20. The emergence of technological hydroscapes in the Anthropocene: socio-hydrology and development paradigms of large dams

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The term Anthropocene has gained currency as a descriptor for the current geological epoch, characterized by human domination of the Earth. One of the most dramatic examples of human impact on planetary processes is the rapid transformation of the majority of river systems through dam building (Baghel 2014). More than half (172 out of 292) of all large river systems have been fragmented by dams, which obstruct two-thirds of all freshwater flows with their reservoirs capable of holding back more than 15% of the global runoff (Nilsson and Berggren 2000; Meybeck 2003; Nilsson et al. 2005). Apart from affecting water flows, large dams also prevent sediment transport to the sea and trap more than half (53%) of the total sediment load. If unregulated basins are included, this means that 25–30% of *all* sediments worldwide are intercepted by these artificial structures (Vörösmarty et al. 2003). This drastic alteration of the world's river systems has received much less attention than global climate change, yet it has been suggested that the 'global impact of direct human intervention in the terrestrial water cycle (through land cover change, urbanization, industrialization, and water resources development) is likely to surpass that of recent or anticipated climate change, at least over decadal time scales' (Vörösmarty et al. 2004, 513).

Large dams are among the greatest single constructions and most massive infrastructure projects built worldwide and provide water storage for hydropower generation, irrigated agriculture, industrial production and flood control. As the most significant tools employed for river basin management, large dams are considered powerful icons of modernization, economic success, national prestige and technological progress. Despite the long history of flow regulation in human civilization, such as that found within ancient China and the Middle East, the global sprawl of dam building has only emerged in the past 60–70 years. By 1950 only about 5000 of these hydraulic structures had been built, before the countries of the Global South witnessed a resurgence of dam construction soon after decolonization (Gleick 1998; McCully 2001). Notable examples include Ghana's Akosombo Dam (completed 1965), which resulted in the formation of Lake Volta, the Aswan Dam in southern Egypt (completed 1970) and the Bhakra Dam in northern India (completed 1963). Since then, China and India have become the most prominent dam-building nations. By the turn of the millennium, the world had built over 45,000 large dams with a total flooded area estimated to exceed 500,000 km² (WCD 2000). The latest synthesis of the World Register of Dams, compiled by the International Commission on Large Dams (ICOLD), includes 58,402 large dams, straddling all major river basins on earth. Together these artificially inundated reservoirs sum up to an aggregate storage capacity of about 16,100 km³ (ICOLD 2016).

Large dams are not only material artefacts of technological advancement or representative elements in the transformation of fluvial environments, but also gigantic manifestations of the social construction of nature. Over the past few decades, the erection and operation of these socio-hydrological structures have become the focus of intense debates with regard to their effectiveness for development, environmental impacts, social justice and sustainability (e.g. McCully 2001; Khagram 2004; Scudder 2005). Whereas advocates of dam construction propound their benefits as incentives for economic development, opponents emphasize a whole range of environmental, socio-economic and political costs (Nüsser 2003). Depending on their specific mode of operation, the environmental impacts of dams include fragmentation of riverine ecosystems, changes in flow patterns, modification of erosion and sedimentation processes, species extinction in freshwater and wildlife habitats, and loss of water by evaporation and contamination. Among the most commonly cited socio-economic concerns are insufficient compensation for displaced persons and the lack of their long-term development perspectives.

A huge body of literature on river control has been published and the main arguments have been repeatedly expressed in reports and case studies (e.g. Fearnside 1988; Bakker 1999; Khagram 2003; Ansar et al. 2014; Hirsch 2016; Kirchherr et al. 2016). The dominant lines of argument are rooted in the classical development paradigms of modernization, dependency and sustainability. However, large-scale physical transformation and fragmentation of rivers by dams and reservoirs are rarely framed within the broader context of geographies of technology. The term 'technological hydroscapes' (Nüsser 2014) is used here to frame the socio-hydrological nature of dam building under diverse technological and ideological settings. It captures not only the physical transformation of fluvial environments but also the implementation of new water and energy governance systems. The term combines the concepts of 'waterscapes' (Swyngedouw 2009), 'technoscapes' (Appadurai 1996), 'energyscapes' (Kaisti and Käkönen 2012) and 'cryoscapes' (Nüsser and Baghel 2014), where the suffix 'scape' emphasizes the fluid nature of these spaces. Such 'scapes' are not considered as physically delimited spaces or merely as social constructions of nature, but rather as dynamic entities constituted by complex flows of technology, funding, ideology and discourses of development and environment (Baghel and Nüsser 2010). The fundamental shift in the rationale and scale from local water use to the human domination of water systems was only made possible with the advancement of modern technology. Following a classificatory overview of large dams, this chapter retraces the origins and historical course of this technology and explores its conceptual foundations, changing development paradigms and geographical implications.

