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# Dams Safety: the Question of Removing Old Dams

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## Abstract

Many old dams in the world today may not be safe enough and represent threats to the communities they serve. They have reached the end of their technical and economic lives making upgrading them questionable. This raises the question of decommissioning or removing them open for further discussion. In this paper the issues related to keeping old dams are discussed showing with one example that the soaring costs of upgrades make it impossible to perform for countries with limited resources without outside financial support. An explanation is also given to show how even in rich countries this is met by budgeting obstacles. Other objections to the presence of these dams, added to the safety question which support of dam's removal are discussed. They include the accumulated damage they have caused to the ecosystems such as siltation and fish migration. An emphasis is put on the need for intensive studies required before removing any such dam in order to mitigate any negative impact subsequent to such removal; and many actual examples are given to illustrate this.

**Keywords:** Upgrading, Decommissioning, Dam Safety, Ecosystem, Siltation, Fish Migration.

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# 1. Introduction

Dam safety is one of the biggest problems facing societies today. While the need for building more dams is increasing due to increasing needs of growing populations and expanding industries, hazards posed by older dams are aggravated by intensified inhabitation and growth of industry in downstream areas much more than the days when these dams were built. Signs of weakening on these dams add to worries of their possible failure causing loss of life and destruction of infra structures and material property loss. The decision then must be taken, whether to continue spending on repairs, rehabilitation and upgrading of such dams with increasing costs as time goes by or, maybe it is cheaper to decommission them or remove them altogether.

Without any doubt, dams built today are generally more secure than those built 50 years ago, but the majority of dams in the world as a whole is ageing. Around the world, 5,000 large dams are at least 50 years old. Dams in USA are 56 years old on average and there are about 2000 dams of all sizes at least 120 years old, Figure 1. These older dams are highly prone to dam break, especially in countries that lack adequate monitoring and maintenance or funds to do meaningful upgrading and repair. Old dams become increasingly more expensive to maintain with the passage of time. But, this is faced by systematic underfunding of dams' maintenance all over the world. Such maintenance is not considered as a budgeting priority, or it is not carried out properly due to shortage of qualified personnel, and in many instances, even lack of understanding by the higher authorities of the possible dangers.

Upgrading of old dams may be necessary in great number of dams which are fifty years old or more which are still in good shape, but they may be considered unsafe in view of the fact that they were designed using design data and criteria which are no longer applicable.

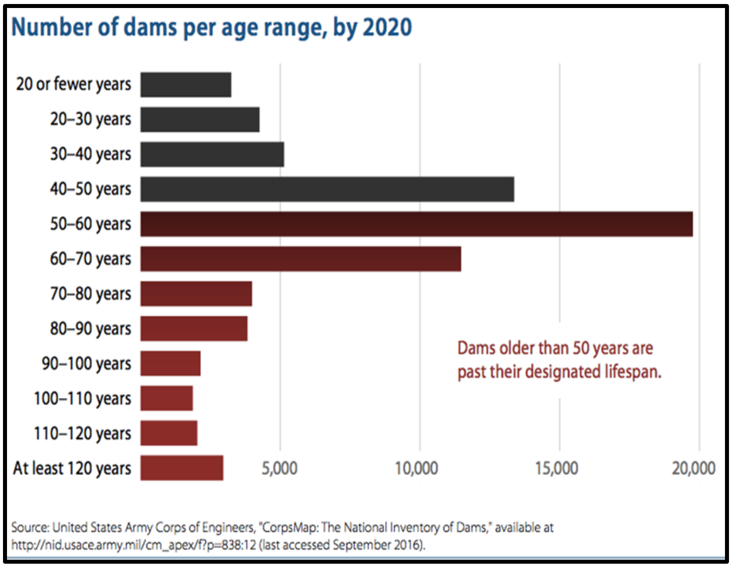


**Figure 1: Statistics of dams in USA by age (Source: as shown).**

Upgrading of such dams may be, neither technically nor economically possible leaving the question to dam owners of keeping such dams and meet the possible hazards, or just take the painful decision of decommissioning or removing them. It is estimated that only in the USA more than $70 billion are needed to rehabilitate the USA dams [1]. Of approximately 84,000 dams in the United States National Inventory of Dams, most are owned by private business, citizens, state governments, and local governments. Many dam owners are unable undertake dam repairs and rehabilitation due to lack of funding. This situation often results in dangerously neglected and deteriorated dams [2].

Accumulation of new data on hydrological events and seismic activity during the past 50 or more years has shown that many flaws do exist in the design of a great number of old dams which call for upgrading measures to be taken making the dams safer. Moreover, great number of large dams, even recent ones, have not been built to allow for the erratic hydrological patterns that climate change is bringing. In this sense, all dams should now be considered relatively unsafe. More extreme storms and increasingly severe floods will have major implications on dam safety [3] and [4]. Dams are not built to serve forever. Today, more communities than ever are considering the option of removing or modifying old dams that have not only damaged local riverine ecosystems, but they pose increasing risks due to their physical conditions and the increased development in their downstream areas, which were not so crowded at the time when they were built. Having all these matters in mind, it is necessary to explore the question of aged dams' safety and their viability from technical and economic points of view and to prob the choice of "Remove or Repair" of dams while at the same time not failing to mention the increasing pressures of the growing Green Movements and Environmentalists to restore natural flow in dammed rivers and minimize the damage to the ecosystems brought about by dam construction.

