Changes in distribution and abundance of invertebrate, fish, bird, and mammal populations
Downstream	First-order impacts	Changes in the timing, magnitude, and variability of daily, seasonal, and annual flows
		Changes in water quality
		Reduced sediment flows
		Alteration of channel, floodplain, and coastal delta morphology
	Second-order impacts	Change in plankton and periphyton assemblages
		Increased growth of aquatic macrophytes
		Change in riparian vegetation
		Change in channel, floodplain, and coastal characteristics
	Third-order impacts	Changes in distribution and abundance of invertebrate, fish, bird, and mammal populations
		Increased salinity of estuaries

McCartney et al. 2001). First-order impacts are the immediate abiotic effects on the hydrology, water quality, and sediment load of the river as a direct consequence of the dam. These are the key driving variables that lead to second- and third-order impacts resulting in long-term changes of the river ecosystem. Second-order impacts are the abiotic and biotic changes in ecosystem structure and primary productivity caused by first-order impacts that take place over several years. Third-order impacts are the long-term biotic impacts on higher trophic levels that result from the integrated effects of first- and second-order impacts. In general, the complexity of the ecosystem processes and their functions that are altered increase from first- to third-order impacts.

1.3.1 Impacts on Flow Regime

The construction of a dam impounds water and converts the river channel from a lotic to lentic system in the upstream area. Flow regulation by the dam alters the intensity, timing, and frequency of downstream flow patterns reducing river discharge and flow variability by increasing low flows and dampening high flows.

The overall effect is a disruption in the longitudinal and lateral hydrologic connectivity of the river (McCartney et al. 2001; Hu et al. 2008; Lajoie et al. 2007; Bergkamp et al. 2000; Stanford et al. 1996). Downstream impacts are specific to each dam and depend on the storage capacity of the dam relative to the volume of river flow combined with how the dam is operated (Bergkamp et al. 2000; McCartney et al. 2001). In addition, the local climate can impact flow regime patterns in dam area as well (Zhao et al. 2012a).

1.3.2 Impacts on Thermal Regime

The large mass of water impounded behind the dam tends to increase water temperatures upstream and modifies the thermal regime of the river downstream by changing the natural seasonal and short-term temperature fluctuations downstream (McCartney et al. 2001). Deep reservoirs will thermally stratify in summer with warm, less-dense water in the upper layer (epilimnion) and the colder, denser water in the bottom layer (hypolimnion). Colder than normal water is released in the summer and warmer than normal water is released in the fall, altering seasonal temperature patterns of the river downstream (McCartney et al. 2009). Reservoirs at higher latitudes can easily become stratified due to variable input of solar energy, while those near the equator are least likely to become stratified (Bergkamp et al. 2000; McCartney et al. 2001). However, even if there is no thermal stratification, water released from reservoirs is often thermally different from the natural flow in the river and native aquatic organisms must adapt, relocate, or perish (Bergkamp et al. 2000; McCartney et al. 2009).

1.3.3 Impact of Evaporation and Greenhouse Gas Emission

Reservoirs increase the total surface area of freshwater which leads to water loss through evaporation. The amount of water evaporated from a reservoir is associated with both the surface area of the reservoir and the climatic conditions which control potential evaporation, i.e., evaporation is greatest from reservoirs with large surface areas located in hot arid climates (McCartney et al. 2001). The loss of additional water from evaporation can affect not only the water utilization efficiency by human beings, but also the downstream ecosystem health, e.g., water salinity associated with evaporation in arid climates can damage downstream river ecosystems.