LARGE DAMS: FUNCTIONS, TYPOLOGY AND TECHNOLOGY

Dams and reservoirs serve a variety of functions. Their most important purposes are irrigation for agricultural production (49%), hydropower generation (20%), water supply for industrial and domestic use (13%) and flood control (9%). An increasing number of multi-purpose dams (17%) meet several of these objectives (ICOLD 2016). The extension of irrigated land is often portrayed as a crucial prerequisite to meet future food demands, which in turn justifies further dam construction. Their enormous economic importance is additionally demonstrated by the fact that about 675 GW of installed hydroelectric capacity produce nearly 25% of total electricity on Earth (ICOLD 2016). In order to define large dams as a distinct category, ICOLD offers a set of criteria. According to their well-established definition, a large dam is one whose height from the lowest point of foundation to the top exceeds 15 m, or whose height is between 10 and 15 m, if it meets at least one of the following five conditions: (a) the crest length of the dam is not less than 500 m; (b) the capacity of the reservoir is not less than 1 million m^3; (c) the spillway discharge potential exceeds 2000 m^3 per second; (d) the dam faces especially difficult foundation problems; and (e) the dam is of unusual design.

There are three main types of dam design, namely embankment, gravity and arch, which are primarily selected according to site topography and geological setting. Embankment dams (e.g. Nurek in Tajikistan, Tarbela in Pakistan, Tehri in India and Mohale in Lesotho), representing around 75% of global dams, are built from excavated earth and rock fill and they are usually triangular in cross-section. These most massive dams can be constructed on soft and unstable riverbeds, because their broad base distributes weight over a wide area. Gravity dams (e.g. Bhakra in India, Grande Dixence in Switzerland) are constructed from roller-compacted concrete, stone or other masonry, and entirely rely on their own weight and internal strength for stability (Figure 20.1). They are mostly built across narrow valleys with firm bedrock conditions. The third type, concrete arch dams (e.g. Katse in Lesotho), are convex upstream to transfer the force of stored water to the adjacent rock walls (Figure 20.2). They require much less concrete than gravity dams of the same length, but are limited to narrow canyons with solid rock foundation. Spillways are general structural features of dams, which are used to discharge water when the reservoir threatens to become dangerously high. The two main categories of dams are reservoir storage projects, which capture runoff and impound water for seasonal or annual storage, and run-of-river schemes. In the second type, water is diverted into head race tunnels before reappearing some distance down the valley, where the powerhouses are located. These run-of-river schemes require smaller reservoirs of inundation and operate with an increased hydraulic head. A third type of hydroelectric installations is pumping–storage facilities, using power during daily low-demand periods to pump water to a higher reservoir, from where it can be used for electricity production during peak-demand periods.

With a height of 305 m, the Jinping I Dam in China, completed in 2013, is currently the world's highest construction. At 300 m, the Nurek Dam in Tajikistan, completed in 1972, held this position for almost 40 years. The Bakhtiari Dam in Iran, under construction since 2013, will exceed the existing dams with a planned height of 315 m and the currently suspended Rogun Dam in Tajikistan may even reach an elevation of 335 m. With a surface of 8500 km^2, the Volta Reservoir behind Akosombo Dam in Ghana forms the largest artificial lake on Earth, flooding more than 5% of the country (Gleick 1998; WCD 2000; McCully 2001; ICOLD 2016; own data compilation). With 22,500 MW of installed capacity, producing 84,900 GW h of energy per year, the Sanxia project in China, also known as Three Gorges Project, located on the Yangtze River, is by far the largest hydropower plant. The gigantic project, a dream of Mao Zedong finally completed in 2010, was accompanied by a massive resettlement scheme that displaced almost 1.2 million persons (Li et al. 2001; Penz et al. 2011). Among those 20 projects causing the highest number of displaced persons, 15 are located in China (ICOLD 2016).