## 2. Cost of keeping aging dams

Dam's owners require to allocate budgets continually to carry out routine maintenance, repairs, and upgrading of safety conditions, in addition to the normal operation costs. While some dams continue to serve their useful purposes, others have reached their planned economic and technical limits. Some dam owners may defer maintenance on the basis of high costs to the point where such dams pose threats to public safety, which may be true for some governments lacking enough funds and so reaching such critical situations. An example is the Inguri Dam in Georgia, which was built in 1975 during the Soviet Union era and represented at the time one of the world's most ambitious pieces of structural engineering. The importance of this dam is reflected by the facts that it is hydroelectric dam which impounds the Enguri River in Georgia and currently it is the world's second highest concrete arch dam with a height of 271.5 meters. It is located north of the town Jvari, and it is part of the Enguri hydroelectric power station which is partially located in Abkhazia. The dam is 650 meters long concrete double curvature arch dam has an estimated volume of 3,880,000 cubic meters of concrete poured into it, with a storage capacity of 1.1 billion cubic meters of water in its reservoir, refer to Figure 2 [5].

Maintenance of the dam and its power plant was neglected due to shortage of funds and the dam was in dilapidated conditions due to such negligence. Lack of maintenance works resulted in early aging signs within the dam and the power station. One of the power plant's five units was shut for over 15 years and the other four were not able to work at their full capacity. At the same time, the dam's structural stability and working conditions had deteriorated, with galleries inside the dam frequently flooding.

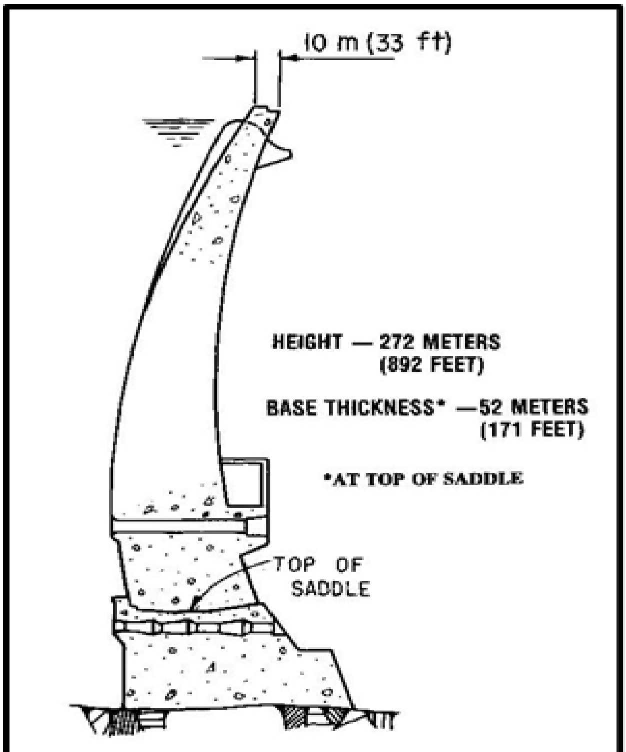


Figure 1-57.—Inguri Dam, cross section. P-801-D-79344.

**Figure 2: Inguri Dam, cross section.**

International experts identified the risks that would compromise the future of the dam back in 1994, and safety concerns were confirmed. In the years following the collapse of the USSR. Lack of maintenance of the dam resulted in a potentially dangerous situation. Close collaboration between the United Nations Educational Scientific and Cultural Organization (UNESCO) and the authorities in Georgia, which had raised concerns over the dam safety and called for technical and financial assistance, materialized in securing the required funds. The operations needed to remedy the situation were too costly for Georgia to bear alone. Remediation and renovation works where only possible after the involvement of the (UNESCO) which helped in enlisting the participation of the European Bank for Reconstruction and Development (EBRD) in 1998.These works covered the hydropower plant, civil engineering works on the structure as well as the upgrades of the generator units with financing totaling €58 million. The project was co-financed by the European Investment Bank (EIB) with €20 million. Moreover, the European Union provided grants for €9.4 million and additional €5 million were granted through its Neighborhood Investment Facility (NIF). In addition, grant funds from the Swiss government were used to finance engineering consultants at the design phase of the project [6] and [7]. More improvements to dam safety were needed in later years and the help of Russia was sought and agreement was reached between the two governments in 2003 [8].

Dams are expensive structures to fix. According to the US Association of State Dam Safety Officials, it would cost about $54 billion to rehabilitate all of the dams in the USA in need of repairs. The money would need to come from myriad sources, being, local, state, and federal coffers as well as thousands of private dam owners [9].

It is not surprising, therefore, to find even in rich countries like the United States that 95% of the of older dams lacked the maintenance needed to guarantee operational integrity and prevent failure. These aging dams represented a potential hazard to downstream communities which in most cases are unaware of the hazards posed by such dams [10].

The European countries with the largest installed hydropower capacity are Norway, France, Italy, Spain, Sweden, Switzerland, and Germany, maintaining or upgrading the existing infrastructure is an important focus throughout Europe. The emphasis in Western Europe is retrofitting hydropower plants with modern equipment and upgrading capacities of plants. In Eastern Europe, the focus is rehabilitating ageing plants that deteriorated during the Soviet era. Apart from the investment and production costs, the other principal cost element is operation and maintenance (O&M), including repairs and insurance, which can account from 1.5-5% of investment costs annually. Both the production and investment costs differ considerably depending on the head height of the plant [11].

Getting the required appropriations for dam upgrading is a long and complicated processes in USA as in all the other countries. For Federal Dam Rehabilitation; after dam safety deficiencies have been identified, rehabilitation activities should be undertaken. However, most federal agencies do not have funding available to immediately undertake all non-urgent repairs. Rather, they generally prioritize their rehabilitation needs, based on various forms of risk assessment, and schedule these activities in conjunction with the budget process.

At some agencies, dam rehabilitation needs must compete for funding with other construction projects.

