ICOLD Dam Decommissioning Guidelines

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1. FOREWORD

The topic of dam decommissioning or dam removal has come up with increasing frequency in the past decade. The reason for considering dam removal may be dam safety concerns, high repair costs, high operation and maintenance costs, or impacts on fish passage and water quality. However, the decision to remove a dam should be based on a careful evaluation of alternatives to address the specific problem at each dam.

The ICOLD Committee on Dam Decommissioning was established in 2005 to develop information that can be used by ICOLD members to respond to inquiries on dam decommissioning and to provide a forum for exchanging information. This document is not intended to be a design manual but to provide guidance on the decision making process, consultation and regulatory approvals, design and construction issues, sediment management and performance monitoring.

The primary authors of these guidelines were:

- Stephen Newman – Australia;
- Michel Dolbec – Canada;
- Nobuo Ishikawa Japan;
- Wayne Edwards – USA.

We are saddened by the untimely death of Mr. Ishikawa in 2011.

I want to thank the national committees that responded to a questionnaire regarding dam decommissioning activities in their country.

Wayne D. Edwards
Chairman, Committee on Dam Decommissioning

2. INTRODUCTION

2.1 Objective of Guidelines

The primary objective of these Dam Decommissioning Guidelines is to provide dam owners, dam engineers, and other professionals with the information necessary to guide decision-making when considering dam decommissioning as a project alternative. They are not intended to be used as a design manual but as a guideline to highlight the issues to be considered. These guidelines apply only to water retaining structures and not tailings dams. Additional details on dam decommissioning and dam removal can be found in guidelines developed by the United States Society on Dams (USSD) (Reference 1) and the Department of Sustainability and Environment (State government of Victoria, Australia) (Reference 2).

2.2 Background

The decision to remove a dam should be based on the careful evaluation of a wide range of alternatives to resolve specific issues at an existing dam – i.e., dam safety concerns, high repair costs, high operation and maintenance costs, impacts on fish passage and water quality or the dam is no longer required and the owner wishes to minimize operations and maintenance costs and their potential liability. In some cases, the problem can be solved by a partial breach of the dam rather than a full breach of the dam or full removal of project facilities. For example, a dam safety concern may be mitigated by partially breaching the dam and lowering the normal maximum reservoir level in order to permanently reduce the loads on the dam, and reduce potential downstream consequences in the event of dam failure.

Lowering the height of the dam and reducing the maximum storage capacity may also remove the dam from the jurisdiction of dam safety regulations. Non-structural methods, such as permanently opening or removing gates from the spillway or outlet works, can also be used to lower the normal maximum reservoir level. Full and partial removal of any type of dam requires careful consideration of a variety of technical, environmental, social, and political issues.

2.3 Definitions of Dams and Dam Decommissioning

Any structure that diverts or stores water can be considered a dam or weir. However, the legal definition of a dam will vary depending on the location and regulatory jurisdiction. For example, in the United States, a dam is typically defined by state dam safety regulations as a structure 6 feet (1.83 metres) or more in height with a storage capacity of more than 50 acre-feet (61,674 cubic metres), or 25 feet (7.62 metres) or more in height with a storage capacity of more than 15 acre-feet (18,502 cubic metres). **Figure 2-1** presents the jurisdictional height and storage for dams in California. However, the state of New Hampshire defines a dam as a structure more than 4 feet (1.22 metres) high or storing 2 acre-feet (2,467 cubic metres).

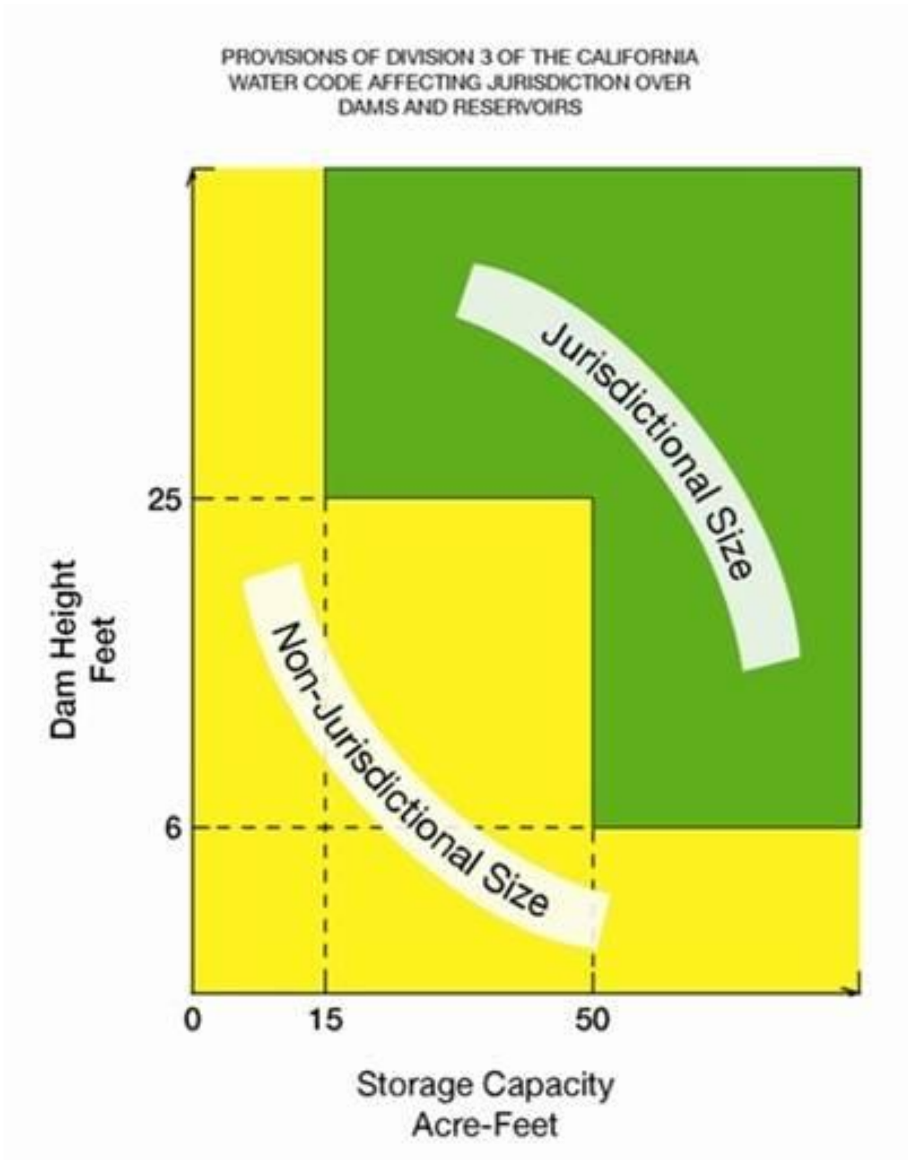

Figure 2-1 Jurisdictional Height and Storage for Dams in California, USA

The jurisdictional definition of a dam also varies widely from country to country. Examples from other countries follow.

In Australia the relevant State Authorities generally reference the Australian National Committee on Large Dams (ANCOLD) guidelines in matters pertaining to the management of dams. ANCOLD defines a dam as “An artificial barrier, together with appurtenant works, constructed for storage, control or diversion of water, other liquids, silt, debris or other liquid borne material”.

Under ANCOLD guidelines, dams are categorized based on the consequence of dam failure. Consequences considered include maximum potential loss of life expressed as Population at Risk, damage and loss expressed in terms of cost of damage to property, commerce and infrastructure, the effects on the owners business such as loss of credibility, loss of financial viability and potential impacts:

- Social and economic disruption;
- Environmental degradation.

The resultant hazard categories from Extreme to Low provide a basis for identifying dam management requirements. On the basis of the hazard category the ANCOLD guidelines enable users to identify and prioritize surveillance (monitoring), safety reviews and contingency planning.

In Canada, a dam is defined as a barrier constructed to enable the retention of water, water containing any other substance, fluid waste or fluid tailings, providing that such barrier could impound 30,000 cubic metres or more and is 2.5 metres or more in height. However, the regulations only apply to three provinces: British Colombia, Québec, and Alberta. The British Colombia regulations also apply to all of the following:

(a) a dam 1 metre or more in height that is capable of impounding a volume of water greater than 1 000 000 cubic metres;

(b) a dam 2.5 metres or more in height that is capable of impounding a volume of water greater than 30 000 cubic metres;

(c) a dam 7.5 metres or more in height;

(d) a dam that does not meet the criteria under paragraph (a), (b) or (c) but has a downstream consequence classification under Schedule 1 of low, high or very high

In the Québec regulations, the following dams are considered to be high-capacity dams

(1) dams 1 metre or more in height having an impounding capacity greater than 1,000,000 cubic metres ;

(2) dams 2.5 metres or more in height having an impounding capacity greater than 30,000 cubic metres ;

(3) dams 7.5 metres or more in height, regardless of impounding capacity ;

(4) regardless of their height, retaining works and works appurtenant to a dam referred to in paragraph 1, 2 or 3, and works intended to retain all or part of the water stored by such a dam.

Other definitions of a jurisdictional dam are:

- Japan – Greater than or equal to 15 metres high;
- Spain – 5 metres high with any storage;
- Russia – greater than 15 metres high and reservoir storage greater than 0.5 Million cubic metres.

Dam decommissioning, or dam removal, as described in these guidelines, can range from a partial breach of the dam to full removal of the dam and appurtenant facilities. For a partial breach, the dam height and storage capacity may be reduced to the point that the structure no longer meets the statutory or regulatory definition of a dam and no longer presents a significant downstream hazard.

2.4 Key Issues

The decision to decommission a dam should be based on a careful evaluation of a wide range of potential structural and non-structural alternatives to address specific issues at an existing dam. These alternatives will typically include rehabilitation, replacement, removal, and reservoir re-operation alternatives. The primary factors to evaluate when considering decommissioning depend upon the type of dam ownership (whether government, public or private) and regulatory requirements but may include:

- Dam Safety Requirements – the dam does not meet current safety standards for floods, earthquakes, or normal operating conditions and requires expensive major modifications;
- Economic Factors - the dam is no longer cost effective due to obsolescence, high repair costs and high operation and maintenance costs. The cost to meet current dam safety standards outweighs the benefits provided by the dam;
- Fish Passage Requirements (for migration of protected species) – cost of installing fish passage facilities to meet regulatory requirements may make the project uneconomic;
- River Restoration Requirements (for improved water quality, aquatic habitat, and sediment transport);
- Funding Availability and Sources (for project financing);
- Potential Public Benefits (fisheries, recreation, navigation, aesthetics);
- Potential Owner Benefits (risk and liability reduction, public relations);
- Potential Environmental Impacts and Loss of Project Benefits

  - impact of releasing impounded sediments once dam is removed;

  - loss of flood control;

  - loss of lake front property;

  - impact on property values;

- replacement of water supply and/or power generation.

2.5 Status of Dam Decommissioning

Accurate statistics for the number of dams removed worldwide are not available.

In response to a survey conducted by the ICOLD Committee on Dam Decommissioning in 2005-2006, nine countries provided information on dam removal activity. Ten countries responded that no dams had been removed and none were planned. Additional information on dam decommissioning was obtained from a literature search. A brief summary of dam decommissioning activity in several countries follows.

Australia

Seven large dams have been decommissioned since the mid 1990s. All were for dam safety reasons as the dams had deteriorated to the point where rehabilitation was either not feasible or could not be achieved at a cost that would allow for an economic return. However, two of the dams removed were replaced by new dams. Decommissioning of a large off stream storage was completed in 2009 at Lake Mokoan in Victoria. Decommissioning resulted in large evaporative loss savings which were subsequently utilized to provide environmental flows. The project involved breaching of an embankment, new control structures, wetland restoration and offset pipeline water supply systems. Case studies of the decommissioned dams, including Lake Mokoan, are included in Section 9.