Emission of greenhouse gases, carbon dioxide (CO_2) and methane (CH_4), from reservoirs as a result of decomposition of submerged vegetation has become a more recent concern (Fearnside 1997). Greenhouse gas emissions vary with reservoir depth, water residence times, temperature, the influx of organic matter from the catchment, age of the reservoir, rates of primary production, and dam operation (McCartney et al. 2001). Shallow tropical reservoirs are the largest emitters of greenhouse gases (McCartney et al. 2001), with average flux rates of 3,500 mg CO_2 and 300 mg CH_4 m^2/day reported for Panama, Brazil, and the French Guyana (Saint Louis et al. 2000). Relatively small reservoirs emit little or no greenhouse gases and are "carbon neutral" whereas large reservoirs can emit large quantities of CO_2 and CH_4 (Bergkamp et al. 2000).

1.3.4 Impacts on Sedimentation

The velocity and turbulence of a river slows down as it reaches a reservoir, and sediment particles being transported by the river drop out of suspension. All reservoirs accumulate sediments and lose water storage capacity over time, but the rate at which this happens varies widely. Sediment transport and deposition varies among rivers and depends on physiographic characteristics of the drainage basin (size, geology, soils, topography, and vegetation) as well as land use activities within the catchment area and the size of the reservoir relative to the volume of river flowing into the reservoir (Bergkamp et al. 2000; McCartney et al. 2001). Due to sediment deposition, about 0.5–1 % of the storage volume of the world's reservoirs are assumed to be lost annually (Mahmood 1987), leading to reduced water storage capacity and hydro-energy generation potentials of the dams. Heavy metals, which are carried by sediments, tend to accumulate in the upstream inundation area of a dam (DelValls et al. 1998). Downstream of a dam, a reduction in sediment load can lead to increased erosion of river banks and beds, loss of floodplains, and degradation of coastal deltas as sediment carried downstream by the river is no longer being replaced by material from upstream (McCartney et al. 2001). Reservoir flushing, the selective release of highly turbid waters, is sometimes used to reduce in-reservoir sedimentation (Atkinson 1996) and to increase sediment loads in the downstream river.

1.3.5 Impacts on Landscape and Morphology

Dam construction can greatly impact the landscape of the catchment area and morphology of the river channel with resultant impacts on the hydrologic regime of the river (Zhao et al. 2012b). Land use and land cover change are some of the most obvious impacts of dam construction on the landscape (Ouyang et al. 2010).

Once the dam is operational, reservoir sedimentation progressively changes the reservoir storage capacity and basin substrate (Buttling and Shaw 1973), which subsequently influences both the character of the water discharged below the dam and the suspended load passing the dam (McCartney et al. 2001). For example, the average annual loss of storage capacity due to sedimentation within the Saalachsee Reservoir, Bavaria decreased from 5.6 % during the first 15 years of operation to 2.5 % over a 47-year period and the output of suspended sediment nearly doubled (Bauer and Burz 1981).

The extent of channel morphology change below a dam depends on the interaction of three factors: the degree of flow regulation, the resistance of the channel bed and bank materials to erosion, and the quantity and nature of downstream sediment sources (McCartney et al. 2001). The reduction in sediment load tends to scour the channel below the dam, but the regulated flow regime (reduced peak flows) will counter this effect by reducing the flow velocity of the river. Both of these processes are modified by the erodability of the channel banks and downstream sources of sediments (Galay 1983; Williams and Wolman 1985). Channel erosion and degradation typically occurs within the first several kilometers below the dam. Further downstream, increased sedimentation (aggradation) may occur because suspended material in the river water is deposited due to slower moving water resulting in a widening of the channel (McCartney et al. 2001).

In addition, changes in sediment transport can result in changes in floodplains and even coastal delta and coastline morphology hundreds of kilometers below a dam site. Dams can either increase floodplain deposition or decrease it by erosion depending on specific conditions (McCartney et al. 2001). In some cases, the reduced frequency of flood flows and the stable low flows associated with the dam operation may encourage vegetation encroachment that can stabilize new deposits, further trap sediments, and reduce floodplain erosion. In other cases, the increased peak flood flow associated with dam operation may increase channel bank erosion, resulting in the loss of floodplains (McCartney et al. 2001). In coastal areas, the reduction of sediment input invariably leads to increased degradation. For example, dam construction on the Nile River has resulted in erosion rates of its delta of up to 5–8 m/year, and in some locations it reached as much as 240 m/year (McCully 1996).