As for the Rehabilitating of Nonfederal Dams, a task committee of the Association of dams in 2002 estimated that $36.2 billion was needed to rehabilitate these dams and that $10.1 billion was needed by 2014 for repairs to “the nation’s most critical dams. In the last update issued in 2019 it was estimated that $4.20 billion is needed to rehabilitate all federally owned dams with $2.93 billion of this attributed to the federally owned high hazard dams. Since 2004, an ASDSO task group has tracked dam rehabilitation cost for non- federal up to 2019 with potential sources of funding from dams as follows:

**Table 1: Funding needs of non-Federal dams in USA [12].**

| Year | Funding needs, non-federal dams ($ Billion) | Funding needs, non-federal High Hazard dams ($ Billion) | | |
|---|---|---|---|---|
| 2003 | 34 | 10,1 | | |
| | | Public | Private | Total |
| 2009 | 51,46 | 8,7 | 7,3 | 16,0 |
| 2012 | 53,69 | Public | Private | Total |
| | | 11,2 | 7,0 | 11,82 |
| 2016 | 60,7 | Total | 18.71 | |
| 2019 | 65,89 | 20,24 | | |

As dams age and intensive developments continues in the floodplains below them, the structural integrity of such infrastructure becomes more significant public safety issue. Moreover, in view of recent climate change impacts, dams' planned capacity to withstand floods has come under increased scrutiny. However, it is unclear to what extent there will be a widespread reevaluation of flood and earthquake ratings at high-hazard dams. Such an evaluation could raise additional policy questions. For example:

i. What criteria should be used to determine whether current risks are acceptable.

ii. If risks are not acceptable, should the dam be improved by introducing changes to its design or may be changes in the downstream be undertaken, or even the option of removing the dam may serve best.

iii. Who should pay?

Regardless of whether dams were constructed to withstand an earthquake or flood of "appropriate" magnitude, they may have age-related deficiencies that need to be corrected to maintain current levels of safety against such events. Therefore, it is likely that appropriations for safety inspections and rehabilitation activities will continue and may increase.

In summary, when it comes to dam integrity, aging is very important matter to be concerned about. In many aging dams around the world structural components, such as; waterways, filters, drainages, and hydro-mechanical equipment are degrading. The process is accelerated by deposition of salts, oxidation and corrosion by chemical runoff or abrasion and potential cavitation of these waterways. Moreover, very old dams were designed and constructed by outdated engineering practices and hydrological and earthquake seismic events data which make them more vulnerable to failure. For many very old dams, the benefits to the public of removing them outweigh the costs of continued operation. In light of aging infrastructures, it is appropriate to evaluate individual dams to determine whether their ongoing economic and social costs justifies the services they provide.

## 3. World views on decommissioning and removal of old dams

The opinion on world dams' future has been sharply split between those countries which have satisfied their needs of water and power and have no more suitable sites to build new dams, and the other countries which have still large potentials to be taped by new dams and such dams are vital for their future development. In the more advanced countries new investments are preferably put in wind energy or solar energy sectors and this competes with rehabilitation and upgrading of their old dams. less developed countries are over burdened by the costs of loans for building their dams and the increasing costs of upgrading these dams.

The construction of large dams reached its peak in the 1970s in Europe and North America. Today most activities in these regions are focused on the management of existing dams, including rehabilitation, renovation and optimizing the operation of dams for multiple functions. An estimated 1700 large dams have been under construction in other parts of the world in the years leading to the end of last century. Of this total, 40% are reportedly being built in India.

According to the report of the World Commission on Dams (WCD-2000), management and operation practices of dams must adapt continuously to changing circumstances over the project's life and must address outstanding social issues. And for this end comprehensive post-project monitoring and evaluation process and a system of longer-term periodic reviews of the performance, benefits and impacts for all existing large dams are necessary. Programs to restore, improve and optimize benefits from existing large dams should be identified and implemented. Options to rehabilitate, modernize, and upgrade equipment and facilities; optimize reservoir operations; and introduce non-structural measures to improve the efficiency of delivery and use of services have to be addressed [13].

The other issues facing dam owners in the world nowadays are the outstanding social impacts associated with existing old dams such as the increasing safety hazards of such dams to communities and/or the increasing deterioration of the environment and ecosystems caused by these dams. In many cases dams' owners had concluded operating agreements with the regulating authorities such that their licenses expire after certain periods. Relicensing conditions of these dams requires generally that major improvements be either made, or decommissioning must be faced. ICOLD in its review of the WCD report endorsed its findings regarding the questions related to the physical sustainability of large dams and their benefits which confirmed that:

i. Ensuring the safety of dams will require increasing attention and investment as dams age, maintenance costs rise and climate change possibly alters the hydrological regime used as a basis for the design of dam spillways.
ii. Sedimentation and the consequent long term loss of storage of old dams is a serious concern, and the effects will be particularly felt by basins with high geological or human induced erosion rates, dams in the lower reaches of rivers and dams with smaller storage volumes.

Experience in North America and in Europe shows that decommissioning of dams has enabled the restoration of fisheries and riverine ecological processes. However, dam removals without proper studies and mitigation actions cause public concerns and environmental problems. These include negative impacts on downstream aquatic life due to a sudden flush of the sediments accumulated in the reservoir. Where there has been industrial or mining activity upstream, these sediments may be contaminated with toxic substances.

While decommissioning efforts in the United States and France have received public support thus far, there may be local opposition where changes in the flow and water levels affect services previously provided by the dam, or where development has taken place around the reservoir and downstream. There is comparatively little experience with the removal of larger dams. The bigger the dam, the more problems decommissioning or removal are likely to face, and the more expensive they are likely to be. More studies are needed to address the costs, benefits, and impacts of decommissioning as dams age and choices must be made between refurbishing and decommissioning.

