In the Midst of the Large Dam Controversy: Objectives and Criteria for Assessing Large Water Storages in the Developing World

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Introduction

> *"We need large dams and we are not going to apologize for it. Those in the developed countries, who already have everything, put stumbling blocks in our way from the comfort of their electrically lit and air-conditioned homes… The Third World is not ready to give up the construction of large dams, as much for water supply and flood control as for power… Hydropower is the cheapest and cleanest source of energy, but environmentalists don't appreciate that. Certainly large dam projects create local resettlement problems, but this should be a matter of local, not international concern."*
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> - Theo Van Robbroek, Former President of the ICOLD

The current crisis and urgency of meeting the food water requirements of the burgeoning world population has further aggravated the debate on 'dams or no dams'. The greatest opposition faced by dam-builders around the world is from the environmental (see D'Souza 2002; McCully 1996), financial, economic, and human rights fronts (see Dharmadhikary 2005; Fisher 2001; McCully 1996), whereas the proponents of large dams push their agenda on the grounds of enhanced food and drinking water security, hydropower generation, and flood control (see Braga et al. 1998; Verghese 2001; Vyas 2001). Both groups have reasons for their stances and chosen options to improve or alter the current practice of constructing large dams.

The latter half of the nineteenth century saw the birth of modern technology and engineering in the construction of large dams. The growth of dam-construction started in the developed countries holding technical know-how and financial resources, and later spread to the developing countries. By 1975, when the United States, Canada and the Western European countries had essentially completed their program of construction of large dams (Biswas and Tortajada 2001), the majority of the developing countries were either at the peak of their dam construction or were just starting to divert their financial resources towards it. As per the data offered by the International Commission on Large Dams (ICOLD), at the end of the twentieth century, China and India kept the United States far behind in the total number of dams constructed. According to the data, there are more than 47,000 large dams constructed all over the world and another 1,700 dams were under construction at the time of publishing this paper. The statistics of large dams presented by the ICOLD are debatable. The total number of large dams is based on the widely accepted and uniform definition of large dams, which considers ‘dam-height’ as the sole criterion. Such statistics on large dams, derived from such narrow technical criteria, if used as an indicator for assessing the extent of dam building a country has undertaken, can work against the larger developmental interest of many countries. While it is widely quoted that Asia has the greatest number of large dams in the world, many authorities are silent on how much water is being stored in these dams, and the extent of the area they submerge.

According to a database of the World Commission on Dams, dated the year 2000, which shows the distribution of dams across continents and regions, China has the largest number of large dams, followed by the rest of Asia, immediately followed by North and Central America. This can send shock waves through any ordinary person, leave alone the environmentalist, because of the fact that these regions with a high concentration of large dams are also the most densely populated regions in the world, with scarce arable land. But an ICOLD register on large dams, dated 1998, makes global comparisons on the basis of the volume of storage created by large dams and thereby brings out a totally different picture. Nearly 29 % of the total storage from large dams (6,464 km^3) is in North America and followed by South America (16 %). China with 10 % is only fourth in terms of volume of storage. The lack of a comprehensive and realistic criteria for defining ‘large dams’ invite unprecedented reactions from the environmental lobby on dam building based, with groups alleging that the statistics are misleading and that dam construction should be subject to stringent scrutiny for social and environmental costs. But the criteria of evaluating dam performance should change with the objectives.[1]

Limitations are also inbuilt in the methods used for benefit-cost analysis. The method identifies only those costs and benefits that can be assigned a market value. Thus, many costs and benefits remained unaccounted due to the difficulties in assigning them an economic value. Moreover, unprecedented costs and benefits are never considered, as revision of the cost-benefit analysis after 15-20 years of project completion is not a practice ever followed anywhere (see Biswas and Tortajada 2001). As many social and environment costs are therefore, not considered, many real benefits are underestimated or un-envisaged at the time of project planning. For example, a water resource planning exercise done in Gujarat, India has checked the possibilities and recommended the use of imported water from Narmada for recharge by spreading methods in the upper regional aquifers and riverbeds (GOG 1996 as cited in Ranade and Kumar 2004).

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[1] If the objective is to assess the civil engineering capabilities of a country, then criteria such as design and foundation material and technology should be used for evaluation. Similarly, to assess the hydraulic design challenges for building large dams in this country, the spillway discharge, and storage capacity etc. can be used as the criteria. But if the objective is to quickly assess how centralized is our water storage, then the storage capacity criteria is good enough.

The Basic Premise

The authors take the position that the criteria used for defining large dams are not true reflections of the socioeconomic and environmental concerns prevailing in developing economies and, therefore, are not relevant. Part of the reason is the geographical spread of the large storage dams in the world. Food security and water security are extremely important concerns for these economies; submergence of productive land is a big concern, given the poor access to arable land; but the engineering challenges posed by the height of the dam are not so much a concern.

The definitions based on such poor criteria often invite unprecedented reactions from environmental lobbyists worldwide to subject dam-building proposals to stringent environmental scrutiny, and to revise the benefit–cost (BC) calculations integrating the social and environmental costs. The authors argue that, while there has been a lot of advancement in the recent past in the BC analysis of dam projects, these methodologies are still inadequate and fail to anticipate future social and environmental benefits that are likely to be accrued, resulting from the failure on the part of the proponents of dams to articulate these benefits. Some of the benefits are drinking water security, groundwater recharge, reduced cost of energy for pumping and so on. Often, dam-builders inflate certain components of the benefits and underestimate certain cost components, to pass the scrutiny of national and international environmental agencies. In the process, little attention has been paid to look at alternative ways of designing dams. Internationally, a lot of experiences now exist with designing dams in a way that can minimize the potential negative effects on society and the environment.

Objectives of the Study

The major objectives of this paper are as follows: 1) to illustrate the role of large storages in the context of development and economic growth, particularly for poor and developing countries; 2) to discuss the criteria used by various national and international agencies in defining large dams, and identify their limitations in the context of developing countries; 3) to evolve meaningful criteria for defining large storages, which adequately integrates the growing social and environmental concerns associated with dam-building; and, 4) identify the gaps in the current cost-benefit analysis and suggest new elements that adequately address (social, economic and environmental) sustainability considerations, and set out further new objectives and criteria for evaluating the impacts of large dams in developing economies.

Dams and Development: Controversies in Developing Countries

The Koran says, “By means of water we give life to everything.” Water is required as much as oxygen to sustain human life. Water gives life, wealth, and delivers people from diseases, and that is why, access to clean and safe water is one of the most basic human rights. However, the latest data released in the Human Development Report of 2006 reveals the minimal way in which this basic human right is met all over the world, largely in the developing and least developed countries. According to the report, one in every five people in the developing world

(11 billion in total) has access to an improved water source; dirty water and poor sanitation account for a vast majority of the 1.8 million child-deaths each year (almost 5,000 every day) from diarrhea— making it the second largest cause of child mortality; in many of the poorest countries, only 25 % of the poorest households have access to piped water in their homes, compared to the 85 % of the richest; diseases and productivity losses linked to water and sanitation in developing countries amount to 2 % of the GDP, rising to 5 % in sub-Saharan Africa—more than the amount that the region gets in aid; women bear the brunt of the responsibility for collecting water, often spending up to 4 hours a day walking, waiting in queues and carrying water; water insecurity linked to climate change threatens to increase malnutrition from 75–125 million people by 2080, with staple food production in many sub-Saharan African countries falling by more than 25 %.

The world's poorest countries are also the most water-scarce ones. This poverty to a great deal can be linked to water-scarcity. The gap in per capita water consumption is also huge between developed and developing countries. As per the Human Development Report of 2006, against the average consumption of 580 litres of water per person per day in the US and 500 litres in Australia, in India it's 140 litres per person, China it's 90 litres, Bangladesh and Kenya it's 50 litres, Ghana and Nigeria it's 40 litres, and in Mozambique it's less than 10 litres (HDR 2006). The threshold limit for per capita consumption is 50 liters (Glieck 1997; HDR 2006). Needless to say, these countries are not meeting even the basic human requirement of water. Besides, two out of every three persons in South Asia and sub-Saharan Africa lack even basic sanitation facilities. Reliance on groundwater is also not feasible without electricity and since no large-scale electricity generation is possible without water, the construction of large dams becomes inevitable.

Construction of large dams is opposed mainly on the grounds of the negative environmental impacts, and problems of displacement they cause, especially the subsequent impoverishment of the displaced people. Issues like 'drying up of rivers' and permanent destruction of the riverine ecosystem have been romanticized (see MacCully 1996; D'Souza 2002). There has been no appreciation of the fact that most of this water gets burnt up in the form of evapo-transpiration in producing food. The threats posed to the developing countries by the lack of clean and safe drinking water; food insecurity; economic and life losses due to droughts and floods; restricted economic growth due to the limited availability of water and power; have been shockingly ignored. On the other hand, the alternative models being advocated to improve water security for the poor, to boost food production and to meet their energy needs are proving to be rather fallacious.

It is important to remember that the negative environmental effects of dams can be controlled with good science and technology, and displacement of people can be turned into an opportunity for better livelihood by giving it a more humanistic face. But, the opportunity cost of delaying or stopping dam- construction could often be severe. There cannot be a better region in the world than sub-Saharan Africa to illustrate the effect of access to water on economic growth conditions. A recent analysis showed a strong correlation between rainfall trend since the 1960s and GDP growth rates in the region during the same period, and argued that the low economic growth performance of the region could be attributed to its long-term decline in rainfall (Barrios et al. 2004).