1.3.6 Impacts on Water Quality

Dams change not only the hydrologic regime but also the chemical, biological, and physical characteristics of the water reducing the water quality and health of the river ecosystem (Ligon et al. 1995; Poff and Hart 2002; Hu et al. 2008). The quality of water stored behind a dam can be very different from the river water that flows into the reservoir. Impacts on water quality vary with the size of the dam, its location in the river system, its geographical location with respect to altitude and latitude, the detention time of the water, and the sources of the water (Bergkamp et al. 2000; McCartney et al. 2001). Large influxes of nutrients into reservoirs can occur as a consequence of both anthropogenic inputs within the water basin (e.g., fertilizer and sewage) and from the biological release of nutrients from flooded vegetation and soil (McCartney et al. 2001). As a result, eutrophication can occur resulting in water blooms of blue-green algae which can deplete oxygen in the deep water layer (Zakova et al. 1993).

Heavy metals originate from both natural and anthropogenic sources and can accumulate in the sediments of reservoirs (Shine et al. 1995; Kidd et al. 2007) impacting the aquatic food chain and leading to serious human health hazards

(Loska and Wiechuła 2003). A study of the Mawan Dam on the Lancang River (Upper-Mekong) measured high concentrations of As, Cd, Cr, Cu, Pb, and Zn in sediments that exceeded either the threshold effects level (TEL) of the US National Oceanic and Atmospheric Administration (NOAA) or Effects Range-Low (ERL) of the Canadian Sediment Quality guidelines (Zhao et al. 2012c).

Changes in water quality of the reservoir will also impact water quality downstream. Water released from a thermally stratified reservoir may change the natural temperature regime of the river, which impacts in-stream biota (Petts 1984), because it influences many important physical, chemical, and biological processes (McCartney et al. 2001). Different water release management practices of a stratified reservoirs will differentially change the water quality as water released from near the surface is generally well-oxygenated, warm, nutrient-depleted water whereas water released from near the bottom is cold, oxygen-depleted, nutrient-rich water (Zakova et al. 1993).

In arid climates, the salinization of water due to increased evaporation can be particularly problematic for downstream river ecosystems and floodplain wetlands (McCartney et al. 2001). Elevated salinity also will affect aquatic organisms (Hart et al. 1991).

1.3.7 Impacts on Aquatic Organism

The changes of hydrology, sedimentation, thermal regimes, and water quality associated with dam construction and operation can impact the composition and biomass of aquatic organisms including phytoplankton, periphyton, macrophytes, and fish in the food web. Upstream of a dam, the impoundment creates an ideal habitat for phytoplankton, but a less suitable habitat for periphyton and rooted macrophytes depending on depth, temperature, light penetration, and the nature of the substrate (McCartney et al. 2001). Changes in the composition of aquatic organisms can significantly affect others, e.g., blooms of phytoplankton and floating plants (e.g., water hyacinth) reduce light penetration and deplete oxygen when they decompose, and thus adversely affect other species (Joffe and Cooke 1997).

Downstream of a dam, primary production of phytoplankton, periphyton, and macrophytes are affected by changes in flow characteristics, water chemistry, turbidity, and thermal regimes. The flood mitigating characteristic of dams tends to promote the maintenance of higher than natural plankton populations within regulated rivers, by both sustaining populations released from the reservoir and promoting conditions for plankton development. Algal growth occurs in the channel immediately downstream from dams because of the nutrient loading from the reservoir releases (McCartney et al. 2001). Algal biomass was found to be up to 30 times greater downstream as compared to an upstream reference site with a very different species composition (Valentin et al. 1995). Flow regulation by a dam will lead to an increase in bed stability downstream, creating new habitat for the growth of aquatic plants. For example, flow regulation has allowed the rapid development of rooted plants (*Panicum repens* and *Phragmites mauritanus*) within the Zambezi River since the creation of Lake Kariba (Jackson and Davies 1976).