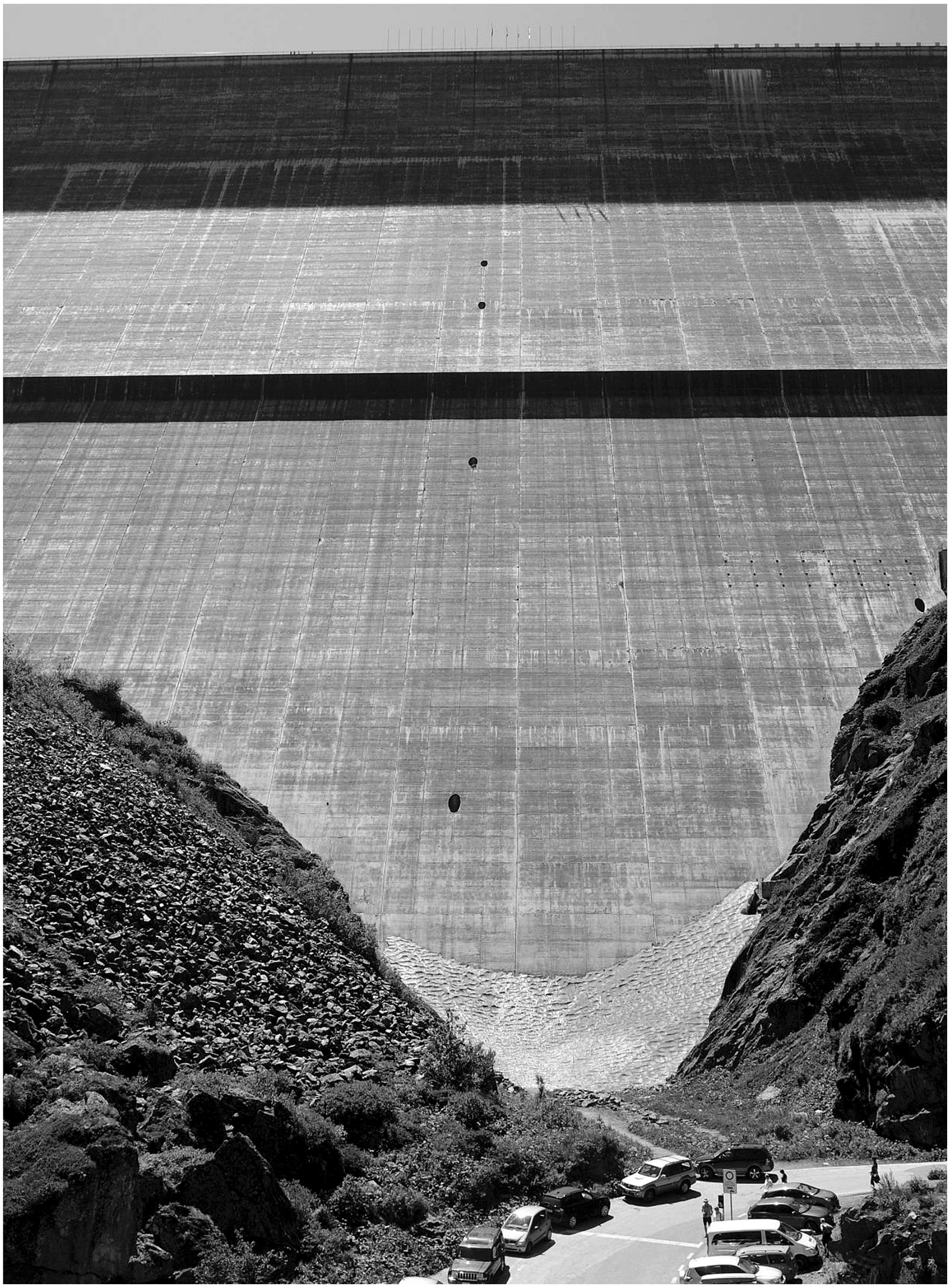


Figure 20.1 With a height of 285 m, Grande Dixence is the world's highest gravity dam. Built between 1951 and 1965, 6 million m³ of concrete were used for construction. Remains of a snow avalanche are visible near the base

