Dam decommissioning: An option for India's ageing water storage infrastructures

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ABSTRACT

India is one of the largest dam builders in the world. It has built over 5000 large dams to date to cater for the power demands by hydroelectricity and to augment irrigation water demands for the agriculture sector. India has an ageing water storage infrastructure. As a matter of fact, it has more than 500 large dams that were built 50 years ago, and 100 of them have passed over a century. Despite having many dams and other water infrastructure, India does not yet have exposure and expertise in decommissioning old dams. However, in most of the cases where dams have been dismantled or are being considered for decommissioning, money is saved in the long run. Dam decommissioning can be expensive in the short term. Although due to the extensive development that generally takes place in and around any dam project and its affected reaches, the rivers cannot be fully restored to their natural state, it always helps the local riverine ecosystem to enrich. This article analyses the facts on India's over-aged and old dams, and their safety matters. It discusses the decommissioning of old dams as one of the strategies to safeguard from potential future threats. In India, the decision for dam decommissioning must be explored as an option based on site-specific objectives and priorities, mainly when the downstream community's safety is the top priority in the case of outdated dams.

Keywords: Dam, Dam-Decommissioning, Dam Safety, Water Storage Infrastructure

1.0 INTRODUCTION

Dams are considered to be the temples of modern India since its independence. India is the third largest dam builder in the world after China and USA, and some of the oldest dams exist in India. A dam is an artificial barrier usually constructed across the rivers and streams to confine and utilize water flow for human purposes such as irrigation and hydroelectricity generation. Timber, rock, concrete, earth, steel or a combination of these materials may be used to build the dam. Spillways are commonly constructed of non-erosive materials such as concrete. Dams should also have a drain or other water-withdrawal facility to control the pool or lake level and to lower or drain the lake for regular maintenance and emergency purposes. According to the National Register of Large Dams of India report, India has constructed about 5334 large dams, providing about 249 BCM (km^3) storage. Another 411 projects with storage of about 29.6 BCM are under construction (CWC, 2019). More than 50% of these dams were constructed during 1970-1990, implying the aging infrastructures of more than 25-45 years old.

Further, there are at least 100 large dams in the country over 100 years old, and urgent steps and a legal mechanism are needed to ensure the safety of people and the structures (Agoramoorthy, 2015). The 126-year-old Mullaperiyar dam on the Periyar river is located in Kerala, causing an ongoing row and a protracted legal battle between the Indian states of Tamil Nadu and Kerala. There are 38 record dam failures in post-independence India (Table 1). The Machhu II (Irrigation Scheme) Dam, Gujarat, India, is a classic example of dam failure due to under design and unprecedented floods.

Table 1: Details of the reported dam failures in India (year-wise) (Sources: CWC reports)

SN	State	Name of Project	Type	Max. Height (m)	Year of Completion	Year of Failure	Cause of Failure
1	MP	Tigra	Masonry	24.03	1914-17	1917	Overtopping followed by a slide
2	MH	Ashti	Earthen	17.70	1883	1933	Slope Failure
3	MP	Pagara	Composite	27.03	1911-27	1943	Overtopping followed by a breach
4	MP	Palakmati	Earthen	14.60	1942	1953	Sliding failure
5	RJ	Dakhya	Earthen	NA	1953	1953	Breaching
6	UP	Ahrura	Earthen	22.80	1953	1953	Breaching
7	RJ	Girinanda	Earthen	12.20	1954	1955	Overtopping followed by a breach
8	RJ	Anwar	Earthen	12.50	1956	1957	Breaching
9	RJ	Gudah	Earthen	28.30	1956	1957	Breaching due to bad workmanship
10	RJ	Sukri	Earthen	NA	NA	1958	Breaching by leakage through foundation
11	MP	Nawgaon	Earthen	16.00	1958	1959	Overtopping Leading to breach
12	RJ	Dervakheda	Earthen	NA	NA	1959	Breaching
13	GJ	Kaila	Earthen	23.08	1955	1959	Overtopping Leading to breach
14	MH	Panshet	Earthen	53.80	1961	1961	Piping failure leading to breach
15	MH	Khadakwasla	Masonary	60.00	1875	1961	Overtopping
16	RJ	Galwania	Earthen	NA	1960	1961	Breaching
17	RJ	Nawagaza	Earthen	NA	1955	1961	Breaching
18	MP	Sampna	Earthen	21.30	1956	1964	Slope failure on account of inappropriate materials
19	MP	Kedarnala	Earthen	20.00	1964	1964	Breaching
20	UK	Nanaksagar	Earthen	16.00	1962	1967	Breached due to foundation piping
21	GJ	Dantiwada	Earthern	60.96	1965	1973	Breach on account of floods
22	TN	Kodaganar	Earthern	12.75	1977	1977	Breached on account of floods.
23	GJ	Machhu-II	Composite	20.00	1972	1979	Overtopping due to floods
24	GJ	Mitti	Earthern	16.02	1982	1988	Overtopping leading to breach.
25	MP	Chandora	Earthen	27.30	1986	1991	Breaching
26	AP	Kadam	Composite	22.50	1958	1995	Overtopping leading to breach.
27	RJ	Bhimlot	Masonry	17.00	1958	-	Breached due to inadequate spillway capacity.
28	GJ	Pratappur	Earthern	10.67	1891	2001	Breached on account of floods.
29	MP	Jamunia	Earthen	15.40	1921	2002	Piping leading to breaching
30	OD	Gurilijoremip	Earthen	12.19	1954-55	2004	foundation scouring
31	MH	Nandgavan	Earthen	22.51	1998	2005	Water flows over the weir to a depth beyond the design flood lift.
32	MP	Piplai	Earthen	16.73	1998	2005	Breaching
33	RJ	Jaswant Sagar	Earthen	43.38	1889	2007	Piping leading to Breaching
34	AP	Palemvagu	Earthen	13.00	U/C	2008	Flash flood resulting in overtopping of the earth dam
35	MP	Chandiya	Earthen	22.50	1926	2008	Breaching
36	RJ	Gararda	Earthen	31.76	2010	2010	Breaching
37	MH	Tiware	Earthen	NA	2000	2019	Breaching
38	UK	Tapovan	Masonary	22.00	U/C	2021	Glacier Burst