Fish are the most sensitive organisms affected by dam construction and flow regulation (Marchetti and Moyle 2001). Changes in the flow regime, water quality, river continuum, channel morphology, habitat conditions, and food webs may benefit some species, but they generally have an adverse effect on the majority of native species. Migratory fish are particularly susceptible due to the disruption of longitudinal connectivity by the dam (Wu et al. 2003). Dams can fragment and alter habitats (Wu et al. 2003; Wozney et al. 2011) to the point where native fish species are extirpated, allowing the invasion of exotic fish species and increasing biotic homogenization (Mckinney and Lockwood 1999; Olden et al. 2006; Olden and Rooney 2006). It is estimated that half the fish stocks endemic to the Pacific Coast of the United States have been lost in the past century, to a large extent because of dam construction (Chatterjee 1997). Upstream of the dam, the changes in flow patterns, and water temperature potentially change the feeding and spawning habitats of fish (Tiffan et al. 2002). Downstream of dams and fish populations change remarkably due to blockage of migration routes; disconnection of the river and floodplain; and changes in flow regime, physiochemical condition, primary production, and channel morphology (McCartney et al. 2001).

1.3.8 Impacts on Riparian Vegetation

Large dams can significantly change shoreline and riparian vegetation in both the impoundment region and downstream reaches (New and Xie 2008), even though the critical environment processes and diverse habitats for flora and fauna are supported by the riparian ecosystems (Beauchamp et al. 2007; Mallik and Richardson 2009). A number of studies have demonstrated that riparian vegetation can be remarkably impacted by damming, leading to habitat heterogeneity, declines in species richness and native species, and exotic species invasion (Nilsson and Svedmark 2002; Stave et al. 2005; Tealdi et al. 2011). Short-term vegetation changes are different from the long-term response due to riparian succession after dam begins operation (Nilsson et al. 1997).

Upstream of the dam, the largest impact on riparian vegetation is biomass submergence, leading to loss of plant biodiversity and primary production. Moreover, variation in the water levels of reservoirs can negatively affect vegetation in the immediate vicinity of the reservoir. For example, in Sweden, the pattern of water-level fluctuations regulated by a dam was not synchronized with the natural regime so that the riparian vegetation cover was extremely sparse (Nilsson and Jansson 1995).

Flow regulation below a dam has an adverse affect on plant species adapted to pulse-stimulated habitats. High discharges can retard the encroachment of true downstream terrestrial plants, while dams can disrupt plant reproduction and allow the encroachment of upland plants previously prevented by frequent flooding (McCartney et al. 2001). For example, *Acacia xanthophloea* is disappearing from the Pongolo system below Pongolapoort Dam, South Africa as a result of miss-timed floods (Furness 1978). However, given sufficient time after dam construction forest types more characteristic of unflooded upland areas may replace the original riparian forest vegetation.

1.3.9 Impacts on Biodiversity

Dams are believed to be not only a major cause for a decline in freshwater biodiversity, particularly the expiration of native fish species, the invasion of exotic fish species, and the decrease in fish beta-diversity, but also a major driver for the loss of terrestrial biodiversity along riparian zones. Dam construction can alter the structure and pattern of both terrestrial and aquatic habitats (Wu et al. 2004; Choi et al. 2005; Stromberg et al. 2007) resulting in the loss of biodiversity in river basins worldwide (Table 1.2). Riparian corridors are particularly important for many birds and terrestrial animals (Naiman et al. 1993), and the creation of reservoirs and inundation of ecosystems upstream will inevitably lead to the loss of these habitats (McCartney et al. 2001). Furthermore, the disruption of seasonal water flow regimes for flood control impacts downstream habitats putting the mammals and birds that use them at risk (McCartney et al. 2001; Nilsson and Dynesius 1994).