## 4. Aging Dams and Ecosystem Restoration

The question of ecosystem restoration has been undertaken in late years in a range of countries where evolving national legislation has required higher standards of environmental performance. In the United States and France, dams have been decommissioned to restore key environmental values, often related to migratory fish (salmon), and often as a condition of project relicensing when there has been serious safety hazards. Substantial ecological degradation can be attributed to the increasing number of dams built on rivers and often on the same river creating obstacles to fish migration and have drastically altered river flow regimes. Moreover, many dams have been in place for 50 years or more, and increasing number of them are now approaching or exceeding their originally intended design life and will require very large investments to reach acceptable levels of safety and function.

Decommissioning of dams and restoration of ecosystems involve costly works, therefore, have often been limited in scale, and its effectiveness is frequently unclear. Nevertheless, there is growing demand, political will, and funding for restoring degraded ecosystems. A total of 467 dams have been removed to date in the United States, 28 of these are large dams higher than 15 meters. Reasons for removal have included safety concerns, the restoration of riverine fisheries, financial considerations, or removal of unauthorized structures.

One example of a removal cases is the Grangeville dam on Clearwater Creek River, Idaho. Grangeville (Harpster) Dam was built on the South Fork of this river in 1910; it housed a 10MW power plant. The removal was motivated by excessive sedimentation in the reservoir and blockage of migratory fish following the collapse of the fish pass in 1949. The dam was removed in 1963, and the river washed out the accumulated sediment within six months with no recorded downstream effects. The demolishing of this dam restored the river's populations of Chinook salmon and steelhead trout and restored access for fish runs to 67km of main stem river and over 160km of tributary habitat in the upper reaches of the Clearwater River. It also allowed members of the Nez Perce Indian tribe to regain a traditional fishery long denied them despite the provisions of the 1855 treaty with the United States. Today, the entire South Fork and its headwater tributaries are free flowing and unobstructed by dams or major diversions [14] and [15]. The restoration of ecosystem involving removal of any dam is not an easy task and it can be complicated for the following reasons:

i. Ecosystem impacts of decommissioning can be complex and site-specific. One major issue in dam decommissioning is what to do with possibly polluted sediment accumulated behind the dam. The fate of this sediment when the dam is removed is frequently a major obstacle to restoration.
ii. Current large dam designs are often not sufficiently flexible to allow for changed operating regimes to meet environmental (or other) goals. Global experience shows that these long-lived structures may be called on to operate differently in the future than in the past as society's needs and values evolve and as other dams are added in the catchment area.
iii. In some cases, the dam design is completed before the environmental flow needs are determined, and cannot accommodate water releases of the required quantity and quality. Five dams on the Colorado River have now been retroactively fitted with variable level offtakes to draw off surface water, increase the temperature of the downstream river, and satisfy the needs of native fish.
iv. Decommissioning can be costly when subjected to cos/ benefit analysis, but sometimes enough justifications are presented to show lucrative advantage. This was made clear in one specific case by an editorial report titled "Dollars, Sense & Salmon" which addressed such a case in 1997. The document was researched by Statesman reporter Rocky Barker and written by editorial writer Susan Whaley. The team dug deep into the numbers and invited experts to discuss the benefits and shortcomings of the four lower Snake River dams and an argument for breaching these dams was strongly advocated. The Statesman cited a net annual benefit of $183 million should the lower Snake River dams be removed.

In 2016, a full 19 years after the Statesman published the report, a historic opportunity came when in May a federal judge in Portland ordered the government to write a new environmental study that weighs a range of alternatives, including lower Snake River dam's removal [16].

## 5. Removal of aging dams

A decision of removing an old dam may be based on two major considerations, which are,

i. Public Safety concerns.
ii. Economics.

If the risks involved in keeping the dam are too great to the downstream communities in case of failure, then it may be best to remove it. Sometimes, the problem can be solved by partial removal of the dam rather than by full removal. This may be done by lowering the maximum operation water level of the reservoir in order to permanently reduce the loads on the dam and the potential downstream consequences in the event of dam failure. In such cases the extra costs of total removal can be avoided. A controlled breach of an embankment dam by means of a notch requires engineering analysis to assure proper sizing, shaping, and armoring to prevent instable conditions and future flooding. Lowering the maximum operation water level may also be accomplished by non-structural methods, such as permanently opening (or removing) gates from the spillway and/or outlet works. Full or partial removal of any type of dam requires the consideration of wide variety of technical, environmental, social, political, and economic issues [17] and [18].

The question of costs involved may be looked at by a cost-benefit approach. The benefits which can still be derived by keeping the dam such as flood control, agriculture, power generation, and recreation will have to be compared with the economic costs and social costs that have to be borne by both owners and society.

The long-term maintenance costs and costs of removal added up together make up the owners share in this evaluation. Social costs may be evaluated by assessing the opportunity cost of hindering the free migration of fish and other species, degraded water quality and negative impacts on the ecosystems and free flowing rivers in addition to cultural values.

In the United States agencies like the U.S. Army Corps of Engineers (USACE) and the Federal Energy Regulatory Commission (FERC) have established processes to evaluate benefits and costs as a part of various agency programs.

Licensing decisions at (FERC), for example, consider multiple management scenarios when evaluating whether to issue new or renew existing dam license. The management scenarios may require dam owners to allow greater water flow through the dam, install infrastructure to allow migratory fish to pass upstream, or make safety upgrades. Often the options include a dam removal scenario. These evaluations also include impact assessments that evaluate the benefits and costs to the many parties affected by each management alternative.

The USACE undertakes similar analyses when evaluating its dams and other river restoration programs. Some dam owners have found that removing a dam is more appropriate than leaving it in place after comparing benefits and costs of addressing the needs of concerned parties and meeting state and federal regulatory requirements. Since 1912, more than 1,300 dams have been removed across the U.S., and 62 dams were removed in 2015 [19].