STATE: MP: Madhya Pradesh; RJ: Rajasthan; AP: Andhra Pradesh; MH: Maharashtra; GJ: Gujrat; OD: Odisa; UK: Uttarakhand; TN: Tamil Nadu; UP: Uttar Pradesh;

Dams have also been encouraged as renewable, clean, and pollution-free sources of energy and hydropower projects have been endorsed as multi-purpose projects. At the same time, there is an obvious need to construct storage dams as they play an essential role in the nation's water resources development. There is also the need to ensure the safety and long life of the dams already constructed and take due safety measures of dams under construction or being planned. Therefore, hydraulic, hydrologic, economic and ecological reviews of existing dams or hydropower facilities are needed. Reservoirs and dam barriers, like any other man-made structure, have a limited lifespan; they should be decommissioned or rebuilt when they get old. An old dam with its exhausted life, poor maintenance and reduced storage capacity due to sedimentation can lead to catastrophe in downstream areas in terms of the dam break and consequent flooding. As per failure data on large dams collected by (ICOLD, 2020), globally, nearly 35% of dams have failed due to causes related to inadequate spillway capacity. Therefore, this becomes a significant concern in the dam safety programme. Thus, planned decommissioning of the aged old dams is the demand of the time concerning the safety of downstream human habitation and river ecology.

Old dams were designed based on whatever information/data was available during construction and using the method prevalent in the past. About 70 percent of dams are more than two decades old. Over the years, a significant amount of hydro-meteorological data have been collected, and a lot of technological development has taken place in the field. Thus, there is a need to set up guidelines for dam decommissioning pertaining to the hydrologic safety of old dams based on scientific data collected in situ and the procedures that have evolved during the period. The likely effect of climate change on extreme events may also require thinking about the hydrologic safety of old dams.

2.0 WHY DO WE NEED DAMS?

In ancient times, dams were built for the single purpose of water supply or irrigation. As civilizations developed, there was a greater need for water supply, irrigation, flood control, navigation, water quality, sediment control and energy. Therefore, dams are constructed for specific purposes such as water supply, flood control, irrigation, navigation, sedimentation control, and hydropower. According to the World Register of Dam web publication (ICOLD, 2020), irrigation is the most common purpose of building dams. Among the single-purpose dams, 47% are for irrigation, 21% for hydropower (electricity production), 12% for water supply, 9% for flood control, 5% for recreation and the remaining for navigation and fish farming and others. The multi-purpose dam is a significant project for developing countries because the population receives domestic and economic benefits from a single investment.

Irrigation**:** Irrigation is needed for the food security of the ever-growing global population. As significant population growth is expected in the coming decades, irrigation potential must be expanded to increase food production. It is estimated that 80% of additional food production by 2025 will need to come from irrigated land, even with the widespread measures to conserve water by improvements in irrigation. Agricultural land covers 33% of the world's land area, with arable land representing less than one-third of agricultural land (9.3% of the world's land area) (FAO, 2020).