1.4 Social Impacts of Large Dams

Large dams significantly impact humans worldwide. Social impacts brought by dam construction generally occur in agricultural activities, economic activities, and local culture. Chapter 4 will narrow the scope to specific study areas in China, and analyze the impacts on local communities using more detailed information and a stringent analytical framework.

1.4.1 Impacts on Agriculture

Large dam projects have multiple negative impacts on agriculture at different scales, but the most direct and significant is the inundation of farmland. The conditions of the land along riverbanks are generally ideal for labor-intensive agriculture: relatively flat, easy access to irrigation water, and fertile. In one of our case studies in Chap. 2, Yunnan China, most of the highly productive paddy fields are along riversides. But since these fields are close to the river and at approximately the same elevation, most of them will be submerged by reservoirs once the dams are completed (Wang et al. 2013a).

Table 1.2 Rivers at risk—summary of threats to the biodiversity in the major river basins worldwide

Basin name	Countries within basin	Large dams	Types of risk
Yangtze	China	46	Large basin under stress from population pressures. Loss of habitat threatens bird species as well as endangered Yangtze River dolphin
La Plata	Argentina, Bolivia, Brazil, Paraguay, and Uruguay	27	River basin with high biodiversity; threats to Pantanal and other internationally important wetlands
Tigris-Euphrates	Turkey, Iraq, Syria, Iran, and Jordan	26	Arid basin; potential for conflicts over water withdrawal between Turkey and downstream countries
Salween	China, Myanmar, Thailand	16	Relatively pristine river with high biodiversity values; serious concerns about human rights abuses in Myanmar
Kizilirmak	Turkey	15	Small heavily fragmented basin; Ramsar site located in Delta
Ganges	India, Nepal, China, Bangladesh	14	Endangered Ganges River dolphin; Sundarbans mangroves in delta
Tocantins	Brazil	12	Relatively developed river basin; further dam development and improved navigation will exacerbate degradation for use of farmland
Amazon	Brazil, Peru, Bolivia, Colombia, Ecuador, Venezuela, Guyana, Suriname, Paraguay, and French Guyana	11	One of the most important basins for biodiversity; lower dams may affect coastal areas
Mekong	Thailand, Laos, China, Cambodia, Vietnam, and Myanmar	11	Basin with high biodiversity and very productive fisheries; droughts, and low water levels are current threats
Brahmaputra	China, India, Bhutan, Bangladesh	11	High biodiversity in upstream areas; high population pressure in delta
Zhu Jiang (Pearl River)	China, Vietnam	10	Highly developed basin; some important sites for amphibians
Danube	Germany, Austria, Slovakia, Hungary, Croatia, Serbia & Montenegro, Romania, Bulgaria, Moldova, Ukraine	8	68 Ramsar listed sites as well as UNESCO biosphere reserve in delta
Huang He (Yellow River)	China	8	River basin with severe water shortages; 4 endemic bird areas, 1 Ramsar site

(continued)

Table 1.2 (continued)

Basin name	Countries within basin	Large dams	Types of risk
Kura-Araks	Azerbaijan, Iran, Georgia, Armenia, Turkey	8	Biodiversity hotspot with 4 Ramsar sites, 1 Endemic Bird Area and 21 IBAs
Yesil-Kelkit	Turkey	8	Breeding populations of many birds in Delta
Büyük Menderes	Turkey	7	River delta protected as National Park, protected bird areas
Çoruh	Turkey	7	Fast flowing river with significant tourist industry based on rafting
Susurluk	Turkey	7	N/A
Ebro	Spain and Andorra	6	High economic importance of delta; important bird sites
Indus	Afghanistan, Pakistan, India, and China	6	Endangered Indus River Dolphin

Source: Adapted from World Wildlife Foundation (WWF 2005)

As a consequence of farmland inundation, new farmland needs to be cleared to compensate for the losses incurred by local farmers. These newly cleared lands, however, are in most cases inferior, since previously they were not arable. Problems relevant to newly cleared farmland include higher or lower temperatures, which may be inappropriate for the growth of certain crops; lower productivity, because it takes raw land several years before it can produce high yields; difficulties in irrigation, since the distance from the river is often much greater than before, and major investments in irrigation equipment are required to obtain the same amount of water as before; and some newly cleared lands have steeper slopes than before, which increases soil erosion. In addition, their relatively poorer conditions also force farmers to use more synthetic fertilizers, which can increase pollution in water bodies and ecosystems (Wang et al. 2013a; Wang 2012).