Such a dramatic outcome can be explained partly by governance failure, and the region's poor investment in water infrastructure. It is important to note here that sub-Saharan Africa has the lowest per capita water storage through reservoirs (HDR 2006). We will illustrate the significance of improving access to water by way of infrastructure through the subsequent paragraphs. The debate on the linkage between water and economic development is characterized by diametrically opposite views. While the general view of international scholars, who support large water resource projects, is that increased investment in water projects such as irrigation, hydropower and water supply and sanitation acts as engines of growth in the economy (see Braga et al. 1998; Briscoe 2005), the counterview suggests that countries would be able to tackle their water-scarcity and other problems relating to water environment only at advanced stages of economic development (Shah and Koppen 2006). The proponents of sustainable development believe that the ability of a country to sustain its economic growth depends on the extent to which its natural resources, including water, are put to efficient use through technologies and institutions, thereby reducing the stresses on environmental resources (Pearce and Warford 1993).

We take the position that developing countries need to invest in water infrastructure to improve their ability to boost economic growth and reduce poverty, apart from meeting food security needs. Before we begin to answer this complex question of ‘what drives what’, we need to understand what realistically represents the water richness or water poverty of a country. A recent work by Kellee Institute of Hydrology and Ecology, which came out with international comparisons on the water poverty of nations had used five indices, namely, water resources endowment; water access; water use; capacity building in water sector; and water environment, to develop a composite index of water poverty (see Laurence, Meigh and Sullivan 2003).

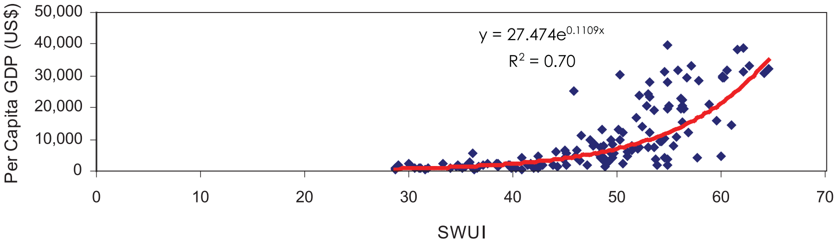
Among these five indices, we chose four indices to be important determinants of the water situation of a country, and the only sub-index which was excluded was the water resources endowment. This sub-index is more or less redundant, as three other sub-indices viz., water access, water use and water environment take care of what resource endowment is expected to provide. Our contention is that natural water resource endowment becomes an important determinant of the water situation of a country only when governance is poor and institutions are ineffective, which in turn adversely affects the community’s access to and use of water, and the water environment. That said, all the four sub-indices we chose have significant implications for socioeconomic conditions, and are influenced by institutional and environmental policy and, therefore, have a human element in them. Hence, such a parameter will be appropriate to analyze the effect of institutional interventions in the water sector and on the economy.

All the sub-indices have values ranging from 0 to 20. The composite index, developed by adding the values of these indices, is called the sustainable water index (SWI). It is being hypothesized that the overall water situation of a country (or SWI) has a strong influence on its economic growth performance. This is somewhat different from the hypothesis postulated by Shah and Koppen (2006), where they have argued that economic growth (GDP per capita), and HDI are important determinants of water access limitations and the water environment. The basis for deriving the new index is that the indices, viz., water access and water environment, do not capture all the dimensions of water use that are essential for development and growth. For instance, it is a truism that high levels of water use would be essential for maintaining high levels of economic growth, especially when countries are in their economic transition from agrarian to industrial. This is because water use for urban and industrial uses would go up exponentially in such scenarios.

It is essential to provide an anecdote for the counter-hypothesis that we propose. For this, we first take the fundamental question of what are the prime movers for economic growth, or what are the necessary conditions for sustainable economic growth. We already know that all the sub-indices of HDI have a strong potential to trigger growth in the economy of a country, be it educational status; life expectancy; or per capita income levels. When all these factors improve, they could have a synergetic effect on economic growth but the actual growth trajectory that a country takes also would depend on the country's macro economic policies, whether capitalist, or socialist or mixed. It is quite expected that in socialist economies, the income inequity along with per capita income would also be smaller. Against this, in a capitalist country, the income inequity as well as per capita income would be higher and this issue will be dealt with subsequently.

Now, worldwide experiences show that the improved water situation (in terms of access to water; levels of the use of water; the overall health of water environment; and enhancing the technological and institutional capacities to deal with sectoral challenges) leads to better human health and environmental sanitation; food security and nutrition; enhanced livelihoods; and greater access to education for the poor (based on UNDP 2006). This aggregate impact can be segregated with irrigation having a direct impact on food security, livelihoods and nutrition; and domestic water security having positive effects on health and environmental sanitation with spin-off effects on livelihoods and nutrition. If it is so, the improved water situation should improve the value of human development index, which captures three key spheres of human development namely, health, education and income status.

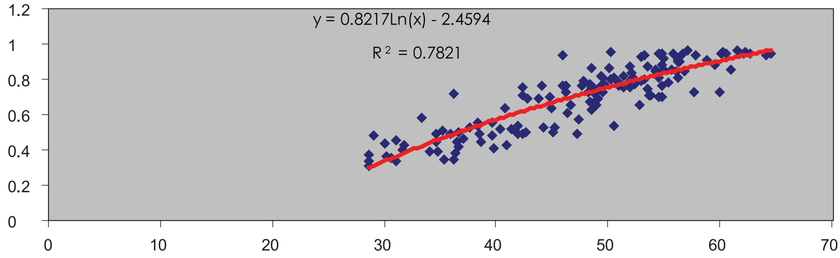
Figure 1. Sustainable water use index (SWUI) vs. GDP growth.



This means that the 'causality' of water as a prime driver for economic growth can be tested if one is able to establish a correlation between water situation and HDI, apart from showing the correlation between SWUI and economic growth. Regression between the sustainable water use index (SWUI) and purchasing power parity (ppp) adjusted per capita GDP for the set of 147 countries explains the level of economic development to an extent of 69 % (see Figure 1). We must mention here that Laurence, Meigh and Sullivan (2003) had estimated an R^2 value of 0.81 for WPI and HDI (*source:* Table 2: page 5; Laurence et al. (2003). Figure 1 shows that the relation between SWUI and per capita GDP is a power function. Any improvement in the water situation beyond a level of 50 in SWUI, leads to an exponential growth in per capita GDP. This only means that for countries to be on the track of sustainable growth, they need to put in place appropriate and effective institutional mechanisms and policies to improve the overall water situation that can result in improved access to water for all sectors of water-users and across the board; enhance the overall level of use of water in different sectors; to regulate the use of water, reduce pollution and provide water for ecological services; and to build technological and institutional capacities to tackle new challenges in all sectors of water use. Regression with different indices of water poverty against economic growth levels shows that the relationship between water availability and economic growth is not as strong as originally envisaged, meaning all aspects (water access, water use, water environment and water sector capacity) are equally important to ensure growth.

Subsequently, to test the causality, regression was run between *water situation* (expressed in terms of sustainable water use index (SWUI)) and HDI. This showed that HDI varies linearly with improvement in SWUI (Figure 2). This means, improvement in SWUI strengthens the basic foundations of economic growth. The R square value was 0.79. This is in spite of the fact that human development index as such does not include any variable that explicitly represents access to and use of water for various uses; overall health of water eco-system; and capacities in the water sector as one of its sub-indices. Now, such a strong linear relationship between SWUI and HDI explains the exponential relationship between sustainable water use index and per capita GDP as the improvements in sub-indices of HDI contribute to economic growth in their own way (i.e., per capita *GDP = F (EI, HI);* here *EI* is the education index, and *HI* is the health index).

Figure 2. Sustainable water index vs. HDI (selected).



On the other hand, if it is the stage of economic development that determines a country's water situation rather than vice versa, the variation in HDI should be explained by variation in per capita GDP, rather than that in SWU, in orders of magnitude. This is because there is already an established relationship between SWUI and HDI. We have used data from 147 countries to examine this closely. The regression between the two shows economic growth levels (expressed in per capita GDP ppp adjusted) explains HDI variations to an extent of 82 %). This is in spite of the fact that HDI already includes per capita income, as one of the sub-indices.

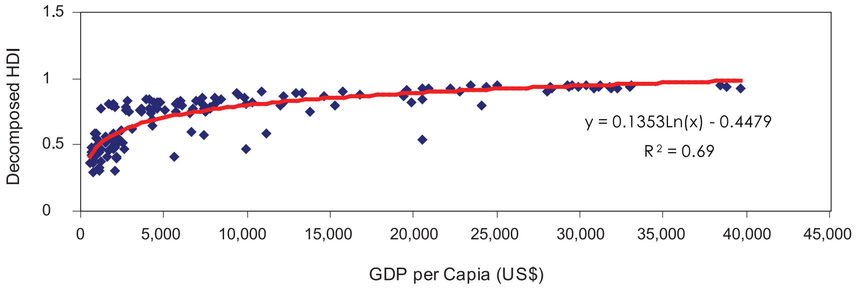
Hence, an analysis was carried out using decomposed values of the HDI index (after subtracting the GDP index). The regression value came down to 0.69 (R^2=0.69) with the decomposed index, which comprised an education index and a life expectancy index, and was run against the per capita GDP (Figure 3) against the 0.79 for the earlier case of GDP vs. HDI. This means that variation in the human development index can better be explained by the 'water situation' in a country, expressed in terms of the sustainable water use index, than the ppp adjusted per capita GDP. What is more striking is the fact that the relationship is logarithmic. Sixteen countries having low-value per capita incomes below 2,000 dollars per annum have medium levels of decomposed index. Again 42 countries having per capita GDP (ppp adjusted) of less than 5,000 dollars per annum have medium levels of decomposed human development index. As Figure 3 shows, significant improvements in HDI values (0.3 to 0.9) occur within the small range in the variation of per capita GDP.