It can be said however at least for the present and for the foreseen future of the economic environment, that the rising costs of operating and repairing dams, and the improved awareness of the economic and social benefits of removing them, has shifted the balance sheet for some dams towards their removal.
One report, published in 2016 by "Head Water Economics Group", lists many dam removals in USA. The case studies, benefits of dam removal, and alternatives considered are listed as shown in Table 2 [20]. The "Headwater Economic Group" presents itself as an independent, nonprofit research group whose mission is to improve community development and land management decisions in the west of the USA.

**Table 2: Case studies, benefits of dam removal, and alternatives considered.**

| Location | Estimated Cost of Removal $ (2016) | Estimated Benefits of Removal $ (2016) | Alternatives to Dam Removal |
|---|---|---|---|
| Whittenton Pond Dam, Mill River, Massachusetts | $447,000: 99 percent paid by state and federal partners, $1.5 million for avoided emergency response | $1,5 million for avoided emergency response.<br>Increased numbers of two vulnerable species: American eel and river herring.<br>Property values projected to increase due to lower flooding risk. | Rebuilding was necessary due to disrepair and safety hazard, cost estimated at $1.9 million |
| Elwha and Glines Canyon Dam, Elwha River, Washington | $324.7 million | $5,3 million annually from increased commercial fishing.<br>Cultural and public safety benefits to the Lower Elwha Klallam Tribe, downstream from the dams.<br>$33 million in personal income and 760 new jobs associated with dam removal<br>$43,8 million and 446 new jobs from 500,000 more visitor days annually.<br>$5,3 billion worth of improved wellbeing for the American public. | Not available |

| | | | |
|---|---|---|---|
| Edwards Dam, Kennebec River, Maine | $10,9 million | $2.5-$38.2 million for improved recreational fishing quality<br>$397,000-$2.7 million for improved river recreation quality.<br>Property values closest to the former dam site increased<br>Electricity produced by Edwards Dam cost 4-5 times the market rate.<br>Water quality prior to dam removal did not meet minimum standards; afterward it could support all native fish<br>Alewife population increased 60-fold, and they now are used commercially for bait.<br>Quality of life in Augusta has improved due to new connection to the river. | $14.9 million to install fish passages and conduct environmental mediation |
| Condit Dam, White Salmon River, Washington | $24,8 million | Cultural benefits for the Yakama Nation from returned salmon and lamprey, including sustenance fishing.<br>Expanded spawning grounds for recreationally and commercially important fish: 12 miles for salmon and 33 miles for steelhead.<br>Increased populations of five fish species listed under the Endangered Species Act.<br>30,000 additional whitewater boaters annually. | $52.4 million for fish passages, plus $3.9 million annually in higher electricity costs |
| Great Works and Veazie Dams, Penobscot River, Maine | $65 million | 76 jobs and $3,6 million in economic impact from dam removal.<br>Access re-opened for 1,000 miles of habitat for 11 depleted historic fisheries.<br>Cultural and sustenance fishing benefits for the Penobscot Indian Nation.<br>New area spending by whitewater boaters, including several events. | Fish passage facilities were insufficient to restore fisheries |
| Small Dams: Hyde Pond Dam, Whiteford Brook, Connecticut | $1,1 million | Avoided public safety hazards from catastrophic failure and upstream flooding.<br>Four miles of stream habitat opened to fish species including American eel, a vulnerable species. | Dam would have to be rebuilt to meet safety standards. Dam owner would have been responsible for full cost of rebuilding dam |

| | | | |
|---|---|---|---|
| Small Dams: Bartlett Pond Dam, Wekepeke Brook, Massachusetts | $325,000 | Avoided public safety and infrastructure hazards from catastrophic failure and upstream flooding.<br>Eighteen miles of stream habitat opened for brook trout and other species. | $671,000 for repairs |
| White Rock Dam, Pawcatuck River, Connecticut and Rhode Island | $800,000 | Avoided public safety and infrastructure hazards from catastrophic failure and upstream flooding.<br>Twenty-five miles of river habitat opened to fish species. | Dam would have to be rebuilt to meet safety standards. Dam owner would have been responsible for full cost of rebuilding dam |

One very important issue which has to be studied carefully if dam's decommissioning is considered is siltation. This is often a critical issue when the reservoir accumulated sediment volume is very much greater than the mean annual sediment load. In such case sediment-related impacts following dam removal can occur in the reservoir itself by activating fast rate erosion of the catchment and in the river channel upstream, and downstream from the project site by affecting installations and clogging water intakes and causing high turbidity depending on the local conditions and the removal methods and rates, the degree of impact can range from negligible to significant. For example, removing a small diversion dam that had trapped only a small amount of sediment would not have much impact on the downstream river channel. Furthermore, if the upper portion of a dam is removed in such a way that very little of the existing reservoir sediment are released downstream, the impacts to the downstream river channel would be related only to the future passage of sediment from the upstream river channel through the remaining reservoir. However, if dam removal results in a large quantity of sediment being released downstream, then the impacts to both the upstream and downstream channels could be significant. Case by case studies must be made, for investigating such things as erosion of the river channel both upstream and downstream of the removed dam site, water quality with respect to turbidity, and impacts on both aquatic plant ecosystem and biodiversity [21].

# 6. Dam removal of old dams: case studies

Three cases are selected in the following to illustrate different dam decommissioning cases from three different countries, namely; France; Germany; and USA.

### 6.1 The Vezins and La Roche Qui Boit hydroelectric dams (France)

These two concrete dams were located in the (Normandy, France), had been operating since the 1920s and 1930s and they were showing signs of aging presenting safety and profitability problems and loss of storage by sedimentation.

As early as 2005 the owner of the dams had been positioning these dams for removal in order to restore the Sélune fish migratory axis. And in 2009, based on a report by Électricité de France (EDF) in 2007, and the lack of technical possibilities to rearrange the dams to ensure fish and sediment continuity, the State decided not to renew the licenses of the two dams and to begin the dismantling process. The removal of the Vezins and La-Roche-qui-Boit dams was definitively decided in 2017.