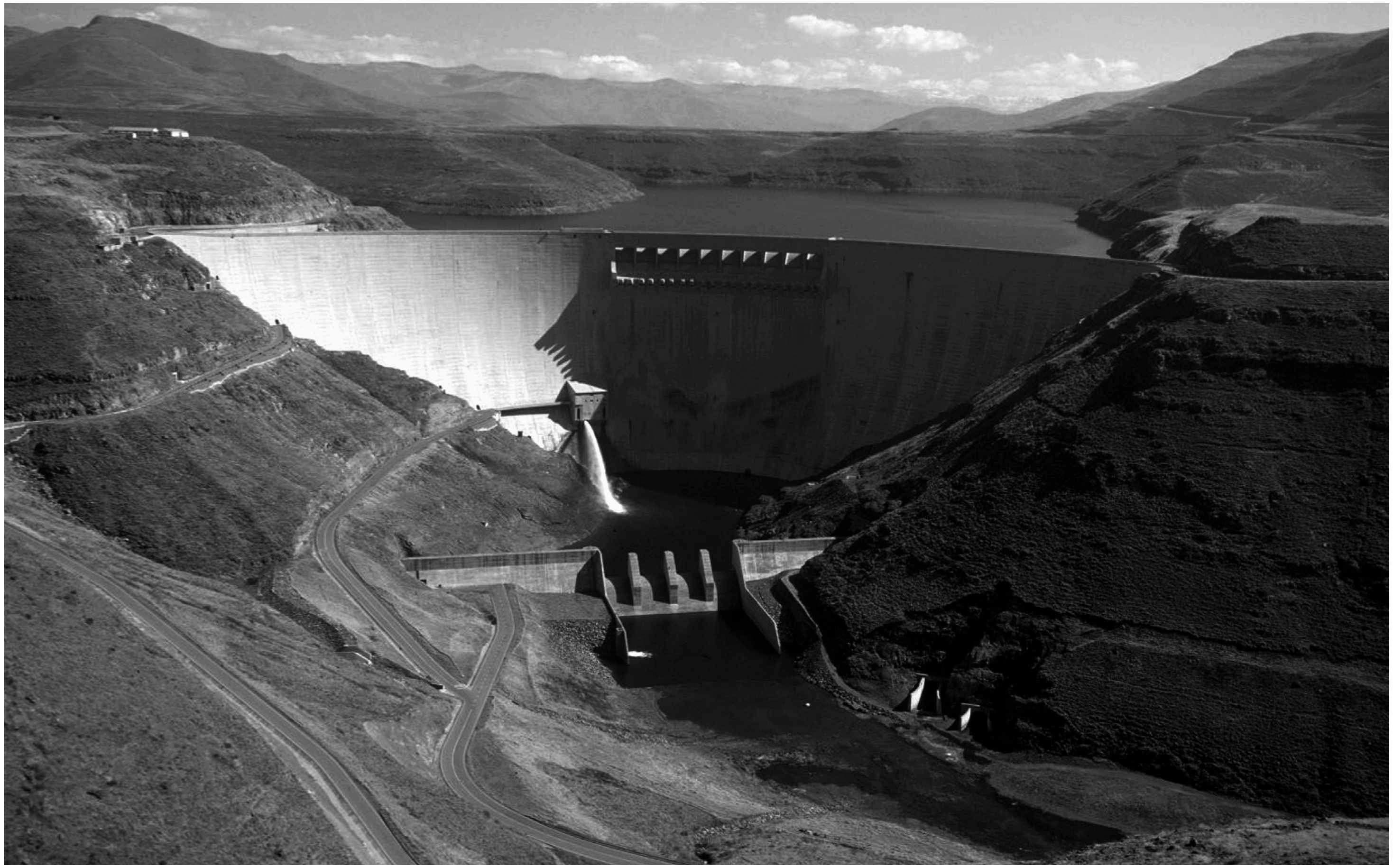


Figure 20.2 *Katse Dam. One of the most spectacular arch structures in the world with a height of 185 m and a crest length of 710 m, it forms a central component of the Lesotho Highland Water Project*

'DAMNED DAMS': HISTORY, IDEOLOGY AND ACTORS

While extensive implementation of dam projects evolved with improvements in engineering knowledge, construction technology and progress in hydrological analyses, the global increase in technological hydroscapes is also an expression and outcome of prevailing development paradigms. The era of big dams began in the United States with the construction of Hoover Dam on the Colorado River in the 1930s. Earlier examples of extensive river control measures and dam building are known from the middle mountains of Germany, where constructions started in the early twentieth century, but the expertise remained confined domestically (Blackbourn 2006). After the Second World War, a number of large dams were built in the Soviet Union, following Stalin's concept of a 'transformation of nature into a machine for the communist state' (McCully 2001; Molle et al. 2009). Around the same time, dam building commenced in the European Alps, with Grande Dixence as one prominent example (Figure 20.1). In the Global South, large dams became icons of modernity and expressions of national prestige and emancipation from colonial rule. As the first Indian Prime Minister, Jawaharlal Nehru, stated, large dams are 'temples of resurgent India' and 'symbols of India's progress'. The modernization narrative was repeated in a different ideological setting under Mao Zedong and resulted in the construction of more than 600 large dams per year as part of the 'Great Leap Forward' (Gleick 1998; McCully 2001). Efforts at river control were not only based on development aspirations, but also upon the quest to conquer nature as a threat, or to tame, control and discipline nature as part of a 'hydraulic mission' to use every drop of water before it reaches the sea (Kaika 2006; Molle 2009; Molle et al. 2009).

Large dams are textbook examples that highlight most sensitive and contested development issues, shaped by tensions between actors, politics and economic aspirations at various scales. Key actor groups in the controversy are government agencies, river basin authorities, bi- and multilateral funding agencies, international construction associations, private sector companies, non-governmental organizations, human rights and affected people's groups (Figure 20.3). Struggles over power and influence within this constellation of place-based and non-place-based actors testify to a politicized environment, where conflicts can only be understood by considering power asymmetries and divergent interests (Baghel and Nüsser 2010). Both advocates and opponents of large hydro projects form coalitions to strengthen their position during the planning and implementation phase. The narrative of modernity, economic benefits, social progress and effective water management contrasts sharply against the counter-narrative of displacement and marginalization of local populations accompanied by the devastation of river habitats.