The remarkable improvement in HDI values with minor improvements in economic conditions, and then 'plateauing' means that improvement in HDI is determined more by factors other than economic growth. Our contention is that the remarkable variation in HDI of countries belonging to the low-income category can be explained by the quality of governance in these countries, i.e., whether good or poor. Many countries that show high HDI also have good governance systems and institutional structures to ensure good literacy and human health, achieved primarily through investment in basic infrastructure including that of improving access to water. Most of these countries belong to the erstwhile Soviet Union (Armenia, Tajikistan, Kyrgyzstan, Uzbekistan and Georgia,) or are under communist regimes either in Latin America (Colombia, Nicaragua, Ecuador and Bolivia) or in Asia (Mongolia, China and Vietnam), which are known for good governance. Incidentally, many countries having highly volatile political systems and ineffective governance, characterized by corruption in government, are also extremely poor.

The foregoing analysis suggests that improving the 'water situation' of a country, which is represented by the sustainable water use index, is of paramount importance if we nee to sustain economic growth in that country. While the natural water endowment in both qualitative and quantitative terms cannot be improved through ordinary measures, the 'water situation' can be improved through legal, policy and administrative measures that support economically efficient, just and ecologically sound development and use of water in river basins.

The very fact that many developed countries had large water storage in per capita terms also strengthens the argument. The United States for instance, had created a per capita normal storage of 1,615 m^3 per annum created through 16,383 dams. In Australia, the 447 large dams alone provide a per capita water storage facility of nearly 3,808 m^3 per annum or a total of 79,000 MCM per annum. Aquifers supply another 4,000 MCM per annum. Against this, the country maintains a use of nearly 1,160 m^3 per capita per annum for irrigation, industry, drinking and hydropower, with irrigation accounting for 75 % of the use (*source*: www.nlwra.gov.au/atlas). China, one of the fastest growing economies in the world, has per capita water storage in the amount of 2,000 m^3 per annum through her dams.

Figure 3. Per capita GDP vs. decomposed HDI.



When compared to these impressive figures, India has a per capita storage of only 200 m^3 per annum. Ethiopia, the poorest country in the world, has a per capita storage of 20 m^3 per annum. But, there are many critiques against this argument based on per capita storage. According to Vandana Shiva, a renowned eco-feminist from India, the norms used for estimating per capita water use is fraudulent, and is a way to push through the large dam agenda by the World Bank. According to her, the many millions of ponds and tanks in the rural areas of India capture a lot of water and supply it to the rural population in a more democratic and decentralized way than the large dams do. But the contribution of such storage in augmenting the nation's water supplies is often over-estimated by environmentalists. In the case of Australia, the National Heritage Trust's report of the audit of land and water resources say, the many millions of farm dams in Australia create a total storage of 2,000 MCM per annum, against 79,000 MCM by large dams (www.nlwra.gov.au/atlas).

One could as well argue that access to water could be better improved through local water resources development interventions including small-water harvesting structures, or through groundwater development. As a matter of fact, the anti-dam activists fiercely advocate decentralized small-water harvesting systems as alternatives to large dams (see Agarwal and Narain 1997). Small-water harvesting systems had been suggested for the water-scarce regions of India (Agarwal and Narain 1997; Athavale 2003), and the poor countries of sub-Saharan Africa (Rockström et al. 2002). New evidence however, suggests that these systems cannot make any significant contributions in increasing water supplies in countries like India which have unique hydrological regimes, and can instead prove to be prohibitively expensive in many situations (Kumar et al. 2006). Also, to meet the large concentrated demands in urban and industrial areas, several thousands of small-water harvesting systems would be required. Recent evidence also suggests that small reservoirs get silted much faster than the large ones (Vora 1994), a problem for which large dams are criticized the world over (see McCully 1996).

On the other hand, the intensive use of groundwater resources for agricultural production is proving to be catastrophic in many of the semi-arid and arid regions of the world, including some developed countries like Spain, Mexico, Australia, and parts of the United States; and developing countries like India, China, Pakistan and Jordan. However, some of the developed countries like United States and Australia have achieved a certain degree of success in controlling the use of groundwater through the establishment of management regimes (Kumar 2007; Shah et al. 2004), which leaves engineering interventions[2] and their economic viability are open to question.

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[2] Complex engineering interventions would be required for collecting water from such a number of small water harvesting and storage systems, and then transporting it to a distant location in urban areas.

Large Dams: History, Definitions and Recent Trends

History of Large Dam Construction and Technology Used

Construction of dams is a vital part of the history of civilisation. The earliest evidence of river engineering is found among the ruins of irrigation canals in Mesopotamia, which are over 8,000 years old. Remains of water storage dams found in Jordan, Egypt and parts of the Middle East date back to at least 3000 BC (World Commission on Dams 2000). Dam- building was continued into the time of the Roman Empire, after which the construction of dams was literally lost until the 1800s. Dams are a structure also seen in nature —beavers build dams to keep the water deep enough to cover the openings to their homes, protecting them from predators (www.arch.mcgill.ca). Table 1 gives a chronological list of dams constructed before the birth of Jesus Christ (BC).

Table 1: Chronological list of dam-construction.

Year Competed	Country	Name of	Type	Function	Purpose
3000 BC	Jordan	Jawa	Gravity	Reservoir	Water supply
2600 BC	Egypt	Kafara	Embankment	Reservoir	Flood control
2500 BC	Baluchistan	Gabarbands	Gravity	Reservoir	Conservation
1500 BC	Yemen	Marib	Embankment	Diversion	Irrigation
1260 BC	Greece	Kofini	Embankment	Diversion	Flood control
1250 BC	Turkey	Karakuyu	Embankment	Reservoir	Water supply
950 BC	Israel	Shiloah	?	Reservoir	Water supply
703 BC	Iraq	Kisiri	Gravity	Diversion	Irrigation
700 BC	Mexico	Purron	Embankment	Reservoir	Irrigation
581 BC	China	Anfengtang	Embankment	Reservoir	Irrigation
370 BC	Sri Lanka	Panda	Embankment	Reservoir	Irrigation
275 BC	Sudan	Musawwarat	Embankment	Reservoir	Water supply

Source: Schnnitter, 1994

The objectives of dam-construction were ranging from flood control to irrigation. As Altinbilek (2002) puts it, the construction of dams in the concept of water resource management has always been considered a basic requirement to harmonize the natural hydrological regime with human needs for water and water-related services.

The number, size and complexity of dam construction increased with the advancement of science and technology. The growth of large dams accelerated, especially during the nineteenth and mid-twentieth centuries. In 1900, there were approximately 600 big dams in existence. The figure grew nearly to 5,000 big dams by 1950, of which 10 were major dams. By the year 2000, approximately 45,000 big dams, including 300 major dams, had been constructed around the world (Khagram 2005). This was the time of population growth combined with industrial development and rapid urbanization. The acceleration of economic growth was not possible without the generation of power and availability of water for agriculture as well as for domestic consumption. Thus, dam-construction was a critical requirement for meeting the growth requirements of all other sectors. Current estimates suggest that nearly 30 - 40 % of irrigated land worldwide now relies on dams and that dams generate 19 % of the world's electricity (Bird and Wallace 2001).

Definitions of Large Dams

Numerous definitions are available of large dams, each serving a different purpose and objective, and, as such, are based on different criteria for evaluation. The definition followed by the National Inventory of Dams in the USA, is based on a dam's storage capacity. According to the Inventory, a dam is to be considered a large dam if it has greater than a 50 acre-feet storage capacity (www.coastalatlas.net). The U.S. Fish and Wild Life Service, under its Dam Safety Program, has adopted the following criteria for defining dams as small, intermediate and large (www.fws.gov). The structural height or the water storage capacity at maximum water storage elevation, whichever yields the larger size classification, is used to determine the size of a dam: 1) small dams are structures that are less than 40 feet high or that impound less than 1,000 acre-feet of water; 2) intermediate dams are structures that are 40 to 100 feet high or that impound 1,000 to 50,000 acre-feet of water; and 3) large dams are structures that are more than 100 feet high or that impound more than 50,000 acre-feet of water.

The Central Water Commission (CWC) of India, in its guidelines for safety inspection has given different definitions of dams on the basis of means of classification such as size, gross storage and hydraulic head. Against this, the Planning Commission of India has categorised all dams as large, medium and small irrigation schemes on the basis of the area irrigated. According to the Planning Commission, a large irrigation project is the one designed for irrigating more than 10,000 hectares (ha) of land.

The most recent, yet widely accepted definition of large dams is given by the ICOLD. The ICOLD defines a large dam as one having a dam wall above 15 m in height (from the lowest general foundation to the crest). However, even dams between 10-15 m in height could be classified as large dams if they satisfy at least any one of the following criteria (Rangachari et al. 2000). First, the crest length is more than 500 m. Second, the reservoir capacity is more than one MCM. Third, the maximum flood discharge is more than 2,000 m^3 per second. Fourth, the dam has complicated foundation problems. Fifth, an unusual design. The ICOLD definition has dam height as the major criterion for defining a large dam. Since this definition has been widely accepted, all the dams in the world are evaluated on the basis of this definition.