Since 2009 and in order to give an operational follow-up to this decision, the Minister of State and the Secretary of State for Ecology have instructed the Prefect of the Department (la Manche) to launch the operations required for the successful dismantling of the two dams and re-naturalization of the river.

Considering the clear desire to implement this project in terms of the environment and sustainable development, the State has launched numerous studies aimed at detailing technical choices. By defining the parameters such as re-naturalization, sediment management, waste management associated with decommissioning, fish management, etc. with the goal of achieving a zero state of the river, essential elements on which to assess the biological benefits, the works will take into account the effect of the removal on local activities and especially the impact on tourism on the surrounding villages. The state was very concerned about the potential risks of the operation and has established:

- A flood risk study to analyze the current effect of the two dams on downstream flood flows.
- A study on the state of polluted sediments present on the site, including A characterization of the sediments and a site management plan.
- A study of the release capacity of contaminants present in the sediments of the reservoir.
- From 2012 a scientific program was conducted to monitor the dam removal operation. It was organized around four interrelated themes: Landscapes, Inhabitants, Uses, Landscape, and Agriculture, Fluvial Dynamics and Aquatic Biocenosis.

As part of the socio-geographical component of this program, a team of geographers and sociologists worked on the transformations affecting the landscapes but also the uses and representations of the valley. This work proposes an inventory of fixtures, a history and a follow-up of the landscapes and uses of the valley of Sélune [22].

Figures 3 and 4, are photos of the Vezins and La Roche Qui Boit dams before removal [23]. Figures 5 and 6 show Vezins dam at various stages of demolition [23], [24].

The removal of both dams was part of an ambitious program, unprecedented in Europe, to restore ecological continuity between the terrestrial and marine habitats connected by river basins [25].

**Figure 3: Vezins dam before removal [23].**

**Figure 4: La Roche Qui Boit before removal [23].**

**Figure 5: Vezins dam at an advanced stage of demolition [23].**

**Figure 6: Vezins dam at an early stage of demolition [24].**

Other dam removal cases are also mentioned in the literature. Such cases are the case of Saint-Etienne du Vigan Dam (built in 1895, dismantled in 1998) and the Poutès Dam built in 1941. Both dams were located on The Allier River, main tributary of the river Loire in France [26].

### 6.2 The Krebsbach Dam, Thuringia (Germany)

The Krebsbach Dam was built in 1962 in East Germany on a small stream which served industrial water supply for the mining of uranium in the area. The 18.5m dam was high rock fill dam with an inner core of clay. Its length was 186 m, its crest width was 5.1m and it retained 320,000m$^3$ of water. In 1985, after mining had stopped the dam was abandoned. By the 1990's, stability problems had worsened as the dam was suffering from structural damage. New laws dealing with security and safety risks associated with flooding forced the owners into action. Comprehensive restoration and continuing maintenance of the dam would have been expensive in order to meet the new regulations which led the owners to decide in 1998 to demolish the dam completely. The aim was to remove the dam and all the technical equipment associated with uranium processing and to restore the continuity of water flow in the stream. But before removal could start, planning approval had to be sought in line with Germany's Water Resources Act. By 2001, planning for removal begun. The planning procedure had to break new ground as there was no precedent in Germany for the demolition of a large dam. An environmental impact study was carried out, a landscape conservation plan was written and stakeholders, including the public and those concerned about effects on the environment, were asked for their opinions. The planners received fifty-three responses which were discussed in detail at a public meeting in May 2003. The main concern of local residents was that there would be a greater risk of flooding to the downstream stretches after the dam had gone.

The environmental impact assessment and landscape conservation plan were approved in 2005 and preparations for demolition started in 2007. Although sedimentation was relatively low and only averaged 35cm in the reservoir but sediment depth was as large as 2.5m close to the dam. A sedimentation pool was created directly downstream of the dam structure to minimize the transport of sediment by related discharge into the stream's lower reaches during demolition of the dam. All fish, amphibians and shellfish were relocated from the whole length of the stream (as it was assumed that water quality would deteriorate) and then the reservoir was drained, and the dam was completely demolished , refer to Figure 7 [27], [28].

**Figure 7: Dam removal in progress in 2007.**

The actual removal process was fully described with lessons learned after eleven years in the International Seminar on Dams Removals that was held by Karlstad University (KAU) in Sweden on 24-26 September 2018 [29].

### 6.3 Elwaha and Glines Canyon Dams, Washington (USA)

Removal of the Elwha and Glines Canyon Dams from the Elwha River in Washington in 2012 was the largest dam removal and river restoration project in the United States to date. Before these two dams were built, the river supported ten runs of salmon and trout, including all five Pacific salmon species. Removing these two dams was the only way to restore these fish runs. This project was a unique opportunity for fishery restoration because the upper section of its watershed lies entirely in Olympic National Park, increasing the chances of successful recovery. The locations of the two dams are shown in the map of Figure 8.

Completed in 1913, the Elwha Dam was located five miles upstream from where the Elwha River empties into the Strait of Juan de Fuca. It was 105 feet high and had a 14.8MW generation capacity. The Glines Canyon Dam was completed in 1927 and was 13 miles from the Strait of Juan de Fuca. It was 210 feet high and had 13.3MW generation capacity. Both dams were used to generate hydroelectric power for nearby paper and lumber mills. Both dams failed safety inspection in 1978 which was followed by modelling study of flood hazard should the dams fail that highlighted potential harm to the communities downstream.