In fact, during the past 40-50 years, there has been a ~70% increase in irrigated cropland area and, consequently, global water consumption via irrigation has more than doubled from ~650 to ~1400 km^3 per year. Irrigation enables farmers to increase crop production by reducing their dependence on rainfall. As per one of the European Union Commission report, worldwide, it is estimated that only 18% of cultivated land is irrigated, yet these lands produce 40% of food requirement (European Union Commission, 2020).

Hydropower**:** Rapid industrialization and urbanization, especially in developing countries like India, China, Brazil, etc., have put the energy sector under extreme pressure. Being the green and cheap form of energy hydroelectric power plants are on prime priority in supplying electricity to millions of people. More than 90% of the world's renewable electricity comes from dams. Between 2000 and 2017, nearly 500 GigaWatt in hydropower installed capacity was added globally, representing an increase of 65% (IHA, 2019). According to a published research (WWI, 2012), Hydropower use reached a record 3,427 terawatt-hours of electricity each year, supplying about 16.1 percent of global electricity consumption. Five countries, namely China, Brazil, the United States of America, Canada, and Russia alone, accounted for approximately 52 percent of the world's installed hydropower capacity in 2010.

Water Supply for Domestic and Industrial Use: It has been discussed how essential water is for sustaining life on earth. Rainfall is the primary source of fresh water on the planet; most of it falls on the sea, and a large portion ends up as runoff. Only a tiny amount of the total is infiltrated to replenish the groundwater. Properly planned, designed, constructed and maintained dams to store water contribute significantly toward fulfilling our water supply requirements for various purposes. Millions of water are needed per day in municipal and industrial facilities. In each of these cases, water would not be provided without dams.

Inland Navigation: The advantages of inland navigation over highway and rail are the large load carrying capacity of each ship, the ability to handle cargo with large dimensions and fuel savings. Integrated, comprehensive basin management, planning and development may result in enhanced inland navigation utilizing dams, locks and reservoirs, which may have a more significant role in national economic benefits. Despite having 14,500 km of water highways, Indian inland navigation is not so promising.

Flood Control: Floods can cause significant damage to human lives, property, and livestock. Cities and towns have been devastated due to flood damage. Lives have been lost and homes destroyed. Flooding can cause epidemics due to sewer disposal and contaminated water supplies. Dams can play a role in limiting the extent of flood damage, thus mitigating its effects. Dams and reservoirs can be effectively used as river level regulators, and flooding downstream of the dam can be temporarily avoided by storing the flood volume and releasing it later. Flood control is a significant purpose for many of the existing dams and continues as a primary purpose for some of the major dams of the world currently under construction**.** The most effective method of flood control is accomplished by an integrated water management plan for regulating the main reservoirs and dams located in a river basin.

3.0 WHAT IS DAM DECOMMISSIONING?

In the recent past, several things have happened to consider the value of some dams. Firstly, we have learned about the adverse impacts of dams on riverine ecology and communities inhabited on river banks. Secondly, the rapid development of non-structural technologies or alternatives of dams for flood management, irrigation water supply, water storage, and power generation have been developed. And thirdly, most of the dams are getting aged, and several old dams need substantial repair and rebuild (WWI, 2012). Because of the context described above, the term dam decommissioning came into existence. Generally, it refers to the complete removal of the dam and its associated structures or partial reduction or lowering of the dam's height. It can be defined as declaring a dam and/or hydropower facility inefficient, unsafe, and/or an environmental disaster and proceeding to washout /tear down the dam structure. Appropriate methods of dam decommissioning depend on project attributes (such as size, type and location of the dam), river characteristics, and intended objectives (such as fisheries restoration, land reclamation and recreation). Dam decommissioning is thus highly site-specific. Careful planning minimizes public health and safety risks to downstream communities. Dam decommissioning can be done broadly as follows:

Dam Dismantling*:* When the dam is dismantled by removing all its physical barriers to stream flow is called dam dismantling, which is the most thespian option of decommissioning. This process's primary objective is the complete restoration of the river's natural flows, including peak flows and seasonal flooding. This would also enable fish passage and the transport of gravel and organic debris downstream. Dam removal can sometimes be immediate, but it is often staged in a cautious, risk-averse way to avoid unwanted release of the sediments that typically accumulate behind old dams.

Dam Modification*:* With these options, there is little or no impact on dam function, and they also allow existing dams to continue providing societal benefits such as hydropower, irrigation water, drinking water etc. The addition of fish ladders for improving fish access to the spawning habitat above the dam without altering the function of the dam itself is an excellent example of dam modification.