A Brief History of Dam Construction, Ideologies and Investments on Dams in India

Agriculture used to be and has remained the major source of employment in rural India. Hence, irrigated agriculture has always been on the list of high priorities for the state exchequer. The early Hindu texts, written around 800-600 BC, reveal certain knowledge of hydrological relationships. The Vedic hymns, particularly those in Rig Veda, contain many notes on irrigated agriculture, river courses, dykes, reservoirs, wells and water lifting structures (Bansil 2004). As per the historical review given by Rangachari et al. (2000) the Grand Anicut on the Cauvery was one of the earliest canal systems built, dating back probably to the second century. The authors have further mentioned that feeding water-deficit and arid regions with extensions from storage reservoirs was a widely accepted practice between 500 AD and 1500 AD. Tamil Nadu alone presently has over 39,400 such reservoirs built from the very early days. During the nineteenth century, India also experienced the benefits of the technology of high-head hydraulic structures. The British rule in India invested in renovations, improvements and extensions of earlier works along with new projects such as the 48 m high and 378 m long dam in the Periyar Project in 1886. The beginning of twentieth century had witnessed some of the ambitious projects of that time such as the Periyar and Peechipari dams in 1906, Krishnarajsagar Project in 1911, and the Mettur Dam in 1925.

At the time of independence in 1947, India was facing an acute shortage of food grain in sustaining her population. Investments in better irrigation facilities and improved agricultural technologies were imperative to achieve food sustainability. The Bhakra and Hirakud irrigation projects contributed significantly towards transforming India from a starving nation to an exporter of grains. Right up to the 1970s, large dams were seen as the synonym for development and economic progress. Dam-building reached its peak between 1970 and 1980, when an average of two to three new large dams per day were commissioned (Table 2).

Table 2: Large dams in India.

No.	Period	Number of Large Dams		
		15 m and more high	10 to 14 m high*	Total
1	Up to 1900	32	13	45
2	1901-1947	135	127	262
3	1948-1970	489	254	743
4	1971-1990	1,564	1,066	2,630
5	1991-2001	265	82	347
6	Data on time period not available	434	174	608
7	Total	2,919	1,716	4,635

Source: Data derived from the World Register of Dams, ICOLD

Note: * It includes dams for which heights are not known

Currently more than 80 % of the total water used in India is for irrigation. As per the estimates of the Ministry of Water Resources, India's water demand is going to increase three-fold by 2050, with increase in population and maturing of the Indian economy (Table 3). However, even then, agriculture would consume the highest share of water, as it would be burdened with a target of producing 420 Metric Tonnes (MT) to feed India's population (Verghese 2005).

These figures, indicating the number of large dams in India counted on the basis of dam height, can be extremely misleading to those who are concerned about the potential negative impact of large dams. The reason (why these numbers are misleading) can be better understood if we really look at the other aspects. For instance, the 2,920 dams having a height of more than 15 metres create a storage space of 296.29 BCM, with a mean storage space per dam to the tune of 101.5 MCM, whereas the rest of the 1,715 dams, which are also classified as large

Table 3: Sector-wise water consumption in India: Present and future scenarios.

Sector	Water Demand Projections			
	1990	2010	2025	2050
Irrigation	460 (88.6 %)	536 (77.3 %)	688 (73 %)	1,008 (70.9 %)
Domestic	25 (4.8 %)	41.6 (6 %)	52 (5.5 %)	67 (4.7 %)
Industries + Energy	34 (6.6 %)	41.4 (6 %)	80 (8.5 %)	121 (8.5 %) 143 (10.1 %)
Total (including others)	519	693	942	1,422

Sources: National Commission for Integrated Water Resources Development Plan; Ministry of Water Resources, 1999

dams, collectively create a storage space of 6.29 BCM only, with a mean storage space per dam to the tune of 3.65 MCM. This amount is equal to the volume of water pumped by 10 irrigation tubewells in a year or in other words, the water sufficient to irrigate nearly 365 ha of land, which means that these dams are not really large dams in any sense.

Further, the total storage created by all large dams (4,635 nos.) in India is only 302.58 BCM, with a mean storage capacity of 64.28 MCM per dam. This, however, does not mean that these dams actually store and provide that much water. The reasons are many. Firstly, many large dams in India do not get sufficient storage due to inadequate inflows from their catchments, whereas many reservoirs capture and release more than their storage capacity, as inflows are received at the time of releasing water. Second, the figures of storage capacity are of gross storage, and not live storage. The current total live storage capacity of reservoirs in India is only 214 BCM, and for many reservoirs, it is reducing due to silting as per recent sedimentation and siltation studies (Thakkar and Bhattacharyya, undated based on State Reservoir Survey data).[3]

Now, let us look at the figures for United States. The country has 16,383 dams, which are listed in the national dams register, and these include small dams as well, or dams having a height much less than 10 m. Of these 16,383 dams, only 1,735 dams have a height more than 15 m, and together they create a storage space of 140.14 BCM, with a mean storage space per dam to the tune of 80.8 MCM. But interestingly, the rest of the 14, 648 dams put together can provide a total storage space of 342 BCM, with a mean storage per dam to the tune of 23.3 MCM (*source*: the authors' own estimates based on US national dams register). This means that dams having a height less than 15 m, including those having a height much lower than 10 m, are very important storage systems for the US, as not only does the their total storage volume exceed that of large dams, but the mean storage volume per dam is also quite significant.

In Australia, the mean storage provided by a large dam is 176.7 MCM. In a nutshell, though India appears to be a champion in terms of building large dams, the actual figures of the water storage potential created by large dams is nowhere near that of countries like the United States, which have a lesser number of large dams (*source*: based on data provided in www.nlwra.gov.au/atlas).

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[3] According to the data cited by the authors, the average live storage loss for the 23 reservoirs surveyed was 0.91% per annum, which in a nutshell means that the actual storage in these dams that can be diverted would be even less.

The Dam Controversy: Underlying Assumptions and Genesis

According to the definition evolved and followed by ICOLD, there are 4,635 large dams in India. All these dams are either 15 m in height or above, or fulfil any other criteria set by the ICOLD to qualify as large dams. In India and elsewhere in the world, the arguments of anti-dam activists become forceful and fierce when they simply magnify the 'negative impacts' of some very controversial dams with this figure and project those as the cumulative effect of all large dams. At the same time, it goes without saying that the pro-dam activists often tend to project the virtues of certain dams as having very good track records to further their cause of building more dams. Therefore, one needs to give a careful look to the details of the 4,635 dams listed in the ICOLD register before generalising the negative or positive impacts of dams on such a large scale.

With the kind of technical excellence achieved in the field of civil engineering and structural design, constructing a dam of 15 m in height or a dam with an unusual design or difficult foundation is not a big challenge any more. Besides, criteria such as the unusual nature of the foundation or complexity in design have not much to contribute towards environmental problems or achieving the targets of irrigation or economic growth. Any average number derived from a select group of few well-known or controversial dams on attributes such as irrigated area against submerged area, the benefit-cost ratio or number of people displaced against the number of people benefited should not be blindly extrapolated to get the cumulative effect of all the dams that are defined as large dams by ICOLD. Braga et al. (1998) point out the danger in using simple indices such as the area submerged per MW of electricity generated or number of people displaced per MW of power generated in the context of hydropower dams in Brazil, as these indices ignore the benefits from multiple uses of water. The primary reason for this is that complex factors—physical, climatic, technical/engineering, social, environmental, ecological and political—which govern the above said physical and socioeconomic attributes of dams, differ from case to case.

Unless relationships and trends are established on the basis of a large database, it would be difficult and often dangerous to draw inferences on any of those. Establishing such trends between the generally known attributes of dams and their social and environmental consequences is what we will be describing in the subsequent sections of this paper.

Analysis of the Criteria Defining Large Dams

Should the sheer number of large dams currently existing in different parts of the world, and those which are proposed to be constructed, really send warning signals on the magnitude of the costs being paid by society in terms of the negative consequences of dam construction on communities and the environment? To answer this question, it is crucial to know the usefulness or relevance of the criteria used for classifying dams as 'large'. The underlying premise is that most of the definitions of 'large dams' have been made or the criteria for classifying dams as large or small, evolved at times when large dam-building continued to pose major engineering challenges to humanity. For example, larger height meant greater foundation stresses and forces in the main body of the dam, posing geo-technical challenges; greater storage meant greater risk for people living in the downstream; and greater spillway discharge meant greater design challenges.

In a nutshell, these criteria never tried to capture the social and environmental imperatives of building dams. The driving force behind this analysis is the strong belief that the controversy of environment and mainly of displacement is critically rooted in the way large dams have been defined in the past and, therefore, really need a re-look, especially in the wake of growing social and environmental concerns in building 'large dams'.

None of the definitions mentioned above, including that of ICOLD, are universally applicable. The reason is that the different physical attributes of a dam, such as height, storage volume, and submergence area have different implications, and as such, no single component can be generalized to measure the various impacts generated by dams. The only criteria used by the Planning Commission of India in classifying dams as large, medium and small is the design command area.

On the other hand, the definition given by ICOLD has taken only dam height as a major criterion for defining large dams. When the impacts of dams are measured on the basis of this definition, ultimately it is only the dam height that is being considered. Other secondary criteria such as crest length, dam foundation or unusual design have no bearing in this fast developing world of technology, nor can reservoir capacity or flood discharge capacity logically substitute the dam height criteria. But height does not always share a direct relationship with factors like environmental impacts, displacement or even with total storage volume and submergence area.