In the State of Victoria Various Water Authorities identified a total of 38 dams that were either being considered for decommissioning or in some cases, had been decommissioned.

Canada

Several dam removal projects in Canada have been documented. Distress and Finlayson Dams are 5 metre high concrete gravity structures located in central Ontario. Both dams were in need of safety repairs and the dam removal option was evaluated against the rehabilitation option. Finlayson Dam was completely removed while Distress Dam was partially removed and converted to an overflow weir. Coursier Dam was a 19 metre high by 685 metre long earthfill dam located in British Columbia. The dam had a long history of internal erosion, seepage, sinkholes, and repairs. The dam was decommissioned in 2003 by excavating a notch through the dam (Reference 10).

With new dam safety regulations in force since 2002 in Québec, an average of 5 small dams per year have been removed. Among them are Camatose-1 Dam (15 metres high), Ruisseau Porphyre Dam (9 metres high) and Lac Savane Dam (9 metres high). Before the new regulations, the pulp and paper company Bowater has removed 14 small dams in two years in a clean up effort of old structures which they no more use for logging.

Chile

No water storage dams have been decommissioned, but some tailings dams have been removed.

France

Three dams, located on tributaries to the Loire River, were decommissioned between 1996 and 1998 to improve fish passage. Kernansquillec Dam was multi-vaulted concrete dam 15 metres high. Saint-Etienne du Vigan Dam was a 12 metre high concrete structure. Maisons-Rouges Dam was a 4 metre high dam built in 1922 for hydro power production.

Italy

In response to the 2005-2006 ICOLD questionnaire, ITCOLD reported that they had established a working group on dam decommissioning. At that time there was not a record of dams which have been removed or decommissioned.

The information gathered so far was the following: 4 dams have been removed, 4 dam removals have been planned. Moreover, there are 15 dams (whose owners cannot be identified) at present under a national inquiry procedure in order to ascertain whether it is necessary to proceed with their removal for problems possibly related to safety or to plan their rehabilitation. The information on these dams is presented below:

Dam name	**Type**	**Height (metres)**	**Length (metres)**	**Reasons for removal**	**Status**
Isollaz	embankment	16	545	High costs to repair leakages and reduced interest of the owner	Breach in the dam body
Disueri	Hand-placed dry masonry	48	-	Construction of a new larger dam downstream	Breach in the dam body
St. Chiara d'Ula	multiple arch	70	260	Construction of a new larger dam downstream	Breach in the dam body
Corongiu	masonry	19	-	-	Demolished by diamond-wire cutting
Acquirico	embankment	20	-	Reduced interest of the owner	Project under development
Garga Saracena	embankment	-	-	De-rating from large to small dam	Project under development

Dam name	Type	Height (metres)	Length (metres)	Reasons for removal	Status
Borgo Priolo (2 dams on the same reservoir)	embankment	9 and 10	-	Reduced interest of the owner	Project under development
Muro Lucano, Figoi, Galano, Pasquasia, Cuba, Zerbino, La Spina, Sterpeto, La Para, Rio Grande, Molinaccio, Muraglione, Montestigliano, Fosso Bellaria, Gigliara Monte	Various	-	-	Safety assessment	Under inquiry procedure

In 2010, the ITCOLD Working Group provided case histories on five dams decommissioned in Italy including Isollaz, Disueri, Santa Chiara d'Ula, Corongui, and Rio Salita (Reference 8). The case histories are presented in Section 9.

Japan

No dams have been removed but the planning for removal of Arase Dam is underway. The concrete gravity dam is 25 metres high and 211 metres long.

Libya

Wadi Qattara Secondary Dam removed after failure in 1978. The earth embankment was 31 metres high and 225 metres long. No other dam removals are planned.

Norway

Very few dams have been removed in Norway, and most of these dams are not constructed for hydropower, but mining, water supply, timber floating etc. Only 4 or 5 dams related to hydropower are decommissioned according to our database. Two or three of these are related to small intake reservoir for small hydropower. Two are related to reservoir for hydropower. The two dams were small, just a few meters regulated height, and they were old. They had been out of operation for years, and a formal decommissioning process took place.

Romania

Several small dams have been emptied by the authorities (forcing a breach) when the dam presented a very high risk for the downstream area. Two dams have been removed. Belci Dam is a clay core earthfill dam, 14 metres high and 380 metres long. The dam was breached by overtopping under an extreme flood. Racova Dam is a concrete gravity spillway with earth embankments, 20 metres high and 7,380 metres long. The dam and reservoir were abandoned due to dam safety concerns and the ongoing cost of rehabilitation.

Sweden

In response to the ICOLD questionnaire, the Swedish National Committee reported that two small dams (Forsby and Edefors) had been removed and two others were planned for removal.

A 2009 article published in *Ecology and Society* discussed 17 Swedish dams that were recently considered for removal (Reference 11). The largest dam was Forsby at 4.8 metres high. The article reported that six dams were completely removed between 2002 and 2007 primarily to facilitate fish passage. Nine dams were not removed and fish passage was constructed or is being considered. Two were small dams at abandoned hydropower stations. The old dams were removed and replaced with new dams.

United States

It is estimated that about 500 dams were removed in the United States between 1920 and 1999 (Reference 12). The largest dam removed was the 160 foot high Occidental Chem Pond Dam D in Tennessee. Wisconsin had the most dam removals with 59 and California was second with 37. Illinois, Ohio, and Pennsylvania also had significant dam removal activity with 26, 35, 28 dams removed, respectively. American Rivers reports that 179 dams were removed from 1999 to 2004 with 42 dams removed in Wisconsin, 37 in Pennsylvania, and 16 in California. Most of the structures were small and were removed for river restoration and to allow fish passage. The largest dam removed was the 45 foot high Sturgeon River Dam in Michigan. Another 52 dams were slated for removal in 2005 including 26 in Pennsylvania and 12 in Wisconsin. These include Birch Run Dam (60 feet high) and Logan's Reserve Pond Dam (59 feet high) in Pennsylvania that are being removed for dam safety reasons.

At the 2007 USSD Annual Conference, Pennsylvania reported that 130 dams had been removed since 1995 and that another 100 removals were planned.

Several large dam removal projects are underway or planned in the United States to address dam safety concerns or river restoration and fish passage. The following table provides information on some recent dam removal projects in the United States. Additional information on these projects is provided in the case histories in Section 9.

Dam name	Type	Height (fee)	Length (feet)	Reasons for removal	Status
Saeltzer	Composite gravity – concrete wall and timber crib	20	185	Fish passage	Removed in 2000
Chiloquin	Concrete gravity	21	220	Fish passage	Removed in 2008
Savage Rapids	Concrete gravity and multiple-arch	33	465	Fish passage	Removed in 2009
Elwha	Concrete gravity	108		Fish passage	Removal construction contract awarded in 2010; Construction planned for 2011 – 2014
Glines Canyon	Concrete arch	210		Fish passage	Same as Elwha Dam
Matilija	Concrete arch	200	600	Dam safety; fish passage	Under study; estimated cost 130 Million United States Dollars
San Clemente	Concrete arch	106	300	Dam safety; fish passage	Under study; estimated cost 75 to 188 Million United States Dollars.

3. DECOMMISSIONING DECISION MAKING PROCESS

3.1 Steps in Decision Making

A general method for Dam Decommissioning Decision Making has been defined by The Heinz Centre (Reference 6) and modified for this document. **Figure 3-1** shows the proposed decommissioning process which start at defining a case for decommissioning and steps through to the actual decommissioning if this is considered appropriate.

Details of each step from 1 to 4 are provided in the sections following **Figure 3-1**. Steps 5 and 6 are addressed elsewhere in the guidelines.

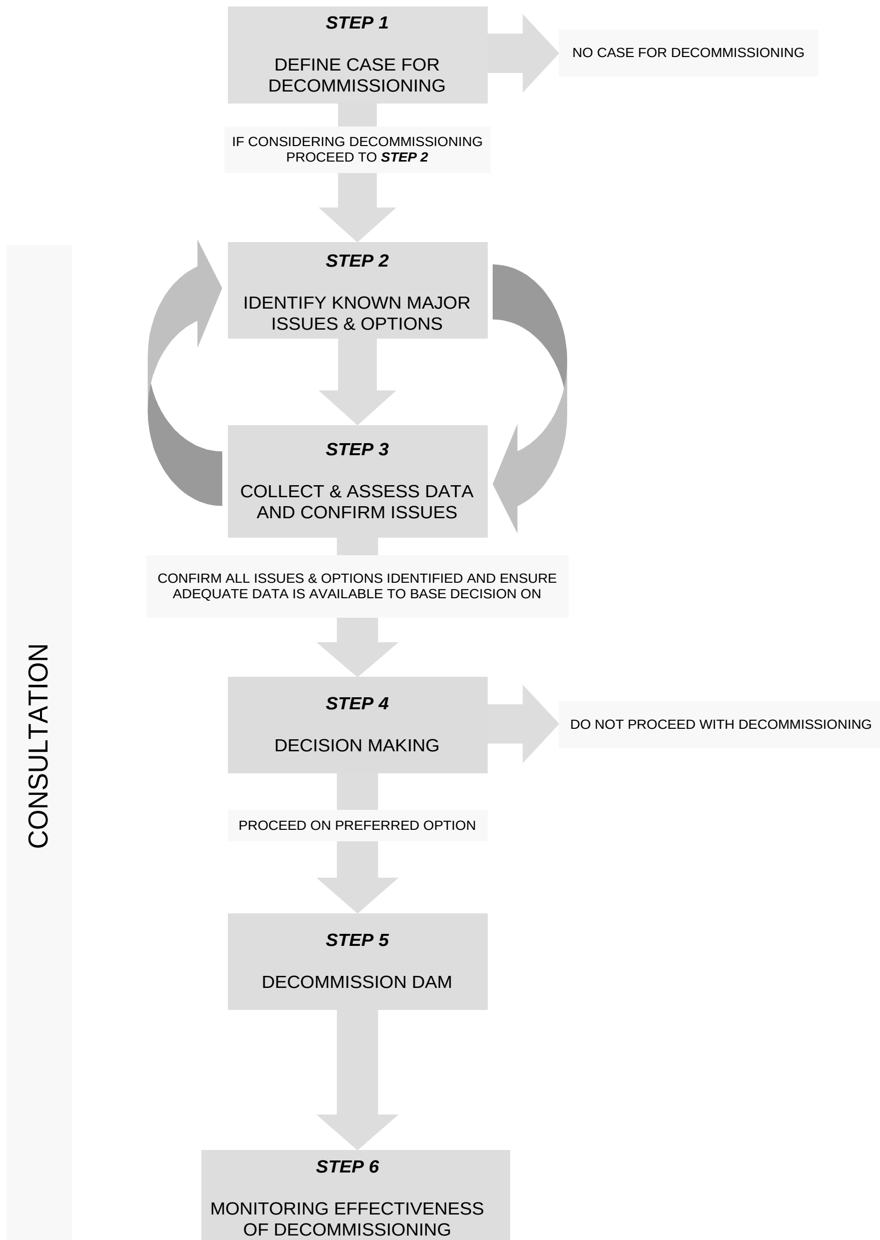

Figure 3-1 Dam Decommissioning Process

3.2 Step 1 - Define Case for Decommissioning

If a dam is being considered for decommissioning it is likely there will be an issue with the existing function of the dam. It may be that current industry or regulatory standards or community expectations are no longer being met by the dam, particularly for aging structures designed under different performance criteria.