4.0 REASONS FOR DECOMMISSIONING

Dams don't last forever. In recent decades, there has been a growing movement toward decommissioning dams where the costs (including environmental, safety, and socio-cultural impacts) outweigh the benefits (including hydropower, flood control, irrigation, or recreation) or where the dam no longer serves any useful purpose, worldwide. There could be many reasons for dam decommissioning, e.g. obsolescence, environmental concerns, economics, safety criteria, risk reduction, and operation and maintenance costs. A few of the several reasons for dismantling or decommissioning ageing dams are as follows (Bowman, 2002; Peterson, 2015):

Structural Safety: Dam safety and security are primary issues in consideration of dam removal. As dam structures age, weaken, crack, and wrench, dams become unsafe. Dam failures could lead to the inundation of the downstream areas, followed by unexpected floods and disastrous results. Many dams have a useful life expectancy of about 50-100 years.

Reservoir Siltation: Siltation due course of regular operation of the reservoir will reduce the dam's ability to store water and produce electricity. It will have less proper active storage and more passive storage. In some cases, the cost of de-silting the reservoir could exceed the cost of dam decommissioning.

Marginal Benefits**:** Obsolete and poor hydraulic and hydrologic design of the structure, inefficient capacity turbines, and changing societal water demands and needs could be a reason for decommissioning an old dam.

Economic Costs: A significant expense associated with maintaining ageing dams is the cost of structural repair required in the course of normal dam operations. Marginal dams cost money to maintain while providing little or no benefit to society. This life span is also typically related to maintenance and upgradation.

Ecological Damage: After safety concerns, the second most prominent reason for dam decommissioning is the environmental damage. These damages mainly include the harm to aquatic life, e.g. fishes and riverine ecology.

5.0 CONCERNS ASSOCIATED WITH PRE AND POST-DAM DECOMMISSIONING SITUATIONS

If planning for dam decommissioning, one should consider the various hydrologic, hydraulic, structural, sedimental, societal, economic, and environmental concerns for the post-dam conditions in the interest area.

Hydrology and Hydraulics Concerns: The hydrological and hydraulic impacts of post-dam conditions will need to be examined over a range of flows and flooding scenarios to understand the potential changes to the river flow system. This impact assessment needs to consider both positive and negative changes upstream and downstream of the dam site. Dams can also alter low flows in the downstream channel, especially when water is stored for supply during more desired release periods, as in the case of flood control or water supply dams. Dam removal will have a reverse impact on the upstream river channel. Previously deposited sediments trapped behind the dam will be especially prone to mobilization and transport downstream. The lower water levels will most certainly impact private and public development near the banks of the former reservoir (Bowman, 2002).

Structural Concerns: Over time, several structures have been constructed near the dam reservoir, e.g. retaining walls, roads, canals, bridges, powerhouses, residences, and water and sewer lines. So, before the dam removal, an assessment of the structural stability of the dam and other affected structures needs to be done. The results of these assessments will help to take a decision regarding stabilization, relocation or, in some cases, reconstruction of associated structures of the dam site.

Sedimentation Concerns: Sedimentation is a phenomenon due to which the capacity of a dam reservoir reduces with a lapse of time caused by settlement and trapping of sediments, e.g. silt, sand, gravel, boulders, and organic debris behind the dam structure due to low flows at the reservoir. This discontinuation of sediment flow due to the dam starves the river of the material needed to replenish and rebuild the stream bed and renew floodplain soils. Sedimentation is a critical consideration in any dam decommissioning process. The improperly managed sediment deposition has adverse effects such as reduction in storage capacity, increase in backwater level, and formation of shoals or islands in the reservoir upstream. On the other hand, the released sediments are transported downstream, creating turbid waters and degrading aquatic animals and plants.

For the reasons described above, it is essential to identify the measures necessary to mitigate the potential for uncontrolled sediment releases once the dam structure has been removed (either in part or in whole). This can be achieved by the appropriate level of sediment sampling, analysis and quantification by the applicants for dam decommissioning projects. Preparation of proper sediment management plans, including sediment stabilization techniques, sediment disposal systems and site restoration methods etc., can be done by sediment modelling.

Environmental Concerns: From the environmental point of view, the restoration of the pre-dam natural flow condition of the stream is the most crucial benefit achieved by the dam decommissioning process. Today, one of the most common environmental considerations is fisheries habitat for selected species, especially salmonids (salmon, trout, and whitefish) and other migratory fish currently threatened or endangered (WWI, 2012). The dam decommissioning may reconnect the migration channel for native fish species and different aquatic habitats. Although the dam decommissioning can potentially restore the natural habitat, it may not result in enhanced habitat due to reduced upstream water levels, increased downstream channel, loss of reservoir storage, channel shape reforms, etc.