**Figure 8: Location of Elwaha and Glines canyon dams on Elwha River [30].**

An act of the Congress in 1992 revoked renewal license of the dams which was issued by FERC and called for restoration of the river. This act stipulated the following:

i. Removal of FERC's authority to license the Elwha Project.
ii. Required federal studies to research alternatives for full restoration of the Elwha River ecosystem and migratory fisheries.
iii. Authorized the Secretary of Interior to purchase and acquire both the Elwha and Glines Canyon Dams for a fixed price and then implement necessary actions to meet full restoration objectives. Thereafter the two dams were purchased from the owner in 2000 for $29.5 million.

Two environmental impact statements (EIS) concluded that neither leaving the dams intact nor installing fish passages would be sufficient to restore the fisheries. Moreover, they both posed Safety risk to the public [31]. As a result, the Elwha and

Glines Canyon Dams were removed in 2012. The total cost of purchasing and removing the dams and hydropower facilities, and conducting river restoration activities was $324.7 million. Costs and benefits of the restoration of the project are given in Table 2 shown already. Photos showing the Elwaha Dam before and after removal are presented in Figures 9 and 10. The stages of removal operation can also be viewed in an interesting video film posted on the following link; https://youtu.be/m96VcCF4Ess

**Figure 9: View of Elwha Dam before removal.**

**Figure 10: View of Elwha Dam after removal.**

## 7. Summary points and conclusions

From the proceedings it is clear that aging dams present serious problems of safety risks and negative impacts on the environments of rivers, in addition to diminishing benefits and soaring costs of repair and upgrading. As conclusions the following may be drawn:

1. Old dams of 50 years of age or more may not meet today's requirements of the accumulated hydrological and seismic activity records collected during these past years, nor they satisfy current design criteria of design which have evolved after the construction of such dams. Moreover, the current climate change impacts on the hydrological cycle have increased the vulnerability of these dams.
2. Case studies have shown that cost of upgrading and proper maintenance of old dams, increases with age against a decreasing benefits. Such decreasing may result from shrinkage of storage due sedimentation of reservoir or restricting operation water levels to limit the hydrologic impacts of un-reckoned floods or reducing the load on the dam itself due to stability problems.
3. Budgeting limitations can exasperate safety problems of old dams which normally need more attention and maintenance and suffer from diminishing returns at the same time. Safety issues therefore are leading issue in the decommissioning of old dams or remove them altogether.
4. The development of environmental protection legislation in many advanced countries has given the question of ecosystem restoration by removing old

dams more prominence. Higher standards of environmental performance required from old dams has led to many decisions for decommissioning of such dams. Key environmental values on which decommissioning or removal of old dams are based are often related to migratory fish (salmon) and ecological degradation of the rivers due to increasing number of dams built on these rivers which drastically alter river flow regimes.

5. Removing an old dam is not an easy task. It requires careful pre-planning, engineering and environmental studies, and design work. Without this, negative consequences of various types and magnitudes can happen. Uncontrolled release of water leads to increased flood hazards, washing large loads of the accumulated sediment can clog and overload water supply schemes, degrades water quality by higher turbidity. In the long run scouring of the downstream reach may threaten the foundations of bridges, jetties and other structures built on the river such as bridges and jetties by eroding them requiring repair works and additional costs. Moreover, scouring of the upper reaches of the river channel bed is another possible outcome which increases erosion of the catchment and impacts the stability of aquatic ecosystem and biodiversity there.
6. Thousands of small dams and few moderate size dams have been removed already mostly in USA and some European countries. There is comparatively little experience with the removal of very larger dams. The bigger the dam, the more problems decommissioning or removal are likely to face, and the more expensive they are likely to be. More studies are needed to address the costs, benefits, and impacts of decommissioning as such dams age and choices must be made between refurbishing and decommissioning.
7. Preparations for old dams' removal can take very long time to complete the necessary studies and to get the required licenses from the legislative and administrative authorities and finally getting the required allocations. Each case has to be the subject of benefit- cost analysis. Admitting at the same time that obtaining values of benefits and social costs related to environmental questions is not an easy task and may be biased due to community and NGO pressures. Keeping old dams, however, must be scrutinized carefully taking into consideration costs of upgrading and maintenance with the benefits still available, but keeping in mind that safety and reduction of risks on downstream communities must come first.

## References


[1] Association of State Dam Safety Officials (ASDSO) (2019). More Than $70 Billion Needed to Rehabilitate Our Nation's Dams. Association of State Dam Safety Officials. Posted April 30th. Retrieved March 12th, 2020. https://damsafety.org/article/awareness/more-70-billion-needed-rehabilitate-our-nation%E2%80%99s-dams

[2] Association of State Dam Safety Officials (ASDSO) (2002). The Cost of Rehabilitation of our Nations Dams: A methodology, Estimates & Proposed Funding Mechanism. Page 7. First Published in 2002 and last updated in 2019. https://damsafety-prod.s3.amazonaws.com/s3fs-public/files/Cost%20of%20Rehab%20Report-2019%20Update.pdf

[3] International Rivers Blog (2020). Wrong Climate for Damming Rivers. Retrieved March 12th. https://www.internationalrivers.org/campaigns/wrong-climate-for-damming-rivers

[4] International River blog (2020). Wrong Climate for Big Dams: Destroying Rivers Will Worsen Climate Crisis. Retrieved March 12th. https://www.internationalrivers.org/sites/default/files/attached-files/intlrivers_wrongclimate_4.pdf

[5] Jansen, R. (1983). Dams and Public Safety. USBR Water Resources Publication, pp.79 and 86. https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/AZ1130.pdf

[6] Sconnoscituo, L. (2013). EBRD helps restore Georgia's Enguri Dam. Published on 8th July. https://www.ebrd.com/news/2013/ebrd-helps-restore-georgias-enguri-dam.html

[7] Global Sustainable Electricity Partnership (2020). Technical Inspection of the Enguri Dam in Georgia. Website page retrieved on 19th March. https://www.globalelectricity.org/capacity-building-activities/technical-inspection-enguri-dam-georgia/