Issues with a dam may include public safety, fish passage, river health or environmental concerns and/or the economics of the dam. These issues should be clearly defined and understood as they form the key inputs to defining any case for decommissioning or retention of a dam.

In addition it is important to define the original, existing and possible future performance expectations of the dam and uses of the river or impoundment.

These topics are discussed further in the following sections.

3.2.1 Is the Dam Meeting its Original Purpose or Need?

The original purpose of the dam needs to be clearly understood and defined. Once this has been achieved an assessment of whether the structure still meets its stated objectives can be made. The typical reasons for dam construction and retention are summarised below:

- Water Supply – urban, domestic and industrial uses of water are made possible by systems supplied by dams. These dams range in size, type and function from small (weirs) that divert stream flow into distribution systems to medium and large structures that create storage reservoirs;

- Irrigation – dams provide a secure water supply and distribution system in rural areas to support the farming of livestock and agriculture;

- Flood Mitigation – dams are used for flood control to capture and attenuate potentially hazardous runoff to protect downstream communities from inundation during large storm events. The volume of runoff is stored for subsequent gradual release;

- Power Generation;

- Recreation – recreational opportunities are a significant by-product of many reservoirs created for other purposes, such as fishing, swimming, boating and picnicking;
- Miscellaneous uses such as Fire Fighting water supplies.

3.2.2 Have Additional Issues or Needs Arisen?

Additional issues may have emerged since the dam was constructed which need to be understood. The performance requirements of the dam and river may have changed over time, along with environmental conditions, public values and relevant laws and polices. The typical reasons for dam decommissioning due to changing objectives or emerging issues since dam construction are summarized below:

- Public Safety – public safety is a major issue in the consideration of dam decommissioning. Dam failure can inundate downstream areas with disastrous consequences to life, health, property and the environment. Dams constructed in the past now often require substantial investment to bring them to modern standards. The investment required is often several times greater than the original construction price;
- Legal Liability Concerns – liability concerns may cause dam owners to decommission a dam to eliminate their own potential liability. The threat of liability for injury, loss of life or property damage following a dam failure gives dam owners an economic incentive to undertake remedial works or to consider the various aspects of dam decommissioning (full removal, partial removal or change of function);
- Waterway Restoration – dam and reservoir removal can contribute to the restoration of aquatic habitats downstream of the dam. Reservoir removal will assist in the movement of sediment, restoring flow regimes and ecosystems as well as returning the water to more natural temperatures. It should be noted however that waterway restoration is a medium to long term outcome of dam removal;

- Water Quality – a dam may be providing poor quality water and due to improvements of the water supply network the dam has become redundant;
- Opportunity – other opportunities to utilize the storage other than its original intended purpose may have arisen, e.g. Storage of stormwater, recycled water or groundwater;
- Alternative Supply Source – with a number of smaller water supply storages an alternative source such as connection to mains water becomes available making the original purpose of the storage redundant.

3.2.3 Initial Assessment Report

Upon completion of Step 1, it is recommended that the outcomes be clearly summarized in an assessment report. This report would then provide the base document supporting decommissioning or retention of the structure. This document will then aid decision makers in preparing their findings.

3.3 Step 2 - Identify Known Major Issues and Options

If it is decided to proceed to Step 2, the specific issues of concern to various stakeholders need to be identified. A review panel or stakeholder group could be established to identify issues in an open and transparent process. For more information regarding stakeholder consultation refer to Section 4. The use of independent technical advice for the review panel/stakeholder group is advisable to support the process. This technical advice will be essential to identify potential options for decommissioning or some other change in dam function and will also allow the costs associated with each option and their unique issues to be better understood.

The remainder of this section highlights some of the key issues with dam decommissioning that would need to be addressed. The options for decommissioning range from full removal of the structure to some form of partial removal or function change. There is a wide range of decommissioning options and the final option selected will be dependent on the specific site conditions.

Major issues that may be identified in relation to a dam being considered for decommissioning include:

- Dam Safety;
- Environmental;
- Legal;
- Social;
- Economic;
- Management;
- Consultation;
- Governance (including future management and ownership);
- Historical Significance

Each of the issue categories described above should be considered for each of the options identified.

3.3.1 Dam Safety

Some dams may not meet contemporary safety requirements. Many dams are old and may have been well constructed with the technology available in their era. However, they do not include features that would be expected of dams designed today, and therefore do not meet current safety guidelines and criteria.

Increased development downstream of some dams has also led to increased consequences associated with potential dam failure. As dams age the probability of failure generally increases and therefore liability and public safety concerns usually prohibit dams being simply abandoned. Some key questions associated with dam safety that should be considered are:

- Does the dam meet current dam safety guidelines and criteria?;
- Is it economically viable for the owner to upgrade the dam to meet current industry standards?;

- Have there been any specific dam safety deficiencies identified and if so what are they?;
- Is there a potential for loss of life, injury and property damage if the dam fails in its current or proposed state?;
- Is a Risk Assessment appropriate for the dam to better understand the dam condition and consequences of failure?;
- Does the current dam surveillance program comply with the requirements of the regulatory agencies?

3.3.2 Environmental

Greater environmental awareness of the impact of dams and weirs is increasing pressure on owners to remove redundant structures and/or to reduce their environmental impacts downstream. Many older dams may require retrofitting with facilities such as fish ladders, multi-level intakes and enhanced environmental water release capabilities. If retained some of these structures may require retrofitting regardless of the revised function.

It should be noted that the environmental issues and expected performance will differ from site to site therefore it is essential that each dam be considered individually. As well it is important to consider the various options for decommissioning including full removal, partial removal or retention with a change of function or operation. The environmental impact will differ significantly depending on the decommissioning option being considered.

Some key questions associated with the environment that should be considered are:

- Will decommissioning the dam reinstate the natural flow regime thereby enhancing the ecological health of the waterway?;
- Will decommissioning the dam assist fish migration?;
- What thermal impact is the dam having on the downstream environment and will decommissioning the dam modify these impacts?;

- Will dam decommissioning modify the ecological value of existing wetlands or their location?;
- What impact will dam decommissioning have on fauna that has adapted to the modified habitat?;
- Will dam decommissioning mobilize accumulated silt currently contained behind the dam?;
- Are the stored sediments contaminated?;
- Will dam decommissioning lead to the upstream movement of unwanted fish species?;
- Have so many other changes occurred in addition to the dam that decommissioning the dam will not achieve the desired ecosystem restoration goals?;
- How will groundwater tables near the dam and reservoir be affected?;
- What impact will dam decommissioning have on the flooding regime within the existing catchment? Will there be a significant reduction in flood control that is currently provided by the dam and reservoir?

3.3.3 Legal and Administrative Issues

There may be a range of legal and administrative issues that require consideration prior to deciding to decommission a dam. These issues will vary between countries and even within local jurisdictions of a single country. Hence the specific legal and administrative requirements for each dam will need to be assessed.

At this stage of the process decision makers should understand and be aware of the political context for the project and keep the relevant political representatives, government bodies and agencies and community leaders informed about all aspects of the issues.

Some key questions associated with the legal and administrative requirements of decommissioning include:

- Are there existing or potential conflicts with laws and regulations designed to protect natural systems, social, historical, or cultural values?;
- What are the legal implications for the owner associated with decommissioning and potential transfer of ownership?;
- Who owns the land adjacent to the dam or weir and the land currently inundated by the reservoir? Are there any potential ramifications of land ownership associated with the decommissioning process?;
- What are the implications for water rights that may exist?;
- What are the political factors that affect dam decommissioning decisions?

3.3.4 Social

An owner can face strong resistance to plans for decommissioning a dam (particularly the option for full or partial removal) even if it is considered superfluous to the requirements of the owner. This resistance can come from a range of parties including a variety local community groups and individuals interested in retaining the reservoir for existing or potential non-water supply uses.

Some key questions associated with the social issues with decommissioning include:

- Will recreational areas used for fishing, swimming and picnicking be lost?;
- How will water supply requirements for future development or for drought amelioration be affected?;
- Are there impacts on fire fighting purposes or other uses?;
- Are there impacts on property values of adjacent land owners?;
- How will water storage for non-potable uses be affected?;

- Are there impacts on environmental values, such as specific flora and wildlife such as fish?;
- Are there impacts on flood mitigation provided by the dam and reservoir?;
- Are there impacts on historical or archaeological significance in relation to the development of the local area including earlier uses or where the dam is on a historical register?;
- What are the impacts on local business opportunities associated with regional tourism?

3.3.5 Economic

Owners may not consider it prudent or justifiable to retain and maintain dams that are not required in perpetuity. However, the economic considerations associated with decommissioning a dam can be significant, and potentially comparable to operating and improving an ageing dam.

Key questions associated with the economic assessment of dam decommissioning include:

- What is the cost of maintaining and operating the dam versus the cost of decommissioning?;
- Will operational restrictions impact on the cost of maintaining and operating the dam?;
- Are there impacts relating to changing regional and local economics?;
- What is the source of funding for decommissioning or restoration efforts?;
- Is the dam providing a service that will need to be replaced by some alternative, and what is the cost?;
- Has future development in the region been considered?;
- Is there potential for land sales to offset expenditure?

3.3.6 Management

The management issues that arise from dam decommissioning will vary from owner to owner and dam to dam depending on a number of issues. This particularly relates to alternative water supply arrangements and how the reservoir storage fits within the overall context of the owners business. It also depends, on a more regional scale, how the storage fits within the existing river systems and the implications of dam decommissioning on the broader river system.

Key questions associated with the economic assessment of dam decommissioning include:

- How does the existing dam fit into the overall management plan for the river system?;
- Does the dam owner have an obligation to provide water for water supply, irrigation, hydro power generation, fire fighting or recreation and provide flood control?;
- What are the implications for these services if the dam is removed?;
- Have alternative water supply sources been identified?;
- What is the status of the procurement of future operating licenses or permits?

3.3.7 Consultation

For further information regarding stakeholder consultation and community engagement refer to Section 4.

3.3.8 Governance

Once a dam has been identified as being redundant by its owner, its future and the decisions relating to decommissioning may depend on identification of an owner with an interest in maintaining the dam for an alternative use. However, finding an appropriate owner can be difficult.

Key questions associated with the governance of a decommissioned dam include:

- What are the future ownership options for the reclaimed site?;
- Can an alternative owner be identified with an interest in maintaining the dam for an alternate use?;
- What are the funding arrangements for decommissioning between the current owner and the future owner?;
- Who will be responsible for ongoing maintenance of the decommissioned storage (whether fully removed, partially removed or retained with a change of function)?;
- Who will be legally liable for the site once the decommissioning process is complete? Has a due diligence process been undertaken to collate all available data and report on the condition of the dam to the proposed new owner?

3.3.9 Historical Significance

It is generally more likely that older dams will be considered for decommissioning rather than incurring the expense of bringing them up to modern safety standards. There could be significant historical or heritage value associated with these older structures.

Increased heritage value could result from the original purpose of the structure, the type of structure or the construction technique used or the relevance of the structure to the development of the local community.

It is important that the owner have a sound understanding of their obligations with regard to potential historical issues at their dam. A starting point for assessing potential heritage is generally through local government bodies or other historical societies however this will vary dependent on location.

Key questions related to heritage issues associated with dam decommissioning include:

- Is the dam, associated structures or the surrounding area currently heritage listed or considered to be of cultural significance?;

- Are there significant heritage issues to warrant additional consultation regarding future potential modification options?

3.4 Step 3 - Collect and Assess Data and Confirm Issues

Following the completion of Step 2 and the development of a list of known issues and options, proceed to Step 3 which involves collecting and assessing data to develop a better understanding of the identified issues and also to help understand the feasibility of various options.