A second common environmental issue is wetlands which are widely regarded as valuable ecological resources. Productive wetlands are sometimes inundated in reservoirs, but new wetlands and aquatic habitats are created in areas upstream. All the riverine aquatic life and surrounding terrestrial wildlife could be positively and negatively affected due to changing water levels upstream and downstream of the dam site caused by dam decommissioning. These environmental concerns should be considered and special consideration should be given to any known endangered or extinctions species. Riverine and riparian habitat impact assessments must be considered as an integrated part of the dam decommissioning plan.

Dam decommissioning is also supposed to restore natural flow regimes, including the peak flows or the seasonal flooding that occurs during storm events which are crucial for moving sediment downstream, scouring river channels, flushing logs, debris, small rocks, gravel bars etc. and natural water temperature harmony that distinguish a healthy river system.

Social Concerns: The safety of the downstream people is of prime importance when considering the social issues linked to decommissioning any old dam. The security of people, their properties, public infrastructure, livestock, agriculture, etc., is highly correlated with the safety and stability of the structure to be decommissioned. As it relates to human lives, it is of primary importance in decision-making.

Apart from the safety point of view, there may be a possibility of opposition to the dam decommissioning by the local beneficiary community, which directly or indirectly depends on the dam for their livelihood, e.g. fishing, boating, swimming, dam tourism, water sports, etc. The people settled in the formerly located outside flood plain regions may become susceptible to flooding under higher flow regimes post dam decommissioning and who have adopted the current ecosystem governed by the dam. Decommissioning dams could lead to legal implications regarding property ownership, compensation, relocation, etc. On the other hand, environmentalists, NGOs, and the public may support partially or fully decommissioning the dam from its original site to have a more natural riverine environment (Bowman, 2002; Peterson, 2015; WWI, 2012).

Economic Concerns: As a part of the decision-making process, the economic consideration of structural modification and rehabilitation plays a vital role in decommissioning dams. The decommissioning projects must be carried out, including various possible costs associated with the tangible components of decommissioning. The decision-making will consider economic factors influencing dam decommissioning prospects, expenses related to the dam decommissioning process and cost-benefit analysis.

Suppose the dam owner can benefit substantially from the ongoing operation of the dam and reservoir. In that case, it usually is feasible to maintain and upgrade the facilities to improve dam safety and comply with regulatory requirements. Where the benefits of the dam have been substantially reduced, there is often a reluctance to invest in dam repairs, although with increasing liability. In this case, dam decommissioning may be considered for economic (and liability) reasons, as the long-term costs and risks for the continued operation of the dam may very well exceed those for dam decommissioning.

The economic considerations associated with decommissioning a dam are significant for operating and improving an ageing dam. Careful planning is required, including analysis of alternatives, preliminary cost estimates, legal permissions and consensus-building with concerned shareholders that must be identified. The economic losses due to discontinuing the operation of the dam (i.e., flood control, irrigation, power generation, recreational uses) must be considered.

6.0 DECOMMISSIONING PROCESS

Planning a dam decommissioning project is similar to any original construction project, except the end product is considerably different. All decommissioning projects are likely subjected to policies and acts pertaining to the environment and water. Therefore, it is critical to identify all issues and obtain stakeholders' concurrence early in the process. The process begins with studying all alternatives, including repair, upgrade, and decommissioning. If decommissioning is the selected alternative, the process, in general, can be seen in the following flow chart (Figure 1) as given by a committee on dam decommissioning constituted by the United States Society on Dams (USSD) (H. John Heinz, 2002).