1.4.2 Impacts on Local Livelihood

Large dam projects submerge large areas of farmland, cause thousands of people to be relocated, and therefore have substantial impacts on local livelihoods. According to the World Commission on Dams (WCD 2000), 40–80 million people were relocated worldwide between 1950 and 2000 because of large dam construction.

The direct impacts of large dams on local people include the loss in houses, farmlands, forests, and other resources that determine a farmer's material wealth. To offset the losses, relocated people are sometimes given new houses and newly cleared farmland, while in other cases, their material wealth losses are addressed through monetary compensation programs. If only material wealth loss is considered, relocated people in many cases are fairly compensated, or in some cases even overcompensated (Wang et al. 2013a).

However, dam projects and associated relocation programs also have various indirect impacts on local people. First, many relocation schemes fail to consider the possible negative effects that might arise from moving to a new and different environment. People rely on specific skills to make a living, but the effectiveness of these skills can be impaired when moved to a totally new environment. Second, the social network supporting the community is probably disrupted in the process of relocation. For example, in a totally new environment, people might need to develop a new network for buying materials and selling products. Third, the inundation of a person's hometown can lead to significant psychological problems, which have occurred in some communities along the Upper-Mekong River (Zhao et al. 2012c; Wang et al. 2013a).

1.4.3 Impacts on Social Equity

The relocation of people due to dam construction not only impacts a farmer's wealth, but it also initiates a process of wealth reallocation. This may broaden the gap in relative wealth at different scales during relocation, which may lead to social inequity problems.

At the household level, relocation often drives people to find new and diverse employment opportunities, instead of continuing agricultural activities similar to those they did in their original village. Some villagers may be relocated to urban areas to work in factories or companies, while others may open their own small businesses. The result of this change in occupations is that some people end up being better off and some others become worse off. This new diversity widens the gap in wealth status among households, which may lead to social problems in the community (Fu and He 2003; Wang 2012).

The wealth status of entire villages also changes differentially because of different compensation policies and the different opportunities that arise from a specific dam project. Hence, compensation policies can vary substantially over time and in different regions. For instance, compensation standards for dam-induced relocation in China quadrupled in 2006 in response to new regulations, which caused large discrepancies in compensation between communities moved before and after this date (Wang et al. 2013a; Wang et al. 2013b). The opportunities available to relocated people also vary greatly. For example, some villages are moved close to an urban area with a convenient transportation system, which can stimulate the local economy. In contrast, other villages are moved to relatively isolated areas with limited access to services and very poor living conditions (Wang 2012).

At an even larger scale, such as the county or province level, the distribution of costs and benefits associated with the dam project may also be uneven. Regions close to a dam project likely will suffer most severely from its environmental and social impacts, but may not benefit greatly from the dam. For example, China's

Three Gorges Dam controls flooding in downstream provinces thousands of kilometers away, and generates electricity, which is fed into national grid, but only a small portion of these benefits reach local people in the dam-affected areas (Jackson and Sleigh 2000). A more detailed analysis of social inequities related to dam construction will be covered in Chap. 4.

1.4.4 Impacts on Culture

The impacts of dam construction on local culture can occur in multiple ways. First, the reservoir formed by the dam could inundate historical heritage sites along the river, since many ancient civilizations originated in river basins and left abundant historical structures. Second, dams are generally built in mountainous areas, which in many cases are the homes of ethnic minority groups with very diverse cultures. The relocation of these groups may disrupt their traditional lifestyles, causing the loss of many unique cultural traditions and intangible features of their heritages.