There is an iterative process between Steps 2 and 3 (as shown in **Figure 3-1**) since additional issues or options may become apparent as Step 3 is being completed.

A table of key indicators for use in assessing potential outcomes of either keeping a dam in its current function or decommissioning it has been developed by the Heinz Centre, (Reference 6). The indicators can be measured in the present and predicted future to gauge potential outcomes of dam decommissioning.

The key areas where data is required for a decommissioning project are listed below:

- Physical;
- Biological;
- Economic;
- Social ;
- Governance;
- Technical/Engineering;
- Legal and administrative;
- Consumption and demand.

The requirements for each of these components are described in the sections below. Where particular questions cannot be satisfactorily answered it may be deemed necessary to complete additional studies or analysis prior to making a decision regarding decommissioning. Appendix 1 of the ASCE, 1997 *Guidelines for Retirement of Dam and Hydroelectric Facilities* (Reference 7). provides a detailed description of the data collection options for a range of areas.

3.4.1 Physical

Dam decommissioning, and in particular dam removal or partial removal, may restore some but not necessarily all characteristics of the river that existed prior to the construction of the dam. Dam decommissioning in its various forms may contribute to a range of physical impacts on a river.

The physical impact on the river will be highly dependant on the form of dam decommissioning selected. For example full removal is likely to have more impact than retaining the structure with a change of function or operation. It is less likely that the physical aspects described in this section will be an issue for “off stream” dams and reservoirs.

Key questions include:

- Will dam decommissioning create a more natural river as some aspects of the downstream physical integrity are restored?;
- Will dam decommissioning change the hydrologic and flooding regime of the river?;
- What impact will dam decommissioning have on the ground water table?;
- What impact would dam decommissioning have on water quality, subject to other influences imposed on the watercourse?;
- Will dam decommissioning restore fish and other aquatic species movement?;
- Will dam decommissioning restore the river’s natural ‘flushing’ function?

3.4.2 Biological

Any potential physical changes on a river potentially due to dam decommissioning may also impact on biological components of the ecosystem. The level of impact on the biological system will depend on the decommissioning option being considered.

Key questions include:

- What impacts will dam decommissioning have on fish and macro-invertebrates movement patterns and habitat opportunities? (The extent and intensity of the change depends on the size of the dam (storage capacity), quantity and quality of sediment in the reservoir and the stability of the downstream river reach);
- Will the dam decommissioning improve the accessibility of upstream habitat and spawning areas for migratory fish species?;
- Are there existing wetland systems upstream of the dam which have been formed due to the establishment of the dam and reservoir?;
- Would dam decommissioning lead to the creation of wetlands downstream at the expense of existing upstream wetlands?;
- What would future aquatic ecosystems look like compared to the existing aquatic ecosystem following dam decommissioning?;
- What are the potential impacts of dam decommissioning on fauna habitat around the perimeter of the reservoir?;
- What options exist for weed management within the basin if the reservoir is to be removed?

3.4.3 Economic

Economic analysis provides a process for identifying and measuring the outcomes of dam decommissioning, including the effect on stakeholders. This will assist the decision making process. Economic analysis can demonstrate the distribution of costs and benefits of various options. This step involves the collection and analysis of both readily quantifiable costs and benefits (eg, lost operating revenue), and costs and benefits that are more uncertain or difficult to establish in monetary terms (eg, environmental, aesthetic and historic values). However, reasonable valuations of outcomes offer the best path to economically informed decisions.

Dam decommissioning, repair or modification will require some level of funding. The source and amount of available funding is therefore an integral part of the decision making process and may be a critical factor in evaluating the viability of options. Funding may not only be needed for studies but also stakeholder involvement.

Many owners would view decommissioning as an operational expenditure rather than a capital expenditure as the decommissioning will not generate future income. This may have implications for funding and taxation and should be considered by the owner when determining funding strategies.

Key economic questions include:

- What is the cost benefit ratio for the various options being considered?;
- What funding options are available?;
- Is there the potential for cost sharing?

3.4.4 Social

Dam decommissioning in its various forms can affect a wide range of community interests, both directly and indirectly. By evaluating and where appropriate, addressing potential community changes, community support can be obtained. Social values influence preferences for certain alternatives or options. Different communities have different values which need to be understood and considered.

Key social questions include:

- How will dam decommissioning impact on the aesthetics of the dam site and adjacent river reaches?;
- How are the heritage aspects of the dam being considered in the dam decommissioning project?;
- What environmental restoration will be completed at the site following dam decommissioning and in particular dam removal or partial removal?;
- What impact will there be on recreational activities associated with the reservoir in its current form?

An understanding of social values and community issues and who benefits from or bears the impact of certain options can assist in the evaluation of options.

3.4.5 Governance

Current ownership of dam sites can be complex, as the dam and reservoir may be sited on land with a variety of ownership including the current owner, private land and public land. These factors can complicate any transfer of assets or land to other parties. There may also be instances where de-proclamation and redefinition of declared water supply catchments may be necessary.

Key governance questions include:

- What options are there for transfer of liability?;
- Have options for transfer of liability been investigated?;
- What documentation is required for a change of ownership and transfer of liability?;
- Where more than one party has expressed an interest, has a process been developed for the equitable disposal?;
- Is due diligence reporting required for transfer of ownership and if so has it been completed?

3.4.6 Technical/Engineering

Engineering analysis can identify the range of options available for achieving the stated goals. It can also determine technically viable options for decommissioning from unrealistic ones. The engineering process can be applied to analysing the costs and benefits of decommissioning (in one of its various forms) or upgrading a dam and the associated adverse consequences of each option.

For a detailed description of the technical and engineering requirements involved to evaluate various decommissioning options refer to Chapters 2 to 5 of ASCE 1997, *Guidelines for Retirement of Dam and Hydroelectric Facilities* (Reference 7). The following is a summary of the aforementioned guidelines.

Engineering & Constructability

Engineering assessment is required for all decommissioning options, however the level of analysis required will vary significantly depending on the option proposed. For example while some engineering will be required if the dam is to be retained with a change of function (predominantly associated with addressing identified dam safety deficiencies) there may be a considerable amount of engineering involved in the removal of a dam and its appurtenant structures and the subsequent environmental restoration and other works. At this stage in the process cost estimates for the options being considered should be prepared. Major issues that may require consideration include:

- Structural removal of parts or all of the dam and appurtenant structures;
- Disconnection of pipe work from the water supply network;
- Removal of part or all of the mechanical and electrical equipment;
- Treatment of facilities partly or entirely left in place;
- Operation and maintenance costs;
- Engineering and constructability relating to proposed mitigation for sediment management, environmental requirements, flood effects and effects on wetlands for removal and partial removal options;

- Flood requirements and spillway/river capacity for removal and partial removal options;
- Diversion and cofferdam arrangements for removal and partial removal options;
- Fish passage facilities for both the current and proposed arrangement;
- Construction of alternate water supplies to any affected users;
- Provision for such items as security or recreational facilities; and
- Construction and demolition cost estimates and schedules.

Data required for the above analysis is discussed in Appendix 1 of ASCE 1997, *Guidelines for Retirement of Dam and Hydroelectric Facilities*.

Environmental and Social

With any dam decommissioning option there is the potential for environmental and social impacts (both positive and negative). Environmental impacts can occur both during the construction/implementation phase as well as over short, medium and long term following completion of the project. Topics which may warrant data gathering and analyses, assessment of potential impacts and possible mitigation and enhancement measures are listed below:

- Water quantity and quality;
- Fish and other aquatic communities;
- Wildlife;
- Vegetation;
- Species of concern;
- Cultural, historical and archaeological resources;
- Aesthetic resources;

- Recreational;
- Land uses.

Sediment

Sediment management is discussed in Section 6 of this guideline.

Summary

Key questions regarding the technical aspects of the decommissioning options considered include:

- What are the costs of the various decommissioning options being considered?;
- What are the potential risks associated with construction for any removal and partial removal options?;
- Will it be necessary to divert an existing waterway during the construction works for removal and partial removal options? If so what will this involve and how will it be managed?;
- If the dam is retained what works are required to address identified dam safety deficiencies?
- What are the potential environmental impacts associated with the construction/implementation of the various options?;
- Has an environmental management plan been developed for options where removal is being considered for the short term construction works?;
- Is there a need for a long term environmental plan for re-instatement and/or regeneration of the inundated area?;
- Has an assessment of the need for inundation area and waterway erosion control measures been made?;

- If the need for inundation and water way erosion control measures has been identified has an erosion control plan been developed?;
- Is a sediment management plan required and if so has it been developed?;
- Is sufficient information available to be able to assess the potential short term, medium term and long term environmental impacts of each option?;

There may be a need to complete additional analysis and investigation to ensure that each of the questions posed above can be adequately answered.

3.4.7 Legal & Administrative

Laws and regulations pertaining to dam decommissioning are key to considering decommissioning as an option. This will vary from country to country and various jurisdictions within a country. It is recommended the local legislation be reviewed to determine any legal obligations for decommissioning of the dam.

Statutory and regulatory requirements provide boundaries for what can be accomplished and clarify roles regarding the decision making procedures and standards that must be met.

3.4.8 Assessment Report

At this stage it is recommended that a report be prepared documenting the process and the outcomes of Steps 2 and 3 of the process. The report should include options identified for decommissioning and potential issues associated with each option. This should include the no decommissioning option. As well, where assessments of various issues have been completed the outcomes of these assessments should be included in this report.

3.5 Step 4 - Decision Making

Following the completion of Steps 1, 2 and 3 there should be sufficient quantifiable data to allow decision makers to determine the most appropriate option. At this stage a decision regarding whether the dam should be decommissioned can be made. If the decision to proceed with decommissioning is made, the preferred option for decommissioning should be selected (based on the outcomes of Stages 2 and 3).

The final decision whether to decommission the dam or not will often be based on a combination of the following factors:

- Safety, security and water management requirements;
- Economics of maintaining the dam versus decommissioning the dam;
- Environmental needs and potential gains;
- Societal considerations;
- Legal relationships;
- Public support and concerns;
- Local, regional and possibly national interests.

Chapter 5 of the ASCE Guidelines provides one methodology for the evaluation process for dam decommissioning studies. Other methodologies may exist.

Key questions associated with the decommissioning decision include:

- Has the owner identified a preferred option?;
- What is the preferred option?;
- What is the justification for selection of the preferred option?;
- Will the proposed option eliminate any future operation, maintenance, surveillance or remedial work?;

- Has the decision making process including the final decision been documented?;
- Is there acceptance or implied acceptance for the preferred option from the relevant stakeholders?

4. CONSULTATION AND REGULATORY APPROVALS

The decommissioning of an existing dam can be a contentious process as there are typically many stakeholders with widely varying interests that have an interest in the fate of the dam, reservoir and catchment. Stakeholders may have conflicting views of the problems and possible solutions. Therefore, in order to ensure all relevant issues are addressed and the relevant stakeholders are adequately informed, some form of consultation process is required.

The purpose of these guidelines is not to provide a detailed discussion on the consultation process but rather to provide some general concepts relevant to the dam decommissioning process and provide references for more detailed guidelines on the consultation process. There typically are many local government authorities and other bodies that provide useful guidance documentation of the consultation process from planning to implementation. These usually will contain information on local legislative requirements and other useful information specific to that area.

For a dam decommissioning project, consultation can occur at a number of different levels and the requirements of the consultation process can vary depending on the scope and nature of the project. For example the full removal of an on-stream storage dam would in most instances require a more rigorous consultation program than the retention of a small off-stream storage dam with a change of function. It is important to consider upfront what the different levels of consultation are and what the purpose of the consultation is. It is also important to identify who the key stakeholders are and what inputs are required from them.