Normally, dam designers use the storage-elevation-area curve to determine the appropriate height of the dam and spillway capacity etc. Depending on the topography of the location, the storage-elevation-area curve would change. In a deep gorge, the area under submergence of a high dam having a large storage volume may be very low. For example, the Idukki Dam, which is a double curvature arch dam, located in a deep gorge in the Idukki in Kerala-India, having a height of 555 feet may not have submerged much area, but its storage volume is 2,000 MCM. An analysis of the data of 9,884 dams from the World Register of Dams by ICOLD shows that the volume of water stored and impounded by a dam, which has implications for dam safety, has nothing to do with its height (Figure 4).

Further analysis with ICOLD data shows that the area of land submerged by the reservoir, which has both environmental and social impacts, such as the number of reservoir-affected people and deforestation, and loss of flora and fauna, has nothing to do with the height of the dam (Figure 5). While it is well known that the dam storage volume varies with elevation (height

Figure 4. Comparison of dam height with storage volume.

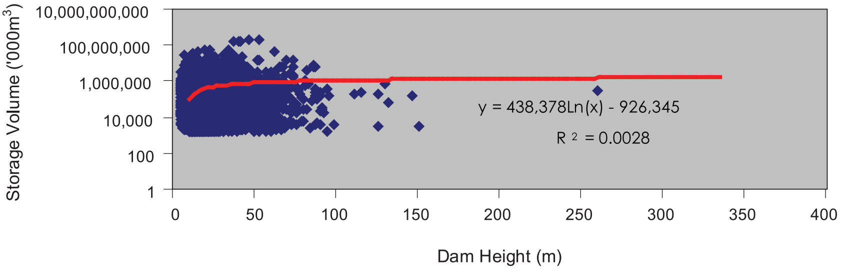
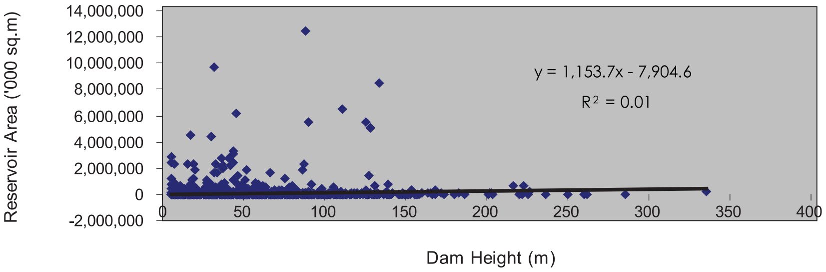


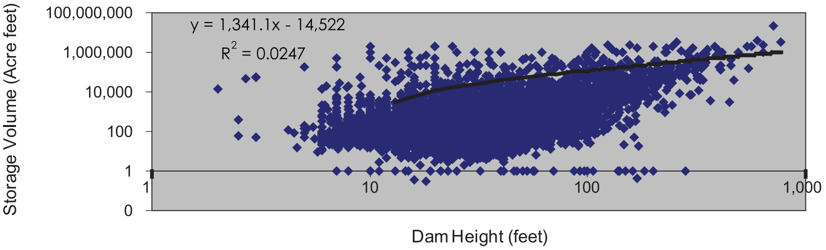
Figure 5. Comparison of dam height with reservoir area.



of the dam), which is in turn determined either by the topography of the area or the catchment's characteristics, the relevance of the above analysis is that it shows very clearly that dam storage volume varies drastically from location to location.

A similar analysis was performed for 16,638 dams in the United States, including small dams (as per ICOLD criteria), but showed no relationship between dam height and storage volume (Figure 6).

Figure 6. Dam height vs. storage volume for US dams.



The results emerging from the foregoing analysis had two major implications. First, they spawned concerns and protests from environmentalists the world over, on the engagement of poor and developing countries in dam-building on the basis of the sheer number of large dams that are ill-targeted. Second, they illustrated that the criteria currently being used by dam-builders and global agencies dealing with large dams, such as height and storage volume, are not true reflections of the changes dam-builders pose in an era of growing social and environment concerns.

Economic, Social and Environmental Impact-related Issues

Of the total 4,635 large dams in India, with either a height of more than 15 m or a storage volume higher than 1 MCM, 2,431 (more than 50 %) are built on local *nalla*, streams or *kotars*. Under such circumstances, some of them might be tank systems, with large surface areas, whereas certain others might be really big dams with either a large height or storage or both.

Also, it is most likely that they are constructed under various small-scale irrigation development schemes to achieve benefits at the local level. Thus, one needs to see whether they are storages created by dams or tanks before analysing their environmental impacts. Moreover, locally initiated water harvesting moves or even small-scale irrigation schemes do not usually face the problem of displacement, and their negative social impacts are also therefore, nil or very limited. In that case more than 50 % of India's large dams are socially and economically rewarding with minimum environmental cost bearing. In fact, their presence might have contributed towards the growth of vegetation, fisheries and water security.

The Environmental Impacts of Dams in India

The economic impacts of large dams in India are surmised as negative on the basis of construction cost overruns; poor performance of irrigation systems with heavy wastages due to poor conveyance efficiencies in the distribution system; negative downstream ecological impacts; preference for water-intensive and low-water-efficient crops; waterlogging and salinity in command areas; and the problems of overestimating of benefits because of the way non-availability of water and other ecological problems shrink command areas (see Rangachari et al. 2000). Very few studies really exist, which comprehensively evaluate the long-term economic and social benefits of large dams, and which show that any one of the dams had outlived its expected life span, but continued to give benefits in terms of food security, employment generation and power generation.

The criteria selected for impact evaluation also plays a major role in measuring the success or failure of dams. Part of the problem is that the same criteria, which was followed for evaluating costs and benefits at the time of planning the project, are used to analyze the dam impacts many years after they become functional. In the process, most of the benefit calculations overlooked some of the major benefits like food security coming from stable food prices, increased rate of employment in agriculture, improved fisheries, increased access to drinking water supplies, development and growth of processing and marketing units etc. The role of imported water in maintaining groundwater balance in irrigated semi-arid and arid regions was another un-intended impact that is much less appreciated by anti-dam activists. In many parts of the Punjab, well-irrigation is sustained due to the continuous return flows available from canal irrigation, which adds to the recharge.

This is not to argue that large dam projects were free of problems. Many of the dams, especially those built in semi-arid and arid regions, are over-allocating water from their respective basins. The irrigation agency is often keen to build over-sized dams, taking the flows of low dependability as the design yield, to inflate the design command and projected economic benefits. The amount of water that these dams are capable of capturing is much more than the amount of water their catchments generate, resulting in conditions of over-appropriation. This leads to reduced flows or no flows in the downstream parts of the river in most of the years causing ecological problems (Kumar et al. 2000; Kumar 2002). But such problems have occurred more due to inadequate governance of water in river basins, characterised by the lack of adequate scientific data for hydrological planning; piecemeal approach to water development; and ad hoc governance of irrigation systems (Kumar et al. 2000).

Objectives and Criteria for Assessing Large Dams

Objectives and Criteria for Classifying Large Dams

There are two sets of questions we are confronted with in this paper. First, do the current technical criteria used in classification of dams as ‘small’ and ‘large’, adequately capture the magnitude of the likely negative social and environmental impacts they can cause? If not, what should be the different criteria and considerations involved in classifying dams as small and large so that they are true reflections of the engineering, social and environmental challenges dams pose? Second, are the objectives, criteria and parameters currently used to evaluate the costs and benefits of large water impounding and diverting systems, sufficient to make policy choices between conventional dams and other water-harvesting systems or groundwater-based irrigation systems? Or what new objectives and criteria, and variables need to be incorporated in the cost-benefit analysis of dams in order to make it comprehensive?

On the first question, we have seen that the existing technical criteria used for classifying dams as large are too narrow, and do not capture the complex factors that govern the challenges posed by large dams, especially in an era when social and environmental concerns associated with development projects are very high. We have seen that the height of the dam, a major physical criterion used for classifying dams as large and small, does not have any bearing either on the area that dams submerge, which affects the environmental consequences of reservoir projects, or the storage that dams create, which can generate a negative impact like creating safety hazards or a positive impact in terms of hydrological and socioeconomic consequences. This takes us to the question of what should be the ideal criteria for classifying large dams.

From an environmental perspective, the area submerged by dams is a good indicator of the potential ecological damage that dams can cause, though the actual ecological consequences would depend on several factors, e.g., the nature of the eco-region where the dam is located. Such data are easily available for existing dams/reservoirs, or can be generated for the dams/reservoirs that are being planned. But, does that reflect some of the negative social impacts dams can cause? In that regard, one of the biggest challenges that developing countries are confronted with today is to minimize the number of humans displaced by the construction of dams, and thereby reduce the task of the government in rehabilitating and resettling such persons. This is a major issue because one of the positions taken by anti-dam activists is that the complete rehabilitation of ‘oustees’ is impossible. Further, this is an area where there is a limited availability of reliable data. Hence, choosing a physical criterion that adequately captures the two altogether different dimensions of the complex problem caused by dam-building becomes all the more important.

Anti-dam activists around the world have been using several different estimates of ‘displacement’ to build their case against dams. The following paragraphs illustrate this problem of how inadequate data create misinformation about an issue as vital as displacement. By identifying the right kind of criterion, and one which uses measurable indicators, for deriving the statistics of large dams helps us also assess the magnitude of the problems large dams pose in any country, by using the data available on such indicators.