The Aswan Dam in Egypt flooded the original sites of many historical monuments, including Abu Simbel, Philae, Kalabsha, and Amada. The UNESCO and the Egyptian government moved many of these structures to higher ground above the reservoir to mitigate the loss of these historical resources (Hassan 2007). China's Three Gorges Dam also affected a large area rich with historical heritage. The most famous one is the "Mo ya shi ke," a place where huge Chinese calligraphy was carved along a cliff dozens of meters above the Yangtze River. The Chinese government moved whole pieces of rock about 50 m up the cliff so that this spectacular scenery remained visible for long distances after the reservoir filled (Childs-Johnson and Sullivan 1996).

The relocation of ethnic minority groups sometimes forces them to change lifestyles, therefore losing their traditions. Some ethnic groups are merged into another ethnic group's culture and have to adapt to the new environment by changing language and/or abandoning some of their old ways of living. For example, along the Upper-Mekong River many ethnic minorities no longer speak their own language after moving into areas dominated by Han, and they often lack appropriate space to celebrate some of their traditional festivals, therefore gradually abandoning these cultural events (Wang et al. 2013a).

1.5 Debates Around Large Dams

Debates about large dams have intensified in recent decades, and they generally fall into three types of concerns: economic feasibility, environmental sustainability, and social equity. This section briefly summarizes the different points of views commonly expressed about these concerns based on a series of key literatures on large dam issues (WCD 2000; Sadler et al. 2000; Magee 2006; World Bank 2009; Mertha 2008; Scudder 2005; Pan and He 2000).

1.5.1 Economic Feasibility

There are many proponents of dam construction, who mainly hold the opinion that building dams will generate opportunities for economic and social development, both at local and national levels. Their arguments include:

1. Dam construction projects will generate employment opportunities for local people and stimulate local economies because the arrival of engineers and construction workers will generate demands for various services.
2. The infrastructure that must be constructed before the dam project begins, such as roads and bridges will enhance the ability of local communities to access other regions, and sell their products across a larger market area.
3. After the dams come into operation, the reservoirs could provide irrigation water for farmland, stimulate a beneficial fishery, and attract tourists to the region because of their "lake-like" sceneries and recreational opportunities.
4. The navigation conditions for upstream regions will be improved, therefore facilitating trade and commerce activities.
5. Hydropower dams generate cheaper and cleaner electricity than those produced by fossil fuel combustion. Cheap electricity could reduce the costs of many industries and benefit the economy in general, and the profit from electricity could increase local government revenues and stimulate local economy.

However, the opponents to large dams argue that many dams actually fail to achieve their original economic goals. Many may not even recover the cost of their construction, nor the secondary costs to the environment and local communities. Their major arguments are as follows:

1. Many large dam projects overrun their budgets significantly, due to underestimating the technical difficulties, the compensation costs associated with the relocation processes, and changes in external conditions, such as the costs of labor and/or construction materials. Therefore, some large dams that are considered economically feasible actually end up failing to recover their total costs.
2. All large dams, regardless of their original purposes, have a problem of shortfall in designed goals to a certain extent. According to WCD's report (2000), most of the irrigation dams and water supply dams fail to achieve their designed goals, while hydropower dams are more likely to fulfill their targets.
3. Most large dam projects do not consider the externalized social and environmental costs in determining their total costs; therefore, the cost/benefit calculations for these projects are problematic. For example, large dams could harm a downstream fishery, but this financial loss is seldom incorporated into the actual cost of the dams during the decision-making process, especially when the downstream area is in a different political region.
4. There exist many alternatives to large dams, which may have much smaller economic, social, and environmental costs. Water-saving agricultural techniques have a great potential to reduce agricultural water demand. For example, micro-irrigation methods, such as sprinkler and drip systems, have already proved their

ability to save water. Renewable energy sources, including biomass, wind, solar, geothermal, and ocean tidal, only constitute about 1.5 % of the electricity generation around the world. If the use of renewable energy were increased greatly, the need to construct of hydropower dams might decline substantially.