Key questions with regard to the consultation process include:

- Is the consultation process aimed at informing and educating or genuinely seeking input?;
- Which stakeholders will be involved in the consultation process?

Key stakeholders may include various government agencies including regulators, water authorities, and environmental agencies.

In many cases not all of government agencies will be relevant to the project, however it is worth considering who the relevant groups are early on in the decision making process. It is considered beneficial to include as many of these groups as is relevant as early in the process as possible.

Another group of key stakeholders are local community and interest groups. These range from landowners or residents who live within the immediate vicinity of the dam or weir to broader community interest groups.

A decision regarding the amount of "community consultation" (that is consultation with the broader community compared to directly impacted stakeholders) that should be completed as part of any project is often a difficult one. Consideration should be given to including any individuals or group of individuals that will be directly impacted by the decommissioning project. In some cases industry groups or other community groups may be beneficial to have in the consultation, e.g. forestry or farming groups.

It is essential to any consultation with the broader community that the information provided is clear and consistent.

4.1 Determining the Appropriate Level of Consultation

As mentioned previously community and stakeholder engagement and consultation can take many forms and covers a broad range of activities. A table produced by the International Association for Public Participation to demonstrate the possible types of engagement with stakeholders and communities is shown as **Figure 4-1** below **(Reference 21)**. This table also shows the increasing level of public impact as you progress from 'inform' through to 'empower'.

INCREASING LEVEL OF PUBLIC IMPACT

INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
Public Participation Goal:	**Public Participation Goal:**	**Public Participation Goal:**	**Public Participation Goal:**	**Public Participation Goal:**
To provide the public with balanced and objective information to assist them in understanding the problems, alternatives and/or solutions.	To obtain public feedback on analysis, alternatives and/or decisions.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision, including the development of alternatives and the identification of the preferred solution.	To place final decision-making in the hands of the public.
Promise to the Public:	**Promise to the Public:**	**Promise to the Public:**	**Promise to the Public:**	**Promise to the Public:**
We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and provide feedback on how public input influenced the decision.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will look to you for direct advice and innovation in formulating solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible.	We will implement what you decide.
Example Tools:	**Example Tools:**	**Example Tools:**	**Example Tools:**	**Example Tools:**
• fact sheets • web sites • open houses.	• public comment • focus groups • surveys • public meetings.	• workshops • deliberate polling.	• citizen advisory committees • consensus-building • participatory decision-making.	• citizen juries • ballots • delegated decisions.

Figure 4-1 The Levels of Engagement with Stakeholders and Communities

Early on in the process, decision making should determine the level of engagement and consultation to be used for the project for the different stakeholders.

Key questions regarding the level of consultation required include:

- Who are the stakeholders?;
- Should a different level of consultation be adopted for different stakeholders?;
- Do we want input and collaboration from some of the government departments and agencies and if so which ones?;
- What permitting is required?;
- Do we have the expertise in house to make a decision about the level of consultation required or should we seek external advice?;
- Is there potential for individuals/groups with personal interests to overly influence the outcomes of the consultation process?

4.2 Planning the Consultation Process

A simple list of questions to be addressed in the planning and design of the consultation process are provided below (Reference 2).

- Why? – why do you need a consultation process what is the motivating issue or need;
- Who? – who are the likely affected individuals/groups? Who will manage the process? Which is accountable for what? Who signs off?;
- What? – what type and level of information should provided? What are people being consulted about?;

- When? – what is the overall practical timeline for the consultation process? How does this timeline fit in with the dam decommissioning decision making process timeline?;
- Where? – are people expected to travel far to participate in the consultation process? Is a neutral venue preferable?;
- How? – what strategies might be used and which ones are best?

With what? – what resources are available – time, people, money?

5. DESIGN AND CONSTRUCTION ISSUES

5.1 Design Process

5.1.1 General

Dam decommissioning projects need a full range of engineering and professional specialists on the design team. The overall site restoration goals and objectives should be well established when designing a dam decommissioning project. The adopted solution should be selected to reduce project costs and to minimize adverse environmental impacts. Natural physical and biological processes of the river should be incorporated to facilitate final site restoration.

The final design specifications should include details of the existing site conditions and the project requirements to achieve the desired results. Any special site restrictions, such as the prohibition of blasting, or any environmental constraints, such as the period when no in-water work is allowed, should be included in the specifications.

5.1.2 Basis of Design

(a) Structure Removal Limits

The limits of structure removal should be identified as part of the planning and design process. Full removal generally means removal of the dam and appurtenant structures to either the original streambed level or an alternate grade, such that no visible evidence of the original structures remains. The stream channel is normally restored to its original alignment and grade, with natural-looking ground contours provided on the abutments following full removal.

Portions of the structures may remain buried on site, especially below the original ground surface. Partial removal allows some structures, or portions of structures, to remain in place, either within or outside of the original stream channel, but no significant reservoir impoundment remains. Remaining structures must be capable of performing satisfactorily in the future under anticipated potential loading conditions and may have to be modified for public safety or for the safe passage of large floods.

Structure removal limits will generally be based on the following factors:

- Are there any regulatory requirements? National or local regulatory requirements for safe passage of flood flows may require any remaining portions of the dam to safely pass a particular size of flood within a certain flow depth or stage (such as the 100 year flood at depths less than 5 feet [1.5 metres]), or require a minimum dam breach width (such as one-half of the structural height, but not less than 10 feet [3.0 metres]);

- Are there any public safety and liability issues? Public safety and liability issues would require consideration of the potential hazards to the public which remaining portions of the dam could represent;

- What are the operation and maintenance requirements? Remaining structures may require some long-term operation and maintenance activities that would be considered in any decision for full or partial removal.

Type of dam and appurtenant structures: The type of dam may play an important role in the establishment of removal limits. If partial removal is considered, the construction materials used in the dam (concrete, masonry, timber, earth, or rockfill) can determine the extent of structure removal required to meet project requirements and the future performance of any remaining structures.

- Dam removal costs: The volume of material in an earthfill or rockfill dam is generally much greater than that in a concrete dam, but excavation and disposal of earth and rockfill materials is usually easier. The type of dam and disposal requirements will influence the choice of demolition methods and dam removal costs. Concrete crushing and recycling may be an economical option. If hazardous materials are identified, the proper disposal of such materials and associated costs may affect a decision to fully or partially remove the dam;

- Are there any sediment management issues? Sediment removal and disposal can greatly increase project costs. Water quality concerns may require strict sediment management during construction. Contaminated sediments require proper disposal. Partial removal to retain the lower portion of a dam to some height above streambed may be desirable to serve as a silt retention barrier and for stabilization of upstream sediments;

- Are there any aesthetic factors? Aesthetic factors will often affect a decision for partial removal, especially in areas subject to public view;

- Are there any historical and cultural values? : Historical and cultural values will also play a role in the removal of older structures. The dam and appurtenant structures may be protected under a law to preserve historic cultural assets, and retention of portions of the dam or appurtenant structures may be desirable to preserve a particular element of the original design for posterity;

- Are land-use and landowner/stakeholder preferences considered? Land-use and landowner/stakeholder preferences must be taken into consideration when establishing removal limits.

Project requirements should be based on a thorough assessment of all relevant factors pertaining to the final site restoration.

(b) Design Data Collection

A complete understanding of the existing structures is important to the success of the dam removal project. All existing data appropriate to the scope and scale of a project should be collected prior to the final design stage. This will include all available construction drawings and any supporting design calculations and specifications. Older structures may have little or no information. The additional information that should be collected includes the following :

- New drawings reflecting current conditions based on field measurements, if no drawings exist;
- Any pertinent information available in the owner or regulatory agencies records, including inspection;
- Records of modifications performed over the years;
- Additional project information, including project histories, construction photographs, and newspaper reports in local historical societies, archives, and public libraries. An internet search may provide some useful information;
- Materials testing data (such as concrete compressive strengths or embankment gradations);
- Details of embedded metalwork, tendons, and steel reinforcement in concrete structures;
- Pre-construction topographic maps would be useful to determine the original ground surfaces within the reservoir for estimating sediment volumes and at the dam site for developing removal limits.

After collecting all available engineering data, additional field work consistent with the project goals and objectives may be required to confirm the site conditions.

- Field measurements of the structural dimensions of all major project features for the specifications drawings and quantity estimates;

- Documentation of the operating history and present condition of gated spillways and outlets to be used for streamflow diversion;
- Complete inventory of mechanical and electrical equipment to be removed, including weights (if available);
- Drawings prepared for the removal specifications may be useful for historic engineering record documentation purposes;
- Offsite locations and haul distances for disposal of materials;
- Additional site surveys for dam-site ground surface contours;
- River cross-sections, including plunge pool and tailrace areas;
- Reservoir bathymetry, to develop a sediment profile at the dam and reservoir cross-sections;
- Field test data including concrete compressive strengths and unit weights;
- Index and engineering properties of embankment materials and reservoir sediments;
- Identification of onsite hazardous materials, including asbestos, coating contaminants (such as lead-based paint), batteries, chemicals, petroleum products, PCB’s, and mercury;
- Assessment of reservoir sediment to characterize its chemical and physical properties;
- Location and testing of septic systems and underground storage tanks;

The evaluation of geologic conditions for larger dam removal projects could include:

- An assessment of slope stability of the abutments and upstream slopes during reservoir drawdown and following dam removal;
- Determination of the erosion resistance of the dam abutments and foundation for flood flows;

- Subsurface explorations for potential diversion channels or tunnels;
- Estimation of foundation permeability and groundwater levels for dewatering the site excavations;
- Sediment transport and river erosion models to predict important changes to the streambed profile (deposition and erosion) and alignment (river meander or avulsion).

The evaluation of the hydrology of the site would be required for partial dam removal to appropriately size a safe breach, particularly if there would remain downstream consequences in the event of dam failure. The hydrologic evaluation may include:

- Analysis of streamflow records for the site to determine frequency flood peaks for diversion purposes;
- Preparation of water surface profiles along the stream for various discharges to develop stage-discharge relationships both with and without the dam.

Remaining site features exposed to flood loadings should remain stable up to some prescribed minimum return period (such as 100 years), depending upon the potential consequences of failure or as required by the regulatory agencies.

5.1.3 Design Stages

Dam decommissioning projects typically include the following design stages or elements, some of which may occur concurrently.

- Owner's Feasibility Study;
- Conceptual Design;
- Consensus Building With Stakeholders;
- Preliminary Design;
- Final Design;
- Post Construction Monitoring;

1. Owner's Feasibility Study

Early in the process of deciding whether or not to decommission or remove a dam, the dam owner should thoroughly evaluate the various potential alternatives. This is often a requirement of the regulatory permitting process. These alternatives will generally include:

- Structure Repair or Rehabilitation;
- Change of Reservoir Operating Procedures (such as removing the spillway gates and permanently restricting the reservoir level);
- Partial Breach (a breach limited both vertically and horizontally);
- Full Breach (breached fully vertically, but may be limited horizontally);
- Full Removal (no remnant of the dam left visible);
- No Action – baseline case required by environmental impact evaluation process;

The scope of the Feasibility Study typically includes:

- <u>Review of Existing Information and Data Collection</u>

  -- Site Topography and Impoundment Bathymetry;

  -- History and Records of Dam Design, Construction and Operation;

  -- Original Project Authorization and Current Benefits;

  -- Cultural, Historical and Archaeological Resources;

  -- Dam Safety Assessments and Performance Data;

  -- Hydrologic and Hydraulic Data;

  -- Geology and Geomorphology;

  -- Fisheries Within, Upstream, and Downstream of Impoundment;

- Sediment Gradation and Quality Within, Upstream, and Downstream of Impoundment;

- Infrastructure Impacted by Decommissioning, both Upstream and Downstream;

- Identification of Property Boundaries and Landowners ;

- Status of Existing Permits and Identification of Permits Required for Decommissioning.