Global estimates of the magnitude of impacts include 40 to 80 million people displaced by dams (Bird and Wallace 2001). In the case of India, no authentic figures are available for dam-induced displacement. Whatever numbers that are available are derived largely from rough calculations and have a stronger emotional base than statistics. Fernandes et al. (1989) claimed that India had 21 million people displaced by dams. Some years ago, the then Secretary, Ministry of Rural Development, Government of India, unofficially stated that the total number of persons displaced by development projects in India are around 50 million, and around 40 million of them are displaced solely by dams. This statement is a personal estimate without any supporting evidence.

Certain other estimates are based on average displacement per dam. After a study of 54 dams, The Indian Institute of Public Administration (IIPA) concluded that the average number of people displaced per dam was 44,182. Roy (1999) multiplied this figure with 3,300 dams in India (CWC estimates, as cited in Roy 1999) and received the figure of 145 million displaced persons. Since she felt this figure is too large, she took an average of 10,000 persons displaced per dam, and arrived at the figure of 33 million as the number of people displaced by dams. Singh and Banerji (2002) have compiled the displacement data of 83 dams with the aggregate of 2,054,251. The list covers dams constructed in 1908 as well as many dams under construction. Based on the submergence area of these 83 dams the authors estimated an average of 8,748 ha of land under submergence and the average displacement per ha as 1.51. While multiplying these two average figures with the total number of dams, which is 4,291 (as given by CBIP, nd01, p21 as cited in Singh and Banerji 2002), the authors obtained the astounding figure of 56,681,879 displaced persons.. The authors wish to mention here that this is a clear overestimation.

Now let us do a careful analysis of these figures. By mooting the figures of 21 million, 30 million and 40 million as the population displaced by dams, the experts refer to these figures as 2 %, 3 % and 4 % population of the country. This means that the government, researchers, volunteer organizations and even political parties have ignored or overlooked the problems of 4 % of the population of India until it was substantially addressed by Narmada Bachao Andolan (NBA) through their movement against the displacement of persons caused by the Sardar Sarovar Project. Let us analyze the flaws in the estimates that form the basis of many of the arguments against the construction of dams.

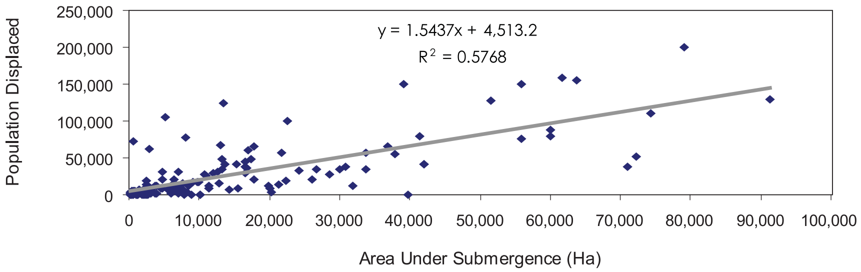
As per the National Register of Large Dams in India there are 1,529 large dams in the state of Maharashtra (CWC 1994), while according to the ICOLD figures there are 1,700 dams in the state. If we adopt Roy’s estimates of 10,000 persons being the average number displaced by a large dam, Maharashtra alone should have displaced between 15.29 and 17 million people. This is an exaggerated figure given that it is unlikely that such a big population of displaced persons in one state would not have gained more visibility i.e. given India’s poor track record for rehabilitation, the majority of such displaced persons should’ve been facing poverty and impoverishment On the contrary Maharashtra is India’s number two state as per the Human Development Index, next to Kerala (GOI 2006).

One of the major limitations of these estimates is that the majority of them are derived from the displacement averages calculated per dam, and are multiplied with the total number of dams. The figures offered by CWC, CBIP and ICOLD on the total number of large dams use ICOLDs definition as their basis. Thus, all the estimates of displacement have the inbuilt assumption that the height of a dam influences the magnitude of displacement. This perception that ‘higher the dam the larger the displacement’ is wrong, in that the increase in height of a dam at a specific location would increase the area under submergence, which thereby may cause an increase in the number of persons who are displaced.

It is a truism that theoretically, the population displaced would be largely determined by the submergence area and the population density of the region under consideration. But still it is important to know whether a strong relationship really exists at the operational level between the land area under submergence and the population displaced. This is in view of the vast variation in population densities from region to region in countries like India. The following figure supports the argument that land area under submergence is a good indicator. It is based on our analysis of 156 large dams in India and shows that the number of people displaced by dams increases linearly with the increase of the submergence area. Submergence area explains displacement to the tune of 58 %. The rest could be explained by variation in population density, and its effect on the displaced population. This is a high level of correlation and therefore, can be used to project the number of people displaced by dams, if we have data on the total area under submergence of all large dams.

The relationship also means that dam height is mainly location-specific, and as we have already seen that dam height does not have any bearing on either storage or submergence area., that it does not have a direct impact on displacement. The graph clearly shows that while 100 ha of submergence can cause the displacement of 150 plus people, what is important to note is that many large dams in India have a very low level of submergence. It should be noted here that in a country with a much lower population density (for instance, United States), the relationship would be different in the sense that the X coefficient would be much lower, meaning the number of people displaced by one sq. km of submergence would be smaller.

Figure 7. Submergence area vs. population displaced.



Now, the total area submerged by 2,933 large dams in India (obtained from Dams Register of India) was estimated to be 32,219.25 sq. km. The area submerged by 4,635 dams was extrapolated to be 49,660 sq. km (32,219*4,635/2,933=49,660). Based on this estimated submergence area and the formula given above, the total number of people displaced by dams was estimated to be at 7, 845 million. This is far less than the figures of displaced people provided by earlier researchers.

The main utility of this relationship is that once it is established for a given population density range on the basis of existing database, the number of people likely to be affected by dams in any region having that population density range could be estimated with a reasonable degree of accuracy, if the extent of the area under submergence is known. A direct approach of estimating displacement based on submergence area and population density in each case would be cumbersome, as it is difficult to get the population density data for very small areas.

In the developing world of today, the proximity of dams to fragile and rare eco-systems etc. could be one of the major criterions to assess the environmental challenge caused by the construction of dams. One major reason why the Silent Valley Hydroelectric Project in Kerala was abandoned in the late ‘80s was the fierce protests from environmental groups worldwide about the potential impact of the reservoir on rainforests, and the rare species of monkeys living in them. On the positive side, the geographical spread of large dams and how many of them supply water to naturally-water scarce regions are factors that illustrate the significance of dams in ensuring water security. These issues would be taken up for discussion in the next section.

Now, since it is true that height and storage volume together reflect the engineering challenges posed by dams, it can be inferred that a combination of parameters such as height, storage volume and submergence area would give a true reflection of the engineering, social and environmental challenges. Hence, the criteria for classifying large dams should be developed by taking into consideration all three of these important parameters collectively and not separately.

New Criteria for Evaluating the Performance of Large Dams

The arguments against large dams are largely on the environmental, economic and social fronts (MacCully 1996; D’Souza 2002). These arguments are founded more on emotional grounds rather than the scientific assessment of real marginal social costs and benefits, which forms the basis for an environmentally sound policy. The emotional ground is that the social costs caused by the development and use of water cannot be compensated by the increased economic benefits accrued from the use of water. This is in tune with the long-held position by Narmada Bachao Andolan that complete rehabilitation of communities displaced by dam construction is impossible. This is due to the deep-rooted belief that cheap and easy alternative options to building large dams do exist.

Internationally, such arguments gain a lot of credibility after the concept of virtual water trade was introduced in the early ’90s; and later on with small water harvesting options gaining acceptance. At least some of the environmental activists, who are against the construction of large dams in developing countries because of the displacement they cause, use the virtual water trade argument to contest the point that dams are important for improving food security. They instead argue that such countries should import food grain from water-rich countries. At the same time, the operational aspects of virtual water trade had not been studied. Recent research shows that globally, virtual water flows out of water-scarce regions to water-rich regions (Kumar and Singh 2005). In fact, many water-scarce regions in India export agricultural produce worth thousands of million cubic metres of water to regions that are water-rich (Amarasinghe et al. 2005; Singh 2004). Similar examples are found in China, Spain and United States. In a similar manner, local water harvesting solutions are found to be having extremely limited scope. This leads us to the point that the empirical evaluation of all direct and indirect costs and benefits of dams is inevitable, and the effort should be to minimize the social costs and maximize the returns from large dams, rather than looking at other options.

But responding to the war cry from environmentalists around the world, many international donors too have come out with criteria for evaluating the costs and benefits of large dams, which involve stringent environmental criteria. Environmental impact assessment (EIA) has been made mandatory for all World-Bank assisted dam projects in the world. But, the underlying premise in EIA is that all the environmental impacts associated with large dams are negative. The positive environmental effects of large dam projects such as their impact on the local ecology and climate are hardly examined (Kay et al. 1997).

During the past couple of decades, there were significant advancements in the methodologies used for evaluating the costs and benefits of dam projects. Hence, it is now possible to evaluate more accurately all future costs and benefits, including those which are social and environmental. But, such methodological advancements have also worked against the cause of dam-building around the world, as much less have been the advancements at the conceptual level in clarifying what should be considered as a positive effect or a benefit and what should be considered as a negative effect or a cost. This was compounded by major failures on the part of both the water resource bureaucracies as well as the environmental lobby to foresee all social and environmental benefits that are likely to accrue in the future from dam projects. This has led to a very unbalanced and biased assessment of all reservoir projects. We will be discussing these issues in the following paragraphs. First, one of the strongest criticisms against large reservoir projects by environmentalists was waterlogging and the salinity problems they can cause in the command area. Part of the reason for this is that nearly 50 % of the reservoir projects worldwide serve the purpose of irrigation. This has been an issue in many canal command areas of northern and north-western India and Pakistan Punjab. But, dramatic changes in agriculture in countries like India and Pakistan during the past 2-3 decades had converted some of these challenges into opportunities. With increasing groundwater draft for agriculture, which happened as a result of an advancement in pumping technologies, massive rural electrification, and subsidized electricity for well-irrigation, waterlogging is becoming a non-issue in many canal command areas that now have an improved groundwater balance. In Punjab, India, which is widely cited in literature as the ‘basket case of ill-effects of canal irrigation’, the area under waterlogging and salinity had actually reduced. One reason for this is the shortage of canal water, which had forced farmers to depend more on groundwater to improve the reliability of irrigation. In Gujarat, most of the areas that are likely to receive Narmada water are experiencing falling groundwater levels and, therefore, the threat of rising water levels due to induced water from canals does not exist.