Nation states and governments are definitely among the most important drivers of large dams, often making them symbols of nation-building or icons of ruling autocratic regimes. Powerful parastatal agencies and bureaucratic institutions are typically established to plan and realize these big projects and take on a life of their own, competing for influence and reasoning for their existence. The emergence of a hydraulic bureaucracy consisting of influential elites of technical engineers, hydrologists, political and financial leaders reinforces centralized planning and management of river control. One example is India's 'Ministry of Water Resources', which has a complicated history, after having variously been a 'Department of Irrigation' under ministries associated with Irrigation, Power, Mines, Scientific Research and Agriculture in different periods until finally becoming a

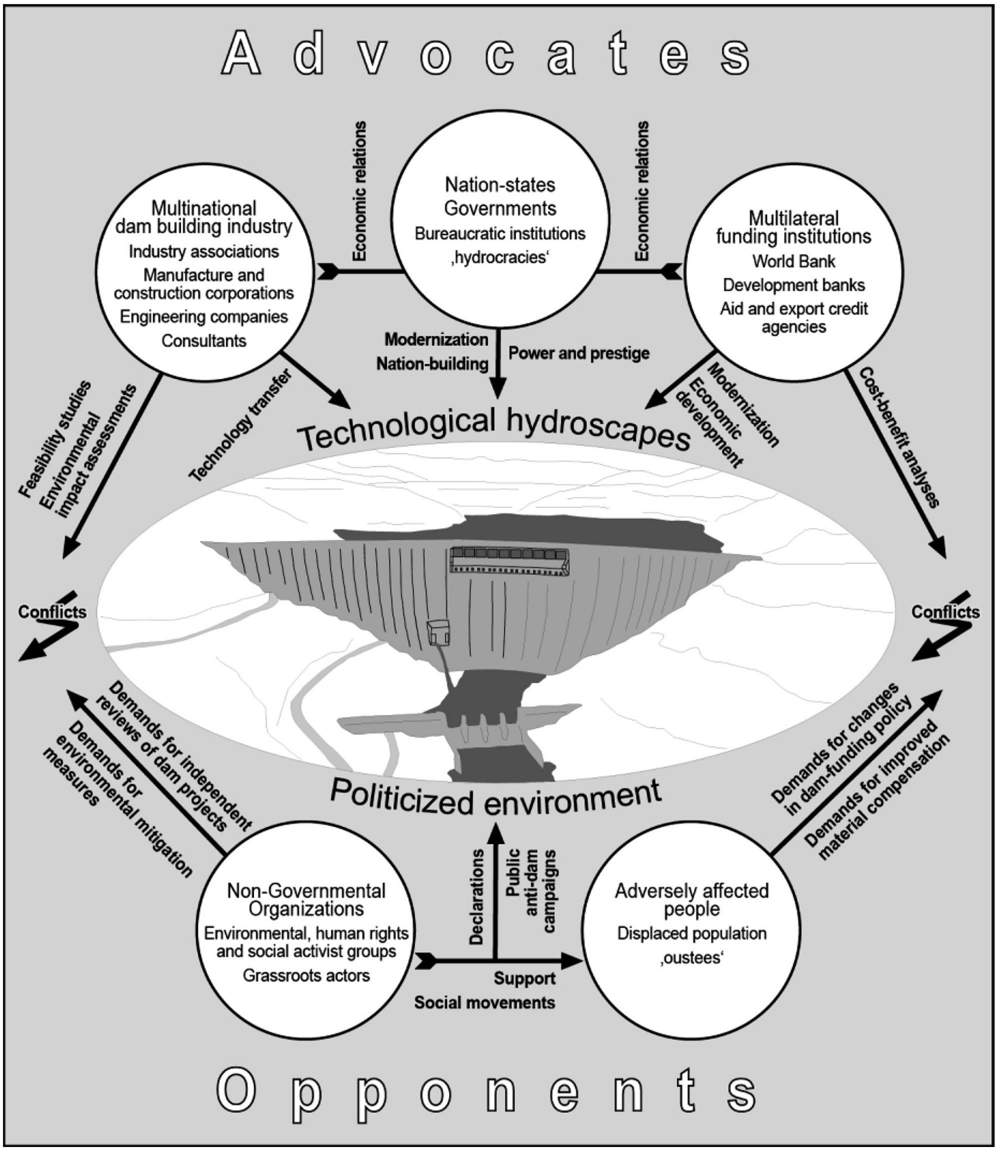


Figure 20.3 *Characteristic actor constellation around large dams (modified after Nüsser 2014)*

ministry of its own in 1985 (Ministry of Water Resources 2012). Pakistan's Water and Power Development Authority, established in 1958, is another case in point (Wescoat et al. 2000). This centralized government-owned organization was founded for the purpose of coordinating and giving a unified direction to the development of water and power schemes, which were previously being dealt with by respective electricity and irrigation departments at the provincial level. The emergence of such powerful and centralized parastatal agencies is by no means limited to the Asian context, as the example of the Lesotho Highlands Development Authority in southern Africa shows. These examples suggest how large dams have served changing bureaucratic structures and development priorities.