- Identification of Stakeholders - Preliminary identification of concerned parties, including landowners within project boundaries, regulatory agencies requiring permits, and other public or private entities judged likely to have strong interests and concerns;

- Evaluation of Advantages and Disadvantages of the Various Alternatives – Consideration of the key advantages and disadvantages of the alternatives critical to the dam owner and/or other stakeholder decision-making process;

- Preliminary Cost Estimates - Development of preliminary comparative cost estimates for the various alternatives, based on available information. Demonstration of cost prohibitive alternatives and subsequent elimination of alternatives from further consideration is possible at this stage;

- Selection of Preferred Alternative/s – Based on the evaluation of data and issues identified at this stage, one (or multiple) alternative/s may be selected for further evaluation. An Owner's Feasibility Report would normally be prepared to summarize the investigations and evaluation of alternatives;

For Coursier Dam in Canada, the owner evaluated three options to address dam safety issues:

- Option 1 – Partial Decommissioning and Abandonment of the Majority of Reservoir Storage;

- Option 2 – Complete Rebuild of the Entire Dam;

- Option 3 – Decommissioning of Dam;

Option 1 was not considered feasible because it did not fully address the dam safety issues and would require continued operating costs with no energy benefits. Option 3 was selected since the cost of rebuilding the dam at $29.5 Million was five times the cost of decommissioning (4.6 Million Canadian Dollars) (Reference 10).

2. Conceptual Design

Upon selection of the preferred alternative/s, conceptual designs are prepared which address proposed topography changes at the dam site and modifications to structures and river banks. These designs may require the collection of additional information, including survey data, material properties, geology, and hydrology.

Diversion of river flows is addressed further for the conceptual design, along with other issues identified in the Feasibility Study. Hydraulics of flow through partial or limited-width breaches should be analysed. If the intention of the partial breach is to render the dam a low hazard structure, flood routings and dam break studies may be required to verify that the consequences of failure of the lower structure are acceptable. If the sections remaining after the breach are expected to withstand flood flows, hydraulic and armoring analysis and design would be needed.

Management of sediment removal is addressed further where the impoundment contains large quantities of clean or contaminated sediment. Considerations are needed for sediment handling, disposal (offsite or onsite), re-contouring, and revegetation.

Computer simulations illustrating the proposed post – removal appearance of the dam site are commonly prepared for larger or more controversial dam decommissioning projects. The conceptual design plans and simulations are used to prepare updated cost estimates and for presentations to stakeholders.

3. Consensus Building with Stakeholders / Preliminary Design

At this stage, the dam owner meets individually and/or collectively with the identified key stakeholders and regulatory agencies. The alternatives considered are discussed and the conceptual design for the preferred project is presented. The input of key stakeholders and regulators is sought and received. Upon receipt of this input, the owner should demonstrate how it will be incorporated into the project design or justify its exclusion. This input may have a significant effect on the conceptual design. Once key stakeholder and regulator input is evaluated, a more advanced preliminary design is prepared to reflect necessary design changes, and the project cost estimates are updated.

4. Final Design

Final design and specifications will be prepared for the preferred alternative based on the preliminary design, following an expression of approval or support from the regulatory agencies and key stakeholders. Project funding should normally be obtained prior to issuance of a contract solicitation or request for proposals. Project approval may be required before the award of a construction contract. Although it is generally desirable to have all permits issued prior to contract award, it may not be necessary and could cause a project delay. Changes to the final design may be necessary during construction depending upon the actual site conditions encountered. These would normally be handled as modifications to the contract, for a price negotiated with the contractor.

5. Construction Monitoring and Adaptive Management

Recognizing that initial project actions may not produce expected results because of unforeseen factors, adaptive management can be an important tool to monitor project results and refine the actions being taken. Adaptive management is a formal, science-based process that (1) uses monitoring and research to identify and define problems, (2) examines various alternative strategies and actions for meeting measurable goals and objectives, and (3) makes timely adjustments to strategies and actions if necessary, based on best scientific and commercial information available.

Under adaptive management, specific dam removal parameters would be monitored and analysed according to the protocols set for data assessment, to determine whether they are producing the desired results or if additional actions are necessary. For example, monitoring may be performed within the formerly inundated area and downstream channel following dam removal to assess the results of sediment erosion and transport on the river system. Unstable slopes within remaining upstream sediment, unexpected downstream deposition or scour within the river channel, unexpected channel meander, or elevated downstream turbidity levels, may require additional mitigation measures which could require additional design and construction activities. Such measures may be implemented as a modification to the dam removal contract or by a separate contract if construction is required, or possibly take the form of operational changes affecting flow rates.

The adaptive management responses could include the following actions:

- Modify monitoring techniques, locations, or frequencies;
- Restore water quality through treatment;
- Mitigate local flooding and bank erosion;
- Reduce rate of dam removal;
- Temporarily halt dam removal;

Actions developed under an Adaptive Management Plan may be funded from an Adaptive Management Fund specifically established for that purpose. An Adaptive Management Fund in the amount of 3 Million United States Dollars was established for the Battle Creek Restoration Project in California by a third-party donor, with disbursements to be requested in writing based on protocols identified in the Adaptive Management Plan.

5.1.1 Construction Sequence and Schedule

The final design for a dam removal project should identify the major construction activities, the sequence in which they should be performed, their estimated durations, and a proposed schedule incorporating any restraints. Key points to consider are:

- Dam removal projects should generally be scheduled around the permissible in-water work period for the site;
- Required work outside of the stream channel, such as for site access, may be performed early to facilitate the removal process;
- In-stream work should not be scheduled during periods that could be interrupted by high flows, as defined by river stage or by flow rate.

The potential risks associated with high flows must be considered in the project plan, especially in the contractor's design of cofferdams and temporary flow bypass facilities. A temporary Emergency Action Plan (EAP) should be developed for the construction period.

The contract specifications may include other schedule constraints including;

- Key fish spawning, bird nesting, or winter hibernation periods of sensitive species that could be affected by the project;
- Site clearing prior to construction may be limited to non-nesting periods, or require special hazing procedures to prevent nesting of sensitive species to occur;
- Some work may be limited to winter months to avoid fire hazards;
- Seeding for revegetation may be regulated, mandating specific periods of time for seeding and specific vegetation types.

The major construction activities should follow a logical sequence to produce optimum results as follows:

- Water release facilities should remain operational until the dam has been lowered below the level for which the facilities operate (such as for an outlet works intake structure or a gated spillway crest);
- Features providing project benefits should be removed near the end of a long-duration contract (such as an upstream diversion dam serving a hydroelectric plant) to maximize power revenue;

- In-water work should be scheduled while upstream diversions are available to minimize streamflow through the worksite;
- Downstream structures may need to be retained as fish barriers until upstream work is completed.

5.1.2 Cost Estimates

Construction cost estimates will be prepared based on the estimated quantities and types of materials to be removed, assumed demolition methods and rates, expected transportation methods and capacities, and disposal locations. Sufficient information must be provided by the designer to price all items of work, including those identified in the bid schedule as lump sum. Additional allowances will generally be included for equipment mobilization, construction access, diversion and care of streamflow, environmental controls (such as water for dust abatement), site restoration, and any unlisted items.

Additional items that can add significantly to the cost of a dam removal project are:

- Proper handling and disposal of hazardous materials;
- Environmental compliance and mitigation required by regulatory agencies;
- Delays in regulatory permits due to inadequate stakeholder involvement early in the project;
- Sediment removal and offsite disposal, especially if sediments are contaminated;
- Disposal of earth and rockfill embankment materials and excavated materials;
- Disposal of concrete. Waste concrete can be crushed for reuse which may result in cost savings;
- Replacement or modification of upstream and downstream infrastructure;
- Compensation of dam owner for water rights and property interests.

The costs of dam decommissioning can be significant even for small dams. The following table provides some examples of the costs associated with the planning, design, permitting, and construction of dam removal projects worldwide.

Dam name	**Type**	**Year Removed**	**Total Cost**	**Major Elements of Costs**
Saeltzer - US	20 feet high Composite gravity – concrete wall and timber crib	2000	6.0 Million United States Dollars	Construction contract -2.8 Million United States Dollars. Compensation for water rights and property interests - 2.5 Million United States Dollars.
Chiloquin - US	21 feet high Concrete gravity	2008	18 Million United States Dollars	Construction contract for dam removal and new pumping plant - 9 Million
Savage Rapids - US	33 feet high Concrete gravity and multiple-arch	2009	39.3 Million United States Dollars	Construction contract -28.3 Million United States Dollars.

Dam name	**Type**	**Year Removed**	**Total Cost**	**Major Elements of Costs**
Elwha - US	108 feet high Concrete gravity	2011-2014	Estimated at 350 Million United States Dollars	Purchase by Federal government – 29.5 Million United States Dollars. New water treatment facilities - 96 Million United States Dollars. Construction contract -28.3 Million United States Dollars.
Glines Canyon - US	210 feet high Concrete arch			Included with Elwha Dam
Oaky Creek - Austraila	10 metre high earthfill	2000	0.6 Million Australian Dollars	Interim upgrade to spillway capacity - 300,000 Dam removal - 300,000
Mount Morgan - Australia	3 dams; the largest 9.7 metre high; Concrete gravity	2004	7.3 Million Australian Dollars	Removal of 500,000 tons of contaminated tailing in reservoir
Wellington - Austraila	15 metre high Concrete gravity	2002	1 Million Australian Dollars	
Kernansquillec - France	15 metre high multi-vaulted concrete	1996	6.1 Million French Francs	Sediment in reservoir
Saint-Etienne du Vigan - France	12 metre high concrete	1998	7 Million French Francs	
Coursier - Canada	19 metre high earthfill	2003	4.6 Million Canadian Dollars	Excavation and disposal of 105,000 cubic metres of embankment material

5.2 Construction Stage

5.2.1 General

The term “construction” is used to describe the physical dam removal processes in these Guidelines, since standard construction equipment and methods are normally employed.

5.2.2 Site Access and Mobilization

Construction access to the project site can be an important factor affecting dam removal costs. Access roads used for original construction of the dam may not be suitable for modern construction equipment or current safety requirements. Significant improvements to existing access roads may be required to perform the work, and should be considered in the project cost and schedule. The impact on the inhabitants who moved to the site after a dam was completed must be considered. Site restoration requirements should specify whether site access roads should be preserved or obliterated following dam removal.

5.2.3 Reservoir Drawdown

The reservoir size and streamflow characteristics of the site, and the capability for drawing the reservoir down safely while passing normal flows, are critical in planning for the removal of a dam and restoration of the site. The size and location of existing release facilities should be determined, and maximum release rates should be evaluated for potential adverse impacts.

1. Drawdown Release Capacity

The first step is to identify all existing release facilities, and to determine their release capacities and operating range. A dam may contain one or more upper-level, mid-level, and low-level release features. Upper-level features include gated spillways, canal outlet works, and fish ladders. Mid-level features include penstocks and municipal and industrial outlet works. Low-level features include river outlet works, sluiceways, and diversion outlets. Sediment levels upstream of a sluiceway or diversion outlet should be evaluated to determine whether any operating problems (such as plugging with woody debris, or release of contaminants) could develop.

Discharge curves for reservoir release features should be developed or obtained from available operating documents or design records to plan for a reservoir drawdown. These curves will indicate the expected discharge for a given reservoir level, based on a specific gate opening. Operating restrictions may be in place to limit gate openings to avoid cavitation damage or excessive flow velocities or air demand. Since the releases are to facilitate dam removal, some damage to the release facilities may be tolerable.