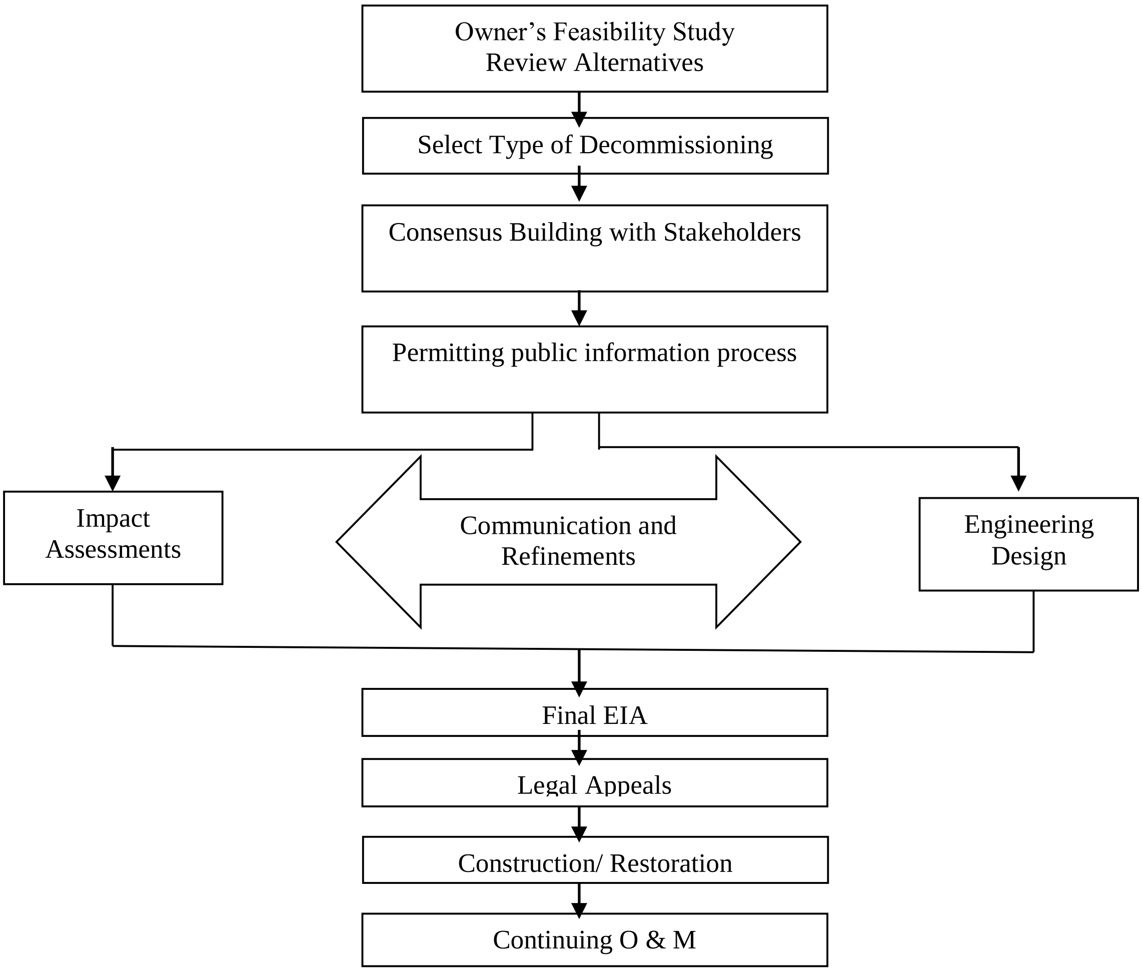

Figure 1. Dam Decommissioning Process flow Chart (H. John Heinz, 2002)

Decision-Making for Dam Decommissioning

Being an essential landscape of national interest, dam removal or decommissioning decision is very complex and peculiar. Who will decide whether dams should be removed or not? Is a big question. In most cases, the dam owner (usually the central / state government in the case of India) is the decision-maker, often deciding that the costs of continuing to operate and maintain the dam are more than removing the dam. Dam regulatory board/ corporation, water ministry, environmental, forest and wildlife authorities etc., can also have a significant role in decision-making concerning their domain apprehensions (European Union Commission, 2020). Such a decision-making process begins with the government's willingness or demand from the local affected communities.

The decision-making process would start with identifying the specific goals and objectives that the government or the communities concerned with the dam anticipate achieving as a first step. Discussions about the advantages and disadvantages of retention versus removal of the dam in public meetings and various data relevant to environmental, social, and economic aspects will be required for better decisions making related to dam removal. General decision-making methodologies for dam removal or decommissioning are very nicely articulated in a few pieces of literature (Bowman, 2002; Peterson, 2015).

Science to support decisions about dam removal is evolving, but there is little cross-disciplinary communication, and research priorities have not been established to guide researchers. A flow diagram of a systematic approach to decisions about dam retention or removal is shown in Figure 2, adopted from Heinz Centre (Peterson, 2015). The steps include the following:

- ***Define Goals and Objectives:*** Establishment of the goals, objectives, and a basis for the decision. It includes collecting information about the environmental, social, economic, regulatory, and policy contexts for the decision and its outcome.
- ***Identify Major Issues of Concern***: Identify significant issues of concern: ranging from the safety and security of a dam to those related to the cultural interests of the population involved.
- ***Collect and Assess Data***: Assessment of the potential outcomes and gathering data about the operations of the river; the dam; the legal regime; and the ecological, social, and economic systems associated with these elements. These assessments depend on evaluating indicators that provide insight into the present and likely future conditions.
- ***Decision Making***: Then, decision-making comes within a framework encompassing available knowledge about the gains and losses, costs and benefits, public support and concerns, and private and public interests.