The dam building industry, consisting of multinational engineering firms, consultants, equipment manufacturers and construction corporations, is another important driving force. These actors are organized in professional institutions such as ICOLD, which was established in 1928 to exchange experience in project design and hydraulic analysis. It consists of national committees from more than 90 countries with approximately 10,000 individual members (ICOLD 2016) and constitutes an active lobby for the propagation of dams. Advantages of technology transfer and economic progress are frequently expressed motivations for dam building in the Global South. Feasibility studies and environmental impact assessments are carried out by consultant companies, some of which are also directly involved in dam building. Dependent electricity-intensive industries (i.e. aluminium smelters) and agribusiness interests are intimately linked to the dam building lobby as well (Fearnside 2016). The World Bank has been the most important financing agency for the dam building industry. During recent decades, it has approved loan packages for a multitude of dams, including some of the world's most controversial mega-projects. Other major funding institutions are the multilateral development banks for Africa, Asia and Latin America as well as the bilateral aid and export credit agencies of most industrialized countries.

Since the mid-1980s, the international anti-dam movement, consisting of a network of environmental and human rights groups, has emerged. Their basic demands include independent impact assessments of projects and participation of affected people in the planning process. Working together with local groups, these 'grassroots' actors have been able to launch public opposition campaigns and declarations. Globally operating organizations like International Rivers and *Narmada Bachao Andolan* (Save the Narmada Movement) in India are prominent in this context (Khagram 2004; Nilsen 2010). The largest set of actors include the adversely affected people who suffer negative economic, social and cultural effects from construction works, impoundment and alteration of river flows. Whereas the displaced populations or 'oustees' are considered 'refugees in an unacknowledged war' (Roy 2001: 65) by activist groups, nation-states identify them as beneficiaries of prospective improvements.

However, the deep-seated differences between various interest groups cannot be reduced to a binary of modernized hydro politics versus environmental fundamentalism. Founded in 1997, the World Commission on Dams (WCD) addressed the conflicting viewpoints on large dams by including representatives of governments, industry, financial institutions, non-governmental organizations and affected people's organizations. As a forum with 68 institutions from 36 countries to reflect the diverse range of interests and to elaborate common ground in the negotiation process, it came up with five guiding principles: justice, sustainability, efficiency, participation and accountability. As a result, critiques of modernization and its neglect of broader social and environmental concerns became an integral part of the debate. The commission's final report (WCD 2000) provided the first comprehensive global and independent review of the performance and impacts of dams and presented a framework for water and energy resources development with criteria, guidelines and procedures for future decision-making. It was hoped that, with the ground-breaking work of the WCD, the controversies of the past would be buried, which they were for a period, symbolized by the drop in funding by the World Bank (Baghel and Nüsser 2010; Moore et al. 2010). However, despite on-going controversy over large dam projects, the discussion at the turn of the century was characterized by efforts to look for suitable compromises that met the requirements of different development perspectives.

THE GLOBAL PICTURE: CONTINUITIES, SHIFTS AND PARALLELS

Large dams as symbols of modernization are not solely for the internal benefit and prestige of nation states, but also have strategic geopolitical implications (Hirsch 2016). India's Bhakra Dam, located close to the border of the Indian states Himachal Pradesh and Punjab on the Sutlej River, eventually flowing into Pakistan, is a case in point. Bhakra Dam was planned and initiated under the British administration, and was completed by Indian engineers under American supervision. Its power station on the right bank was built and later upgraded with Soviet assistance and technology during the height of the Cold War. India's control of the water flow through the dam was a major source of contestation from the Pakistan side of the Punjab owing to the need for a regular water supply for irrigation during the green revolution in both countries. This eventually led to the signing of the Indus Water Treaty in 1960 (Baghel 2014). Generally, such large hydropower projects include a flow of international expertise and financial investment, setting the blueprint for future development. In the case of China, the technological capacities needed for construction and management of hydrological infrastructure were initially provided by the Soviet Union, with thousands of engineers being trained. In the present day, China has by far the world's largest installed hydropower capacity, with aspirations for further expansion (Gleick 2012). Moreover, Chinese funding institutions and engineering companies are increasingly involved in dam projects in neighbouring and overseas countries (Brewer 2007). China's involvement in the construction of the Diamer Basha Dam in the Indus Valley of northern Pakistan, with the promise of several thousand experienced workers from the Three Gorges Dam, is just one example. This dimension of technology and knowledge transfer is in many ways similar to the expertise flowing from the Tennessee Valley Authority in the United States to India in the 1950s. Regardless of the political and ideological positions of respective countries, large dams have been considered as important foundations for national development, legitimized by the modernization paradigm (Ahlers et al. 2014).