The downstream channel capacity should be evaluated to determine whether any damage could result from maximum reservoir releases during drawdown. Emergency Action Plans (EAP) or downstream inundation maps may contain information pertaining to safe channel capacities, based on a stage-discharge relationship. New developments may have encroached on previously-established flow boundaries, or low-water crossings may be adversely impacted by sustained releases, requiring a field investigation of conditions prior to reservoir releases.

Reservoir drawdown requires the release of reservoir volume as well as the downstream passage of inflow to the reservoir. A storage-elevation curve or reservoir capacity tables should be obtained from project records, or developed using site topography if available.

2. Drawdown Rate Limitations

The rate of reservoir drawdown must be evaluated pertaining to the potential instability of upstream embankment slopes or landslides along the reservoir rim. Drawdown rates may have to be limited to prevent a rapid drawdown condition which could cause a slope stability failure.

The erosion and transport of impounded reservoir sediments may require additional drawdown limitations. Environmental impacts to fish related to water quality may require the establishment of "fish windows" during which time no drawdown producing elevated turbidity levels would be allowed.

3. Impacts of Reservoir Drawdown

Reservoir drawdown may produce impacts that need to be identified and evaluated as part of the dam removal project.

- The original benefits for which the dam was authorized and constructed may be permanently lost. This would include water supply, flood control, power generation, and recreation;
- Legal rights to water diversions may need to be addressed;
- In addition to the loss of water storage, lower groundwater levels may result which in turn could impact local wells and springs;
- Downstream water quality may be impacted by the passage of natural sediments (either as suspended solids or bed load) which had previously been contained within the reservoir;
- The coarser sediments may be deposited along the downstream channel, producing higher river stages and greater flooding potential.

The removal of a dam and loss of reservoir storage may also produce significant impacts to infrastructure within the reservoir area.

- The loss of channel depths may affect river navigation, and the removal of the dam may eliminate an important river crossing;

- Bridge piers, roadway and railroad embankments, levees, drainage culverts, and buried utilities (such as water and natural gas pipelines) within the reservoir area may become subjected to higher flow velocities, scour, and surface erosion;
- Previously inundated cultural and archaeological sites may become exposed and subject to erosion or human disturbance;
- Property values along the former shoreline may be lost;
- The lakebed exposures may produce dust hazards that require erosion control and vegetation;
- Mitigation for any upstream impacts may be required as part of the permitting process.

Streamflow Diversion

The ability to safely pass streamflow during dam removal is often critical to the dam removal process. This is especially important for an embankment dam, which is much more vulnerable than a concrete dam if overtopped. When the existing release facilities are incapable of passing anticipated flows, or are not low enough to draw the reservoir down sufficiently, alternative diversion methods must be employed. For smaller dams, streamflow diversion may be accomplished by constructing a channel around the existing facility, as was done during the removal of Saeltzer Dam in California (Reference 20).

For larger dams, a diversion tunnel may be excavated through one of the abutments, with a lake tap used to construct the intake structure. Concrete dams can typically accommodate diversion more easily by passing flows over the top of the dam. Notches can be constructed through the dam to permit reservoir drawdown for excavation of upper portions of the dam in the dry, as is planned for removal of Glines Canyon Dam in Washington. More information on these two projects is included in Section 9.

The streamflow diversion method and release capacity will determine reservoir levels during demolition, which may affect demolition options. The passage of flood flows which exceed the release capacity of the streamflow diversion facilities may control the contractor’s schedule. Hydrologic analysis is necessary to define the range of flood events expected during dam removal. Streamflow data may be obtained from gauging records for the site (or transposed from a nearby site) and from reservoir operations data.

Surface diversion channels pass streamflow around the dam, through an excavated rock channel, a lined earth channel, or a temporary flume or pipeline. Diversion tunnels pass streamflow through the abutment, typically through an unlined tunnel in rock, requiring a costly lake tap excavation beneath the reservoir surface. Diversion outlets pass streamflow through the dam, either through an existing outlet conduit with relocated gate controls and modified access, through the original diversion outlet restored for use (e.g. by removing a concrete plug), or through a new outlet constructed in a concrete dam by blasting to an upstream underwater bulkhead.

Some form of flow control is often provided for the diversion facilities, especially for those requiring streamflow to pass through the dam or abutment well below the reservoir surface. This provides a means to control the rate of reservoir drawdown for sediment management purposes, or to prevent downstream releases which could exceed the safe downstream channel capacity.

A new outlet constructed through a concrete dam can be fitted with a large slide gate on either the upstream or downstream face to provide flow control.

The construction of an upstream cofferdam can provide temporary storage to reduce the natural flow through the demolition site, or provide greater head on a temporary diversion pipeline to increase its diversion capacity. A downstream cofferdam can prevent backwater effects on the demolition site.

5.2.4 Demolition and Removal Methods

A preferred demolition method should be selected for project planning and cost estimating purposes, but the specifications should only define the removal limits and any pertinent constraints or restrictions, thereby allowing alternative demolition methods to be submitted by the contractor for approval.

1. Concrete Removal Methods

- Drilling and blasting. Drilling and blasting is generally the most economical and effective method for concrete demolition;
- Diamond-wire sawcutting. Diamond-wire sawcutting is typically used on large concrete dams where other methods are not practical;
- Mechanical demolition. Mechanical demolition is typically used for removal of small concrete dams. Methods include boom-mounted hydraulic impact hammers (“hoe-rams”, crane-operated wrecking-balls, jack-hammers, and hydraulic splitters;
- Chemical demolition. Chemical expansive agents are mixed with water in drill holes to crack the concrete;
- Other demolition methods. Other less common concrete demolition methods include hydroblasting, flame-cutting and plasma, a high voltage electric discharge.

2. Embankment Removal Methods

Earthfill and rockfill dams are typically removed using common excavation methods and earth-moving equipment, and can provide a source of clay, sand, gravel, cobbles, and rock for site restoration or for local commercial use. For small embankment dams, a controlled breach may used providing the resulting erosion of the embankment does not create downstream damage or unacceptable environmental impacts.

5.2.5 Disposal of Removed Materials

Materials removed from a dam and its appurtenant structures may include a wide range of materials that must be disposed of in accordance with local regulations. Suitable waste disposal sites within a reasonable haul distance must be identified for all of these materials. On-site disposal of materials usually requires special permits and approvals from governmental and regulatory entities.

Hazardous materials will require special handling and disposal at approved facilities.

Waste concrete can be crushed for reuse as a road base or other construction uses. The disposal of reservoir sediments is discussed in Section 6.

5.2.6 Site Restoration

Following removal of all or parts of the dam and appurtenant structures, the remaining features may have to be modified to ensure public safety or to minimize long-term operation and maintenance requirements. Typical site restoration activities may include:

- Reshaping and revegetation of the dam site and reservoir areas;
- Backfilling stilling basins, plunge pools, powerplant tailrace areas, building foundations, and canals to the original or otherwise designated ground surface;
- Constructing stability berms or retaining walls to stabilize potentially unstable slopes or landslide areas following reservoir drawdown;
- Installing rock anchors or post-tensioned tendons to stabilize loose rock wedges in narrow rock canyons following dam removal;
- Plugging or backfilling tunnel portals to prevent entry, with possible special provisions for future inspection and drainage;
- Removing buried pipelines to prevent future deterioration and collapse;
- Removing or stabilizing tall and slender structures, such as intake towers and surge tanks that may be susceptible to toppling during an earthquake;

- Construction of dikes or levees or bank stabilisation along the downstream river channel to minimize flood damage;
- Installation of protective measures to deter trespassing and vandalism if portions of the dam and appurtenant structures remain;
- Disposition of land ownership, easements, and rights-of-way associated with the facilities.

6. SEDIMENT MANAGEMENT

6.1 Impacts of Sediment

In most cases sediments will be trapped in the reservoir behind a dam. The volume of deposited sediments and their physical and chemical properties can have a large impact on project costs and on the upstream and downstream river channel once the dam is removed.

In 2006, the United States Bureau of Reclamation identified five indicators for evaluating the extent of whether sediment management is likely to be a significant issue within a reservoir (Reference 13).

1. Relative Reservoir Capacity

The ratio of the normal reservoir storage capacity to the average annual inflow is an estimate of the reservoir sediment trap efficiency. Based on this relationship, a reservoir with the capacity to store more than 10% of the average annual inflow would be expected to trap between 75% and 100% of the sediment. A reservoir with a storage capacity of 1% of the average annual inflow would be expected to trap between 30% and 35% of the sediment. The sediment trap efficiency would be nearly zero if the reservoir storage capacity is less than 0.1% of the average annual inflow.

2. Reservoir Operations

The operation of the reservoir will influence the sediment trap efficiency and the distribution of sediments within the reservoir. The trap efficiency of the reservoir is greater if a substantial portion of the inflow is stored during floods. For run-of-river projects, where the reservoir is normally full, the trap efficiency would be lower.

3. Relative Reservoir Sediment Volume

The ratio of reservoir sediment volume to annual capacity of the river to transport sediment is a key indicator. When the reservoir sediment volume is small relative to the annual sediment transport capacity, the impact on the downstream river channel following dam removal will likely be small.

4. Relative Reservoir Width

The maximum reservoir width relative to the active channel width upstream of the dam is an indicator of how much sediment would be released during and after dam removal. If the reservoir is many times wider than the upstream river channel, the river may not be capable of eroding all of the reservoir sediments, even long after the dam is removed.

5. Relative Concentration of Contaminants

Even the erosion of clean sediments can cause turbidity and environmental impacts downstream of a dam. Sediments that contain contaminants above background levels would likely require removal and proper disposal or stabilization to prevent downstream transport.

The above indicators are useful for the initial evaluation of sediment management issues. However, extensive field investigations and hydraulic modeling may be necessary to characterize the sediments and evaluate the impact of sediment transport downstream once the dam is removed. A sediment management plan should be developed to address both engineering and environmental issues.

6.2 Sediment Management Alternatives

Sediment management alternatives can be grouped into four general categories as follows.

1. No Dam Removal Alternative

The dam, reservoir and sediments would be left in place under this alternative. Retaining the dam and keeping the sediments in place may be the preferred alternative if the sediments are contaminated. For example, the owner of Rising Pond Dam in Massachusetts initially planned to remove the dam rather than make safety repairs. However, since the sediments were found to be contaminated with Polychlorinated biphenyl (PCBs), it was found to be less expensive to repair the dam rather than remove the dam and dispose of the contaminated sediments.

2. River Erosion Alternative

Allowing reservoir sediments to erode and discharge into the downstream river channel by natural processes may be the least costly alternative. However, the downstream impacts must be evaluated and found to be acceptable. This alternative may not be feasible if the sediments are contaminated or if the sediments would negatively affect water quality or downstream infrastructure.

Numerical and physical modeling will likely be required in order to predict the rate and extent of reservoir sediment erosion and the transport and redistribution of the sediments within the reservoir and downstream river channel.

Removal of Elwha and Glines Canyon Dam in Washington State started in 2011. The project includes full removal of Elwha Dam and partial removal of Glines Canyon Dam leaving the spillway and powerhouse. The dams will be removed in stages to allow natural erosion of 6 to 9 Million cubic yards of sediment out of the 18 Million cubic yards in the reservoirs. Additional information on this project is included in Section 9.

3. Mechanical Removal Alternative

Mechanical removal of sediments reduces the downstream impacts but is potentially the most costly alternative. Sediments are removed by hydraulic or mechanical dredging or by excavation and transported by truck to an appropriate disposal site. Transport can be by slurry pipeline, truck, or conveyor. It may be required to transport contaminated sediments to a hazardous waste disposal site.