1.5.2 Environmental Sustainability

Some opponents to dam construction argue that building large dams is an environmentally unsustainable solution for generating electricity, flood control, and irrigation for the following reasons:

1. The lifespan of a large dam is limited. Because of problems like sedimentation, most dams lose part or all their functions after about a hundred years. However, the impacts on the environment are irreversible and perpetual. Therefore, the short-term benefits of the large dams do not offset their long-term negative impacts.
2. Large dams alter the conditions of river systems so dramatically that many species cannot adapt appropriately, and therefore are likely to go extinct. According to various studies, dam construction is among the most harmful human-caused reasons for biodiversity loss.
3. The impacts of dam construction on the environment could act at different spatial scales, and therefore are very difficult to assess. Many studies focus only on the local impacts, but dams may also affect the regional climate and geological conditions, such as triggering earthquakes, and could even contribute to global climate changes because of increased greenhouse gas emissions.

The proponents of dam construction do not necessarily deny these negative impacts on the environment, but often argue that they are exaggerated. They note that ecosystems have the ability to adapt to the changes, and that there are many technological approaches that can be applied to mitigate the negative impacts. In sum, they argue that there is still an overall advantage to society to building large dams, as their positive benefits outweigh the negative impacts.

1.5.3 Social Equity

Opponents of dams argue that dam construction could generate many social inequity problems, mostly during the cost and benefit distribution and the resettlement processes. Their main arguments are as follows:

1. The distributions of costs and benefits of dam construction are uneven. The electricity generated from hydropower dams is in most cases fed into national grids, but local communities bear most of the negative impacts from dam construction. Most of the benefits arising from dams do not reach the local people.

2. The construction of dams often, if not always, involves large-scale relocation of local people. Relocated people lose their houses, land, and many other resources during the relocation, but are generally not fairly compensated. Most studies show that the dam-induced relocated people are generally adversely impacted economically and socially.
3. Local minorities and indigenous groups are underrepresented in the decision-making process, and are often unfairly treated in dam projects. Large dams are usually built in mountainous areas, which in many cases are the homes of ethnic minority groups. Statistics show that the percentage of ethnic minorities among all people affected by the dam projects is much higher than the percentage of the minorities in the whole population. These minorities generally lag in social and economic development, and are therefore more vulnerable to any changes brought about by dams.

The proponents of dams argue that better compensation policies that take regional benefits and costs and the rights of local people into consideration would resolve these social inequity problems. They suggest the following principles be considered during the decision-making process:

1. It is critical to make sure that all stakeholders involved in and impacted by a dam construction project participate in the decision-making process, and the entire process should be transparent to all stakeholders and even to society as a whole. Central and local governments, local communities, companies, scholars, and non-government organizations (NGOs) should have opportunities to express their concerns and opinions before the start of a dam project.
2. Better design in compensation policies that take various losses of relocated people into consideration is needed to mitigate the impacts to the minimum level. When relocation of people and communities is unavoidable in dam projects, reasonable compensation policies are critical to ensure the standard of living and the development opportunities of the relocated people are not greatly sacrificed.
3. The rights of the indigenous people and ethnic minority groups should be given particular attention and protected. Their interests should be considered during the decision-making process even though they may lack the ability to formally defend their own rights.

Because of the complexity and wide-range impacts of large dam construction, the ideas held by diverse stakeholders are often confounding and opposite, and make this issue a particularly difficult dilemma to address by modern societies worldwide. The following chapters will focus on China, a country that leads the world in the construction of large dams while also facing significant sustainable challenges arising from rapid and unprecedented economic development. By analyzing environmental and social impacts of large dams in different watersheds in China, and introducing frameworks to assess these impacts, we hope to provide helpful insights into the decision-making process for dam construction in China and beyond.

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