As opposed to the Bhakra Dam, which gained widespread support as an icon for economic growth, the Narmada Dam cascade became a symbol of social inequity, resistance and an expression of failed development (Gadgil and Guha 1994; Drèze et al. 1997). Besides socio-economic and environmental concerns, the Tehri Dam (completed in 2006) in the Himalayan state of Uttarakhand, being the highest dam in India, has been criticized for the risk associated with it being located in a seismically active zone. Whereas the debate in India takes place in a democratic setting with multiple actors voicing their opinions (all too often with little real effect), the decision-making in China is primarily limited to the Communist Party with little local opposition (Dai 1998). Other prominent examples of the controversy are Pakistan's Tarbela and Diamer Basha dams, projects on the Mekong River (Bakker 1999; Matthews 2012; Merme et al. 2014; Hensengerth 2015) and Brazil's Tucurui Dam (Fearnside 1999). Earlier projects such as the Aswan High Dam in Egypt (completed 1970) or the Akosombo Dam in Ghana (completed 1965) remain contentious in terms of their long-term impacts on the environment, demography and economy of their surrounding regions.

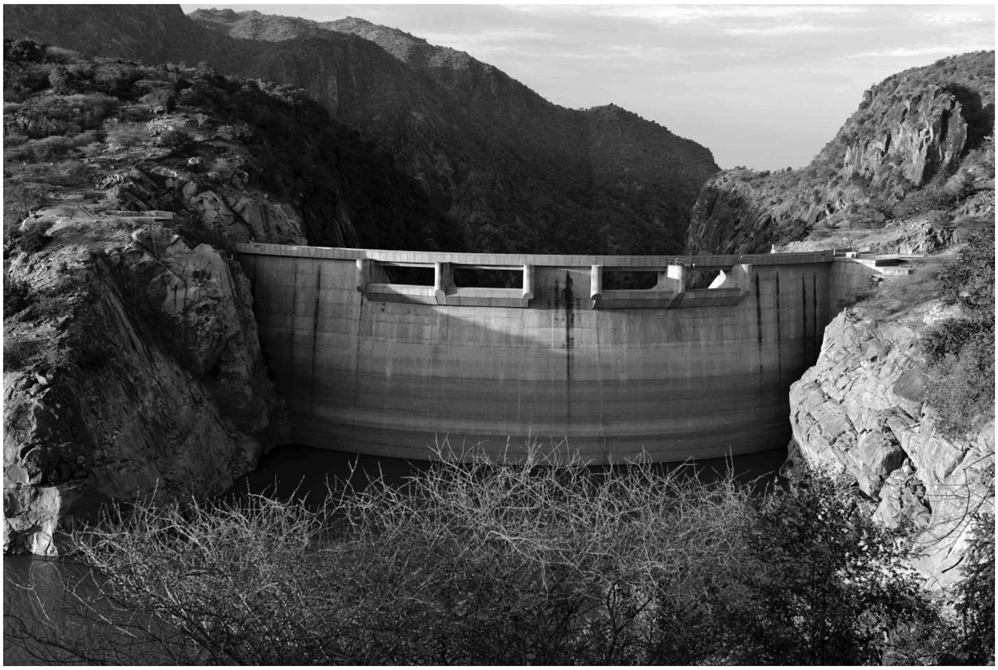
In the Himalayan region, the governments of India, Pakistan, Nepal and Bhutan are transforming the upper reaches of the mountain drainage system into the sub-continental powerhouse of South Asia at an unprecedented pace (Baruah 2012; Huber and Joshi 2015). At an even faster rate, China taps the water resources of the Tibetan plateau to cope with growing water and energy demands in its urban agglomerations. The importance of the Himalayan region as a water tower for freshwater supply for the adjoining lowlands is now being supplemented by the additional function of a 'power tower', thereby intensifying the resource transfer from the mountains to the economic centres in the plains of the sub-continent (Erlewein and Nüsser 2011; Erlewein 2013). Prominent examples are the northern states of India, namely Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh and Assam, which supply the adjoining lowlands with hydroelectric energy. Upcoming projects are also situated in territorially disputed regions, such as Arunachal Pradesh and the wider Kashmir region, where India and Pakistan are now building dams (Figure 20.4). In addition, India supports dam building in the upper

Source: Nüsser, September 2014.

Figure 20.4 The Nimoo Bazgo Hydroelectric Plant is a run-of-the-river scheme on the Indus River, aimed at ensuring power supply to the electricity-deficient Ladakh region in northern India riparian countries of Bhutan and Nepal so as to fulfil the nations' energy demands as future powerhouses (Lord 2014, 2016). Major hydropower plants, which are currently under construction or in the planning phase in Nepal are primarily designed to generate power for export to India. One example is the Arun III project, which was expected to produce 404 MW. As a result of strong local and international resistance to the project it was cancelled in 1995, but is currently being redesigned as a run-of-river project. Such designs with increased hydraulic heads are widely used in the Himalayas, often in the form of a series of cascades and turbines. These constructions have been shown to have adverse hydrological consequences, such as river fragmentation and the periodic desiccation of river flow in certain parts (Erlewein 2013).