While much attention has been given to the un-intended negative impacts or costs of dam/reservoir construction, such as water logging and salinity, downstream ecological damage, less consideration has been to identify, recognize or feel, the un-intended positive impacts such as drought proofing; drinking water security in rural and urban areas; increased biomass availability in canal command areas through energy plantation; and increased inland culture fisheries due to year-round access to water. This is a significant failure on the part of the pro-dam lobby, and the agencies concerned with dam- building.[4] Their performance is not evaluated in relation to the number of jobs these dams create in rural areas; or the increase in fishery

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[4] One of the reasons for this has been the very sectoral nature of agencies involved, wherein the irrigation department, which is the primary dam-building agency in India, is pre-occupied with showcasing the benefits of irrigation expansion.

production; or the number of people benefited by the availability of drinking water, as each category of such information is privy to a different agency.

Let us now examine the unforeseen benefits. Almost all major dams in the world are constructed for hydropower (Altinbilek 2002). In many regions of the world, especially in Africa and Asia, the hydropower potential is huge and mostly untapped, and globally, nearly 19 % of all electric power is generated from hydropower. Hydropower is accepted as one of the cleanest source of power in the world and, as such, pursuing it as an alternative renewable source of energy to burning fossil fuels, is a great environmental benefit and one that has prompted discussions on multi-purpose dams.

Ideally, the negative externalities created by thermal and nuclear power on the environment could be treated as the positive externality that hydropower generation creates on society. So, a kilowatt hour of energy produced from a hydropower plant should give an additional benefit equal to the cost of environmental damage, which a thermal or nuclear power plant would cause for the same amount of power generated, and at higher levels of generation, the marginal social benefits (sum of positive externalities and economic benefits) would be much higher. The future of the energy economy in India and China, the two fast-growing Asian countries, is very much dependent on how they exploit their renewable energy resources like hydropower given that both countries have vast untapped hydropower potential. In India, most of it lies in north-eastern mountainous region and in the Western and Eastern Ghats. It would be quite logical to assume that India would construct more dams to generate more hydropower, in which case the discussions on the negative environmental impacts of dam construction would surely become null and void.

Large dams have an important role to play in replenishing groundwater resources and the water supply for domestic and industrial use. The return flows from canals had played a significant role in sustaining tubewell irrigation as well as sustaining agriculture during the years of water scarcity (Dhawan 1990). A recent analysis by Kumar (2007) showed that nearly 5 % of the deep tubewells, 10 % of the dug-wells and 5 % of the shallow tubewells in India are located in canal command areas. Unlike other parts of the world, where many large reservoirs are earmarked for water supplies, many large reservoirs in India are planned primarily for irrigation. But the real use of these reservoirs had diverted far from their planned use. India's National Water Policy has set drinking water as the first priority over irrigation and industrial demand. During droughts, water from irrigation reservoirs gets earmarked for drinking water supply in rural and urban areas.

The Sardar Sarovar Project in Western India, for example, is expected to make a major dent in the rural and urban drinking water needs of 9,663 villages and 137 urban centres. Many dams in India are exclusively designed for drinking and domestic water supply, while numerous other dams originally meant for irrigation are now supplying water for domestic consumption. Without the Sardar Sarovar Project, the drinking water situation in these drought-prone areas would have been precarious in the absence of any sustainable source of water to meet the basic requirements (Talati and Kumar 2005) their residents. This is becoming a widespread phenomenon in India as many of her cities and towns are running out of water as a result of their local groundwater-based sources being exhausted by aquifer mining and permanent depletion (Kumar 2007). While NGOs, which advocate local alternatives in water management, especially in managing drinking water supplies, had fiercely opposed regional water transfers from Narmada to Saurashtra and Kachchh on cost grounds, they failed to set up demonstrations of such alternatives, which are effective in both the physical and economic front (Kumar 2004).

If health, ecology and environment were the major fronts on which large water projects were critiqued in the past, the future would increasingly find environmental, social and ecological reasons for their implementation (Vyas 2001; Kumar and Ranade 2004). Age-old arguments, such as water logging, salinity and downstream ecological impacts, which are still being used by the anti-dam lobby, would find little relevance in the present context. On the other hand, seepage from canals would help improve the groundwater balance over a period of time. The arguments about downstream ecological impacts primarily concern the potential reduction in lean season flows after impoundment. But, in practice, in large stretches between Indira Sagar and Sardar Sarovar, the flows are going to be regulated, and as a result there would be an increase in lean season flows.

The more immediate and positive ecological impacts would be accrued in water-starved regions where surplus flows from reservoirs can be diverted for ecological uses. The gigantic water transfer project in China involving a bulk transfer of water from the water-rich Yangtze River basin to seven provinces in the water-scarce north China plains could benefit more in terms of providing water for ecological flows in the Yellow River and meeting the drinking water needs of big cities like Beijing. The Yellow River had already dried up due to the heavy diversion of water for irrigation in agriculturally productive plains, and therefore, no water reaches the end of the river.

In Gujarat, western India, the Sardar Sarovar, being the terminal dam, can receive all surplus flows from the dams upstream and these surplus flows will be significant so long as upstream dams are not built. This water can be used to create induced flow in rivers in north and central Gujarat viz., Sabarmati, Watrak, Shedhi, Meshwo, Khari, Rupen, Sipu and Banas. There, rivers do not carry any flows for the entire year even in typical wet years and can therefore, receive the excess flows being diverted by Sardar Sarovar reservoir. This is already being practiced in the rivers of Central Gujarat. North Gujarat aquifers have high levels of salinity and fluoride at many places, which deteriorate the drinking water supply and causes major public health consequences (Kumar et al. 2001). The induced groundwater recharge can help to improve the quality of water by diluting the mineralized water in the aquifers, along with improving riverine ecology (Kumar and Ranade 2004).

While certain positive social, economic and environmental effects of dams were ignored or misunderstood, there are problems in the way the performance of dams are being evaluated by global interest groups. For instance, the criteria selected by the World Commission on Dams' (WCD) in its report, for evaluating dams are completion on time and completion within the budget (Perry 2001). Such technical and financial criteria often provide an unfair assessment of large dams. According to the author, criteria such as food availability, food security, food prices or even resettlement success are the right indicators to measure the economic performance of dams.

Food security is an important water management goal for many water-scarce countries including India and China (Kumar 2003; Kumar and Singh 2005). Food security is the central goal of constructing around 90 % of the large dams in India and other parts of Asia, while the ratio in Africa is 70 %. As per ICOLD data, worldwide, nearly 48 % of all large dams in the world were built for irrigation. Still, neither the dam-building lobby nor the irrigation agency has been successful in influencing the public debate to review dam performance on such social objectives as food security. While the positive externalities induced by the improved food security of regions and nations were less articulated in general, one particular reason for this has been the growing criticism that the surplus food India is producing is rotting in the godowns (warehouses) of the Food Corporation of India (FCI) and that dams therefore, do not lead to any improved access to food and, do not effectively contribute to food security at the domestic level.

Therefore, it is clear that the performance of dams should also be measured on the basis of food production and whatever additional purposes they serve. According to Bhalla and Mookerjee (2001), the total irrigation expenditure on major and medium irrigation schemes since independence in India has totalled Rs. 187,000 crore at 1999 prices. Against this, the total value of the agricultural output in 1998-99 was close to Rs. 500,000 crore. The authors have used these figures to calculate the internal rate of return (IRR) for big dams. As they have mentioned, depending on the assumptions one makes as to how much of the total investment for irrigation is investment for big dams (whether 100 % or 75 %) and depreciation rates (3 to 5 %), one obtains IRRs in the range of 3 to 9 %. Needless to say, without large dams, India would not have succeeded in feeding its burgeoning population. While what has been presented is just the direct economic benefit, the positive externality effects of dam-building should be added to it to get the social benefits as well. The benefits accrued from such positive externalities of increased food security benefits, should be assessed in terms of the opportunity cost of not producing that additional food internally, i.e., the cost of importing food. This is nothing but the import price of food grains minus the price at which they are available in the local market.

An IFPRI study attempted to examine the influence of Asian giants, China and India on international food prices by examining scenarios of rising cereal imports due to increasing meat consumption, which is a response to income rises and declining domestic production given the depletion of the natural resource base. The study used IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) to simulate a scenario of increased food imports by India to the tune of 24 million tonnes and China to the tune of 41 million tonnes in 2020 and showed an increase in international wheat and maize prices to the tune of 9 % and rice prices to the tune of 26 % (Rosegrant et al. 2001).