[8] Water Power and Dam Construction (2003). Georgia and Russia to cooperate on hydro. Published on 1st April. Retrieved on 19th May 2020. https://www.waterpowermagazine.com/news/newsgeorgia-and-russia-to-cooperate-on-hydro

[9] Popovac, J. (2015). Aging and Underfunded American Dams Safety Problem; In 4 Charts. National Radio Program Organization, 11th October 2015. https://www.npr.org/2015/10/11/447181629/aging-and-underfunded-americas-dam-safety-problem-in-4-charts?t=1584541908344

[10] Lane, N. (2008). Aging Infrastructure: Dam Safety. Report of Natural Resources Policy Resources; Science and Industry Division, 25th March. Citations from Pages: CRC-1, CRS-11, CRS-12, CRS-15 and CRS-16. https://fas.org/sgp/crs/homesec/RL33108.pdf

[11] EU commission (2012). Hydropower. Europa. Published in 2012. Retrieved on 19th May 2020. https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Hydropower.pdf

[12] Association of State Dam Safety Officials (ASDSO) (2020). Dam Rehabilitation Funding. Retrieved on 19th May. https://damsafety.org/dam-owners/dam-rehabilitation-funding

[13] World Commission on Dams (2000). Dams and Development-A new Framework for The Decision Making. November, Earthscan Publications Ltd, London and Sterling, VA. https://ia800301.us.archive.org/3/items/DamsAndDevelopmentANewFrameworkForDecision-making/wcdreport.pdf

[14] Wikipedia (2020). South Fork Clearwater River. Retrieved on 20th May. https://en.wikipedia.org/wiki/South_Fork_Clearwater_River

[15] Northwest Power and Conservation Council (2020). Extinction. Retrieved on 20th May. https://www.nwcouncil.org/reports/columbia-river-history/Extinction

[16] Merrill, D. (2016) Today in Idaho River History: Idaho Statesman Launches an Argument for Breaching four dams on the Lower snake River. July 20th. Idaho Rivers United. https://www.idahorivers.org/newsroom/2016/7/27/today-in-idaho-river-history-idaho-statesman-launches-three-part-editorial-proposing-to-breach-lower-snake-dams

[17] Merchant, S. (2008). Aging Infrastructure and Ecosystem Restoration. Originally written by (Doyle, et.al) in Science Magazine, Vol. 319, January 18. https://restorationsystems.com/press-rs-in-the-news/aging-infrastructure-and-ecosystem-restoration/

[18] ICF Consulting and Woodlot Alternatives (2005). A Summary of Existing Research on Low-Head Dam Removal Projects. Report prepared for the American Association of State Highway and Transportation Officials (AASHTO). http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/25-25(14)_FR.pdf

[19] Kober, A., Thomas-Blate, T. (2017). 72 Dams Removed in 2016, Improving Safety for Rivers. American Rivers.org, 16th February. https://www.americanrivers.org/conservation-resource/72-dams-removed-2016/

[20] Lawson, M. (2016). Case Studies on the Fiscal, Economic, Social, and Environmental Benefits of Dam Removal. Head Water Economics, Research Paper. https://headwaterseconomics.org/wp-content/uploads/Report-Dam-Removal-Case-Studies.pdf

[21] US Society on Dams (USSD) (2015). Guidelines for Dam Decommissioning Projects. pp.60-82, July. https://www.ussdams.org/wp-content/uploads/2016/05/15Decommissioning.pdf

[22] Hoving, I. (2019). Vezins Dam, Normandy, France. Dam Removal Europe, June 1st. Web Page retrieved on 21st March 2020. https://damremoval.eu/portfolio/vezins-and-la-roche-qui-boit-dams/

[23] European Rivers Network (2020). Large of Two Large Dams (Vezins et Roche Qui Boit) to Free the Sélune River. Retrieved on 20th May. https://www.ern.org/en/selune-libre/

[24] Breyer, M. (2019). Biggest dam removal in European history has begun with the Vezins dam. TreeHugger web site, June 17th. https://www.treehugger.com/environmental-policy/biggest-dam-removal-european-history-begins-vezins-dam.html

[25] INRA (2018). Ecological restoration of the Sélune river- The Program. Web Page retrieved on 21st March 2020 http://selune-river-restoration.inra.fr/

[26] Xin, G. (2012). French Dam Removal Opens Way for Atlantic Salmon. Published on International Rivers on Monday 5th 2012 from World Rivers Review – March https://www.internationalrivers.org/resources/french-dam-removal-opens-way-for-atlantic-salmon-1632

[27] Dam Removal Europe (2020). Krebsbach Dam, Thuringia, Germany. Web page retrieved on 21st March. https://damremoval.eu/portfolio/krebsbach-dam-thuringia-germany/

[28] Stracturae (2020). Krebsbach Dam Data. International Database and Gallery of Structures. Web page retrieved on 21st March. https://structurae.net/en/structures/krebsbach-dam

[29] Iboga, E. (2018). Removal of Krebsbach Dam-Lessons Learned after 11 years. Bauhaus University of Weimar (Germany). Presented in International Seminar on Dams Removals held by Karlstad University (KAU), Sweden , on 24-26 September. https://damremoval.eu/wp-content/uploads/2018/10/Day2-0930-Ayboga_Krebsbach.pdf

[30] Lohan, T. (2018). The Elwha's Living Laboratory: Lessons from the World's Largest Dam-removal Project. The Revelator-Wild Life October 1st, 2018 retrieved on 21st March 2020. https://therevelator.org/elwha-dam-removal/

[31] Lawson, M. (2016). Case Studies on the Fiscal, Economic, Social, and Environmental Benefits of Dam Removal October 2016. Head Water Economics, Research Paper PP14-16. https://headwaterseconomics.org/wp-content/uploads/Report-Dam-Removal-Case-Studies.pdf.