7.0 DAM REMOVAL EXPERIENCES AROUND THE WORLD

The USA is the world leader in dam decommissioning, and it has decommissioned nearly 888 numbers of the dam up to 2010 (USSD, 2015). The 43-meter-high Elwha Dam and 82-meter-high Glines-Canyon Dam are the highest dams ever slated for removal at government expense, built in the early 1900s to power timber mills in the nearby town of Port Angeles on Elwha River, Washington. The private dams within the Olympic Peninsula National Park destroyed magnificent local runs of *Pacific salmon*, diminishing an irreplaceable cultural symbol. The extinction of Elwha River *sockeye salmon*, and drastic declines in the river's ten other native species, undermine the fishing rights of the Lower Elwha Klallam. In 1992, the US government finally heeded tribal demands to provide "full restoration" of the Elwha River, including dam removal (H. John Heinz, 2002). Complete decommissioning of Elwha Dam was done in March 2012 and started in July 2011. The final explosion blasting of Glines-Canyon Dam was completed in 2014. Restoration of the Elwha represents the last, best hope for resolution of Lower Klallam fishing rights and a once spectacular salmon river.

Inspired by decommissioning efforts on the Elwha River in the US, the SOS Loire Vivante (Living Loire) network is working to restore France's only remaining native Salmon River by removing old dams. In 1998, two dams on tributaries of the Upper Loire were demolished to help protect the last Loire salmon. First, the 12-meter-high Saint-Etienne-du-Vigan Dam on the Upper Allier was removed, marking the first case in which France's state-owned electricity utility destroyed a dam to restore salmon habitat. The Vienne River, the second largest Loire tributary, also flows freely after demolishing the 4-meter-high Maisons-Rouges Dam. A dam in Kernansquillec on the Leguer River was also dismantled, in 1996, after rapid sedimentation had reduced the reservoir capacity by 50%. Dam removal in France and the Loire River management plan reflects growing awareness across Europe, where concessions for thousands of dams built before 1950 are to be reviewed in the next decade (H. John Heinz, 2002).