A similar situation exists in various African settings, where water and energy resources from mountain regions are transferred to downstream countries or regions. Rapid hydropower development is transforming the mountains of Ethiopia into an African power plant. Lesotho is another prominent example of an inter-basin water transfer scheme, where damming the headwaters of the highlands, which receive heavy rainfall, benefits the water-scarce metropolitan region of Gauteng in South Africa (Horta 1995; Nel and Illgner 2001; Hitchcock 2015). This has brought water revenues, hydro-electric power and major infrastructure to Lesotho; however, the local mountain dwellers, the Basotho, have lost arable and grazing land and have experienced drastic negative changes in livelihood conditions. This project was also criticized for massive corruption, similar to the case of the Turkwel Dam in Kenya (Figure 20.5), which, at more than 20 billion Kenyan shillings, ended up costing five times as much as initially proposed.

From the early enthusiasm surrounding the emergence of technological hydroscapes as economic drivers of modernization to the disillusion caused by the negative social and environmental outcome, the large dams debate has been tumultuous. Once being praised as temples of progress, they became decried as tombs of the displaced (Khagram 2003). However, with the current discussion about global warming, dam building has once again come into vogue as a climate-friendly technology, validated by global concerns for the reduction in carbon emissions. In the course of this latest disjuncture in the debate, large dams are now seen as mechanisms for mitigating the adverse effects of climate change. Not only has climate change brought a new assertiveness to the benefits of hydro-dams, it has also given birth to the emergence of climate economies, whereby funding is now relatively more easily available in the 'free market' through trade mechanisms of carbon emission certificates. This trend becomes apparent in the huge financial support whereby the international carbon trading scheme Clean Development Mechanism subsidizes dam building in China, India and Brazil as 'carbon offsetting dams' (Erlewein and Nüsser 2012; Erlewein 2014; Ahlers et al. 2015). Neoliberal ideals have taken hold, with the private sector becoming a key player in the funding and construction of large dams. However, empirical research has shown that Clean Development Mechanism projects fall short of achieving their objectives and their contribution to climate protection and sustainable development is questionable. Given the adverse impact of these technological hydroscapes on the local scale, carbon-offsetting dams are alleged to be a form of 'carbon colonialism' that exacerbates the asymmetries of problem causation and burden sharing.



Source: Nüsser, March 2016.

Figure 20.5 With a height of 153 m and a crest length of 150 m, Turkwel Dam was constructed between 1986 and 1991. It is the highest dam in Kenya and is located on the border between the dryland counties of West Pokot and Turkana

CONCLUSION

Various examples from different geographical regions and distinct historical, social and economic settings shed light on particularities and highlight the deep interconnections and disjunctures between different aspects of the large dam debate. The social costs of involuntary resettlement owing to large hydro projects are as dramatic as the environmental ones. The number of people flooded off their settlements, agricultural lands, forests and other resources is estimated to reach 40–80 million worldwide (WCD 2000). Besides the displaced population, other people affected by dam construction include rural dwellers residing downstream from a dam. They are often neglected in project assessments because it is assumed that they will benefit from the project; however, there are frequently significant negative downstream impacts (Scudder 2005). A huge number of case studies from the Global South provide evidence that the adverse impacts of large dams have fallen disproportionately on subsistence farmers, indigenous peoples and ethnic minorities, who often rely on common property regimes of resource utilization. Reservoirs inundate floodplain soils, woodlands, wildlife, fisheries and forests, which many local communities subsist and depend on to secure their livelihoods. Especially in mountain environments, dams force displaced inhabitants into the upper valleys, where they may cause further degradation of natural resources. Moreover, drastic natural hazards include reservoir-induced seismicity, which may lead to dam collapse and catastrophic floods (Chao 1995).

To meet the challenge of understanding the complexity of the issue, it is necessary to focus on the different development perspectives of the advocates and opponents of dam building. Framing large dams within the broader field of geographies of technology draws attention to their spatial dimension. This includes flows of technology, spatial inequalities between upstream and downstream populations, between mountains and lowlands, and between centres of decision-making and affected locations. On a national scale, power asymmetries between states lead to the transfer of benefits such as hydropower while bearing the cost of inundation. With the emergence of carbon-offsetting schemes, the costs and benefits are now traded at a global scale. Ultimately, the creation of technological hydroscapes is a political exercise carried out at the socio-hydrological interface, strongly affecting development paths at every scale (Swyngedouw 2015). Therefore large dams are not only transformative technologies that rewrite rivers and landscapes, but are also unique creations and creators of the Anthropocene.

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