If we consider that half of the additional food grain production of the 94 million tonnes produced from irrigation in India since the 1950s, is from large dams (Perry 2001b), and if we decide to compensate through food imports the reduced production resulting from the absence of large dams, and we assume that prices would go up by just US$20/tonne (nearly 10 % of the current price), the imported portion alone would attract a total additional burden of 4,230 crore rupees annually. This is more than 1 % of India’s GDP. If we assume that the current domestic cereal prices are close to the import prices, the lower price consumers pay (say by US$20/tonne) is the impact of the domestic production of cereals on the food prices or the cost to the consumers and, therefore, can be considered as a positive externality effect of large dams. This whooping opportunity of cost of importing cereals itself seems to justify the large investment India had made in the irrigation sector. Such benefits should be added to the direct economic benefits to get the real social benefits of dam-building. This amount is the subsidy the government provides to the people by avoiding food imports and keeping the cereal prices in the local market under control.

The performance of irrigation reservoirs is often evaluated on pure engineering considerations, in terms of the area they irrigate against the total volume of water supplied; or the total amount of water consumed by the crop against the water supplied.

In addition to these, the irrigation bureaucracies in poor countries in Asia and Africa show an unwillingness to include the negative externalities as part of the project cost, as they do not like to transfer those costs to the water users, due to the fear that it would bring down the demand for water, and as a result would make benefit-cost ratios very unattractive. Instead, the practice is to bundle all such costs, and come out with a compensation package for the affected people, which is subject to scrutiny for economic viability by the donors.

This myopic tendency can be explained by the fact that the reduction in benefits, resulting from the decision to cut down the size of the project to minimize the negative effects on society, would be disproportionately higher than the reduction in cost. This can adversely affect B-C ratios. Hence, in an effort to get donor funds, the size of the project is stretched beyond the point where the net benefit becomes equal to net social costs through the exclusion of the negative externalities in cost calculations. This creates social ill-fare due to inequity in the distribution of project benefits. In other words, those who get the benefits do not bear the costs. Since the project agencies do not earn sufficient revenue from the services they provide, adequate attention is not paid to compensating those who are adversely affected by their projects. Such tendencies have also helped dam-builders in inflating the net benefits of the projects. If the donors make it mandatory for the dam-builders to include the economic value of negative externality effects in the project cost, it would have the following desirable consequences. First, the agencies would try and come out with innovative designs to reduce the marginal social cost of water development. Second, they would try and improve the quality of provision of water to raise the marginal value of the water. By doing this, even with lower level of development, the net social welfare from large dam projects could be enhanced.

In a nutshell, the criteria for evaluation of costs and benefits of dams needs to be made more comprehensive, taking into account all possible future ecological, environmental, economic and social benefits that dams are expected to accrue. For many developing economies, such benefits include: a) ecological benefits due to improved groundwater recharge through water transfers and canal return flows; b) economic benefits due to additional well-irrigation that is made possible with the availability of increased groundwater; c) greater drinking water security in drought-prone areas; and d) the environmental benefits of producing clean energy, which is made available through hydropower. Further, apart from economic criteria, large dams meant for irrigation should be evaluated in relation to the social criteria of how much they contribute in terms of improving regional and national food security, e.g., lowering food prices and making it accessible to most people. On the other hand, the negative externalities a large dam project creates should be included in the project cost, and be transferred to those who benefit from large dams in terms of the additional price they pay for the services that dams create.

Major Findings

1. Analysis of data from 145 countries shows that an improvement in the water situation of a country determines its degree of development and economic growth. The sustainable water index, which captures 1) access to water and the use of water; 2) water environment and human resource capacities in the water sector— seems to determine to a great extent the human development of a country, which in turn drives its economic growth. While the relationship between SWI and HDI is linear, that between SWI and per capita GDP is exponential. It is further argued here that building large storages would be crucial to improving the overall water situation of a country, against widely talked about alternatives such as intensive use of local groundwater resources and small-scale water harvesting.

2. Therefore, large dams are important for human development and the economic growth of a nation. This is also strengthened by the high per capita storage capacity achieved through dam-building by many developed countries such as Australia, United States, and fast growing developing countries like China.

3. The criteria used by ICOLD for classifying large dams, such as height and storage capacity, are not sufficient to capture the potential negative environmental and social consequences, for which large dams face opposition from environmentalists around the world. Analysis of data for 9,884 large dams around the world shows that the height of a dam neither determines the storage volume nor the amount of land submerged by reservoirs, which, in a way, imply the amount of safety hazards and the negative social impacts dams can cause. The use of such criteria results in an over-estimation of negative impacts like displacement, leading to over-reaction from the environmental lobby against the construction of large dams.

4. While India appears to be a world champion in building large dams in terms of the number of large dams built so far, the actual storage volume achieved by these dams is nowhere near those in the United States, Australia and China. While in the United States the mean storage per dam is (including those which are small as per ICOLD standards) is 80.8 MCM for large dams, and 28.8 MCM for small dams. Therefore, classification based on dam height neither indicates the potential benefits of dams nor their cost.

5. Analysis of data for 156 large dams in India shows that the number of people displaced by dams is a linear function of the total area submerged by them. Every one sq. km of area submerged by large dams in India displaces around 154 people. Using this formula, and the total estimated area of 49,660 sq. km area submerged by large dams, the total population displaced by large dams was estimated to be 7, 845 million persons. While the nature of the relationship between submergence and displacement will be the same for dams in other regions of the world, what might change is the number of people displaced per unit of submergence area according to the variation in population density. As shown by our analysis, while the area submerged by dams could be an

important criterion for deriving more reliable statistics about displacement, the available estimates of dam-related displacement in India are gross overestimates, in an order of a magnitude of eight more than the actual displaced.

6. In an era of the growing social and environmental concerns associated with building large dams, the criteria for classifying dams should be developed on the basis of three parameters, namely, dam-height, storage volume, and submergence area for them to truly reflect the true engineering, social and environmental challenges posed by them.

7. It is becoming increasingly clear that local water harvesting and virtual water trade options are non-existent in many countries, which need water for producing more food. This would compel water professionals to look for ways to minimize the social costs and maximize the returns from large dams. Apart from the economic cost of negative externalities on society in terms of human displacement and ecological degradation, the criteria for evaluating the costs and benefits of dams should involve considerations such as the impact of large dams on positive externalities associated with larger social and environmental benefits, such as stabilizing domestic food prices, reduced carbon emission for energy production, improvement in groundwater replenishment in semi-arid and arid areas due to imported surface water, and social security through improved access to water for drinking. A rough calculation shows that the benefit due to lower food prices (as a result of achieving a domestic production of 47 million tonnes of cereals, the approximate contribution of large dams to India's food production) alone would be Rs. 4,290 crore.

8. Water and power development agencies in poor and developing countries are not willing to transfer the additional cost of water provisions due to the negative externalities on society, on to the beneficiaries of dams. They fear that the increase in cost and the resultant increase in prices that users would have to pay, would significantly reduce the demand for water, making it difficult for these agencies to justify the implementation of large projects. This helps them show high demand for water, thereby being able to build large dam projects. However, the marginal social cost of these dam projects often far exceeds the marginal social benefits they generate, causing negative welfare effects on the society. If the donors make it mandatory for the dam-builders to take into consideration the economic value of negative externality effects of dam building into the project cost, the net social welfare from large dam projects could be enhanced.

Conclusions

We have investigated mainly three issues in this paper: 1) The role of water in development and growth, and the role of large dams in particular; 2) does the current technical criteria used in the classification of dams as 'small' and 'large' adequately capture the magnitude of the likely negative social and environmental impacts they can cause? If not, what should be the criteria for classifying dams for them to be true reflections of the engineering, social and environmental challenges they pose; and 3) are the objectives, criteria and parameters currently used to evaluate the costs and benefits of large water impounding and diverting systems, sufficient to make policy choices between conventional dams and other water harvesting systems or groundwater-based irrigation systems and if not, what new objectives and criteria, and variables need to be incorporated in the cost-benefit analysis of dams so as to make it comprehensive?

Our analyses of data from 145 countries showed that for a country, improving the water situation, expressed in terms of the sustainable water index, can propel its economic growth, through the human development route. The analysis based on data for 9,884 dams across the world showed that the height of the dam does not have any bearing on the volume of water stored, the latter of which is an indicator of the safety hazard posed by dams. Further, the height of the dam has no bearing on the area of land submerged, the latter of which is an indicator of the negative social and environmental effects of dam construction. At the same time, the regression, using data on 156 reservoirs across India and representing different population densities, showed that a normative relationship exists between the number of people displaced by dams and the reservoir area. Therefore, it can be inferred that neither the dam height nor the storage volume alone are indicators of the negative social and environmental effects of dams. Instead, a combination of physical criteria such as height, storage volume, and the area under submergence needs to be considered for developing criteria for classifying dams.

Extrapolating the relationship between area under submergence and displacement of persons for nearly 4,635 large dams in India, showed that the available estimates of displacement in India could be ‘gross over-estimates.

Given the current reality that large reservoir projects have a significant positive impact on containing national food prices, providing clean energy, improving groundwater recharge in semi-arid and arid regions that are facing over-draft problems, and ensuring social security through the provision of water supplies for basic survival, the economic viability of these projects should be assessed in relation to the positive externalities they create on society and the environment. At the same time, the negative externality effects of large dams are often not transferred to the beneficiaries of the project, resulting in many negative welfare effects on society from dam-building. To avoid this, the donors should make it mandatory for dam- builders to include such negative externalities in the project cost so as to increase their accountability towards the communities that are adversely affected by dams. It is argued that such an approach will also increase the pressure on the dam-builders to come out with innovative system designs that minimize these costs, and raise the marginal value of water, thereby raising the net social welfare.

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