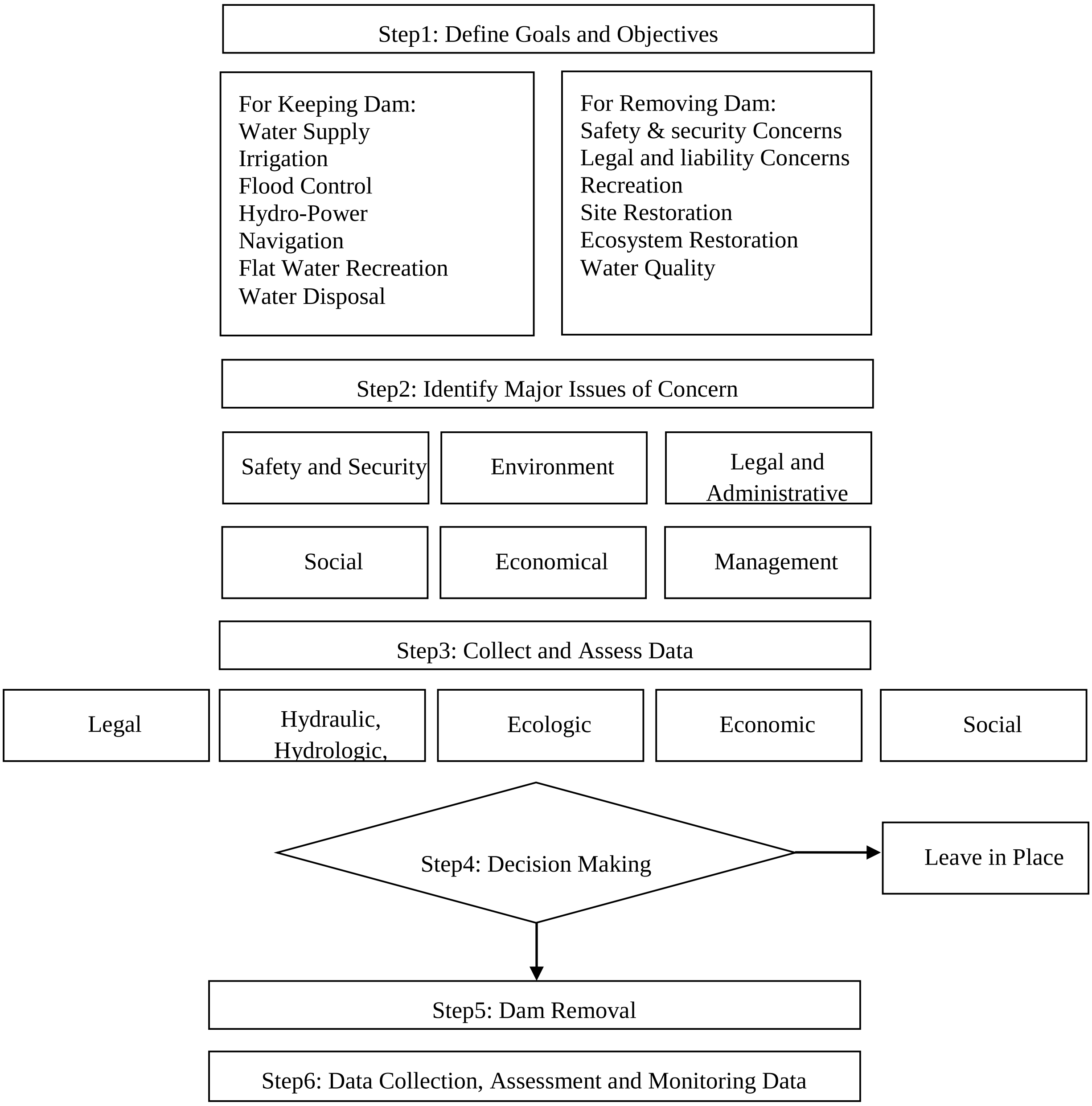

Figure 2: A general method for dam removal decisions (Peterson, 2015)

8.0 CONCLUSIONS

Water scarcity is becoming critical in many parts of the world, with increasing pressure to build more large dams as the critical solution. The global growth in electricity demand is also pushing the development of more hydropower dams. Dams and reservoirs usually have a defined lifespan beyond which they may become unsafe or uneconomic. In most cases, 50-100 years is deemed to be the active lifespan of a dam, after which it is prone to be unsafe and turns progressively less productive. After that, the cost of maintaining the dam starts outweighing its benefits. Decommissioning of dams is a reality and a feasible dam management option that engineers and dam owners will be opting for more and more in the next few decades. It is time to gather and begin to exchange ideas now. It is also evident that most of the dam decommissioning implementation has been done in developed countries and the developing countries of Latin America, Asia and Africa are still in the process of dam building for fulfilling their various desired objectives, mainly hydropower and irrigation. The dams are still seen as the symbol of development in these countries and they are required for the irrigation and hydropower needs of their people indeed. Dam decommissioning is taboo in developing countries like India, as lots of public money was involved during their construction. A major technical issue that is usually completely ignored is the significant climatic differences between developed and developing countries, especially in terms of the distribution of rainfall over the year. This is an essential issue because storage is more important for developing countries than for developed ones.

As the concept of dam decommissioning is progressing, the researcher and scientific community are now accepting it with more leniency. Considering all scientific and non-scientific factors, the costs associated with decommissioning can be many times the cost of maintenance and safety repairs as well as direct and indirect expenses related to upgrades (e.g. fish ladders and mitigation for fish mortality). Dam removal can be expensive in the short term, but when dams have been removed or are being considered for removal, money is saved over the long term. However, most rivers cannot be restored entirely to historic conditions simply because of the development on and along them. Still, scientific and systematic dam decommissioning can recreate conditions that move the river towards those historical conditions. Much can be learned from reviewing the decision process from decommissioning case studies. Rivers are very dynamic and resilient, and the natural river systems can be restored relatively rapidly after dam decommissioning.

Without sufficient knowledge and site-specific data, the feasibility of decommissioning cannot be adequately evaluated. While there is often no definitive answer to a question about whether a particular dam should be removed, there is a right and wrong way to go about making a dam removal decision. Until the site-specific needs, conditions and requirements have been carefully assessed and considered, a 'dam' or 'no dam' solution should not be imposed based on experience outside the region. Decision-making regarding the consideration of dam decommissioning as an option should be made based on the site-specific objectives and priorities, particularly where safety is the primary concern of the downstream community in the case of old-aged dams.

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NOTE:

The views expressed in this paper may not necessarily belong to the organization which the authors represent.