4. Stabilization Alternative

Sediments are stabilized in the reservoir by constructing a river channel through or around the sediments. This alternative is more expensive than river erosion but less expensive than mechanical removal.

6.3 Evaluation of Sediment Management Alternatives

Table 6-1 presents the possible combinations of dam decommissioning alternatives and sediment management alternatives (Reference 7).

Table 6-1 - Relationship between dam decommissioning and sediment management alternatives [ASCE, 1997]

Sediment management alternative	Dam decommissioning alternatives		
	Continued operation	**Partial dam removal**	**Full dam removal**
No action	• Reservoir sedimentation continues at existing rates, • Inflowing sediment loads are reduced through watershed conservation practices, or • Reservoir operations are modified to reduce sediment trap efficiency.	• Only applicable if most of the dam is left in place. • The reservoir sediment trap efficiency would be reduced. • Some sediment may be eroded from the reservoir.	• Not applicable.
River erosion	• Sluice gates are installed or modified to flush sediment from the reservoir. • Reservoir drawdown to help flush sediment.	• Partial erosion of sediment from the reservoir into the downstream river channel. • Potential erosion of the remaining sediment by sluicing and reservoir drawdown.	• Erosion of sediment from the reservoir into the downstream river channel. Erosion rates depend on the rate of dam removal and reservoir inflow. The amount of erosion depends on the ratio of reservoir width to river width.

Sediment management alternative	Dam decommissioning alternatives		
	Continued operation	Partial dam removal	Full dam removal
Mechanical removal	• Sediment removed from shallow depths by dredging or by conventional excavation after reservoir drawdown.	• Sediment removed from shallow depths before reservoir drawdown. • Sediment removed from deeper depths during reservoir drawdown.	• Sediment removed from shallow depths before reservoir drawdown. • Sediment removed from deeper depths during reservoir drawdown.
Stabilization	• The sediments are already stable, due to the presence of the dam and reservoir.	• Retain the lower portion of the dam to prevent the release of coarse sediments or retain most of the dam's length across the valley to help stabilize sediments along the reservoir margins. • Construction of a river channel through or around the reservoir sediments.	• Construction of a river channel through or around the existing reservoir sediments. • Relocate a portion of the sediments to areas within the reservoir area that will not be subject to high-velocity riverflow.

The steps to preparing alternative sediment management plans for evaluation are shown in **Table 6-2** (Reference 1).

Table 6-2 Steps to preparing alternative sediment management plans

1	Examine the possible range of dam decommissioning alternatives (continued operation, partial dam removal, and full dam removal).
2	Determine the reservoir sediment characteristics including volume, spatial distribution, particle-size distribution, unit weight, and chemical composition.
3	Investigate the existing and pre-dam geomorphology of the river channel upstream and downstream of the dam.
4	Inventory the existing infrastructure around the reservoir, along the downstream river channel, and along the upstream portion of the river channel influenced by the reservoir.
5	Determine the feasible range of sediment management alternatives and formulate specific alternatives.
6	Coordinate the details of each sediment management alternative with the other aspects of the dam decommissioning alternative.
7	Conduct an initial assessment of the risks, costs, and environmental impacts for each sediment management alternative.
8	Determine what mitigation measures may be necessary to make each alternative feasible and include these measures in the alternative.
9	Finalize the assessment of the costs, environmental impacts, and risks for each modified sediment management alternative.
10	Document the risks, costs, and environmental impacts of each alternative for consideration with the engineering and environmental components of the study. Provide technical support to the decision making process.

The selected sediment management alternative will depend on the sediment management objectives, design and construction constraints, and regulatory permit requirements. A comparison of the advantages and disadvantages of the sediment management alternatives are listed in **Table 6-3**.

Table 6-3 Summary Comparison of Sediment Management Alternatives [ASCE, 1997]

Sediment management alternative	**Advantages**	**Disadvantages**
No action	Low cost	• Continued problems for fish and boat passage. • For storage reservoirs, continued reservoir sedimentation, loss of reservoir capacity, and reduced sediment supply to the downstream river channel.
River erosion	• Potentially low cost alternative. • Sediment supply restored to the downstream river channel.	• Generally, largest risk of unanticipated impacts. • Temporary degradation of downstream water quality. • Potential for river channel aggradation downstream from the reservoir.
Mechanical removal	• Generally low risk of reservoir sediment release. • Low impacts to downstream water quality. • Low potential for short-term aggradation of the downstream river channel.	• High cost. • Disposal site may be difficult to locate. • Contaminated sediments, if present, could impact ground water at the disposal site.

Sediment management alternative	Advantages	Disadvantages
Stabilization	• Moderate cost. • Impacts avoided at other disposal sites. • Low to moderate impacts to downstream water quality. • Low potential for short-term aggradation of the downstream river channel.	• Long-term maintenance costs of the river channel through or around reservoir sediments. • Potential for failure of sediment stabilization measures. • Reservoir area not restored to natural conditions.

The selected sediment management plan may be a combination of several alternatives. The removal of Matilija Dam in California has been under study and planning for many years. The 200 foot high long concrete arch dam was built for water supply but the reservoir is now about 90% filled with 6 Million cubic yards of sediments. Numerous sediment management alternatives have been studied. The preferred alternative is to remove about 2.1 Million cubic yards of fine sediments by slurry pipeline and allow the coarse sediments to erode naturally downstream to the ocean. Additional details of the project are included in Section 9. The estimated cost of the project is 130 Million United States Dollars.

San Clemente Dam in California is a 106 foot high by 300 foot long concrete arch dam. The dam was constructed for water supply but the reservoir is about 90% filled with 2.5 Million cubic yards of sediments. In addition the dam does not meet current safety standards under earthquake and flood loading. Mechanical removal of the sediments and hauling by trucks was ruled out due to traffic impacts and cost. Two options are being considered:

1) **Off-Site Storage Option**: Approximately 2.5 Million cubic yards of sediment would be excavated from the reservoir and transported less than one-half mile by a conveyor belt system to a small canyon with no active watercourse. The reservoir would be de-watered by diverting the Carmel River to San Clemente Creek. After removal of the sediments and the dam, the river channel would be restored and natural flows directed through the reservoir site.

2) **By-Pass Option**: Approximately 2,500 feet upstream of the dam, a portion of the Carmel River would be permanently bypassed by cutting a 450 foot long channel to San Clemente Creek. The dam and fish ladder would be removed. The bypassed portion of the Carmel River would be used as a sediment disposal site. Approximately 380,000 cubic yards of sediment in the San Clemente Creek arm would be relocated to the Carmel River arm of the reservoir.

The cost to remove the sediments is estimated at 75 to 188 Million United States Dollars. Additional details of the project are included in Section 9.

7. PERFORMANCE MONITORING

7.1 General

Performance monitoring may be needed during any phase of the decommissioning process (reservoir drawdown, construction, post process of decommissioning). It's may be necessary in order to quantify and evaluate the environmental impacts caused by a dam decommissioning project, even though many of the impacts would likely be identified and partially quantified throughout the dam removal evaluation process. Environmental impacts may be characterized as desirable or undesirable, and are classified as direct, indirect, or cumulative.

- Direct impacts of an action occur at approximately the same time and location as the action itself;
- Indirect impacts are reasonably foreseeable consequences that occur later in time (in the future) or at some upstream or downstream (relative) distance from the initiating action;
- Cumulative impacts refer to the incremental effect of an action which is added to other effects derived from past, present and future actions.

An environmental review performed during the project planning stages should identify and address potential impacts. A performance monitoring program should address the following topics:

- Performance monitoring program objectives;
- Minimal duration of the program;
- List of elements that should be monitored during and after dam decommissioning;
- Limits or criteria of acceptability for each element;

- Periodic reporting requirements (frequency, format);
- Mitigating measures in the event that a problematic situation occurs;
- Intervention procedure in the event of an unforeseen situation.

The physical, biological, and socioeconomic impacts of a dam decommissioning project, and the associated monitoring and potential mitigation of these impacts are discussed in the following sections.

7.2 Physical Impacts

Typical physical impact parameters related to dam decommissioning projects include:

- Flood flow – higher downstream peaks and greater flow fluctuations;
- Groundwater level – lower groundwater levels and less well production;
- Water quality - changes in turbidity, temperature, dissolved oxygen, total suspended and dissolved solids, hardness, nutrients, metals, and contaminants;
- Sediment bed load and transport – sediment deposition can decrease downstream river capacity causing flooding and bank erosion;
- Ice jam formation - changes in ice jam patterns at cold weather sites

The river erosion alternative generally is the most exhaustive analysis from a sedimentation perspective. To predict the impacts associated with the movement of cumulated sediments, a model of the system needs to be constructed. The complexity of the model applied to the system should be consistent with the data and resources available. There are two important elements to consider when modeling the downstream impacts:

- Sediment transport through pool-riffle systems;
- Transport of fine sediment over a rough bed.

In order to verify these predictions, monitoring is essential during reservoir drawdown.

For projects that have a significant reservoir sediment volume, monitoring and adaptive management are critical components. Typically, the objectives of the sediment monitoring plan are to detect and avoid significant impacts related to flooding, erosion of infrastructure, and water quality. In addition, the monitoring program could assess project performance and provide scientific information applicable to other projects. A monitoring program could be designed to provide the following types of information:

- Reservoir sediment erosion and redistribution;
- Species composition and abundance;
- Aquatic habitat assessment and suitability;
- Slope stability within the reservoir and downstream river channel;
- Water quality, including suspended sediment concentrations;
- Riverbed aggradation and flood stage along the downstream river channel;
- Aquifer (groundwater) characteristics;
- River channel planform and channel geometry;
- Large woody debris;
- Coastal processes, including the delta bathymetry and turbidity plume.

The frequency and duration of monitoring activities depend on the local project conditions such as the relative volume of the reservoir sediment, rate of dam removal, time of the year, hydrology, and project budget. Measurements of initial conditions are necessary to establish a monitoring baseline for comparison. Monitoring should be conducted prior to dam removal, for a period sufficiently long to test monitoring protocols and determine the range of variability in the data. Monitoring should continue after the dam removal until the reservoir sediments have either been eroded and flushed into the downstream river channel or stabilized in the reservoir.

7.3 Biological Impacts

Typical biological impact parameters associated with dam decommissioning include:

- Abundance and diversity of fish, invertebrates and plankton;
- Aquatic habitat for fish reproduction and nursery;
- Wildlife and vegetation.

An assessment of biological impacts must begin with information on the existing conditions. Habitat surveys may be needed to identify important reproductive and nursery habitat, and focus on particular seasons depending on the species of concern.

Partial or full removal of a dam that permanently reduces reservoir levels will alter the resident fish community and could affect surrounding wildlife habitat. Some apprehended impact negative or positive may be:

- Reduction of access to an upstream aquatic habitat used for fish reproduction and nursery;
- Transition of lake fish community to a river community;
- Easier passage to anadromous fishes such as salmon by removing barriers;

- Reintroduction of some anadromous fish to upstream areas and extension of the range of fish populations [ASCE, 1997];
- Drainage of existing wetlands affecting wildlife species that depend on shallow water habitat;
- Possible natural restoration of previously inundated areas or other areas along the river corridor.

Species of special concern include fish, animals, and plants either already listed as threatened, endangered, or proposed, under the authority responsible of endangered species. Resource agencies should be consulted early during the design of studies to document the presence, absence, relocation, or recovery of sensitive species and habitat. Studies may have to be performed during particular times of the year, and over several years, to account for natural variation in nesting and migratory patterns. Development of conservation and management plans with a specific monitoring program in order to avoid or minimize or evaluate impacts on listed species and habitats may be necessary.

7.4 Socioeconomic Impacts

Socioeconomic impacts include:

- Land use (navigation, water supply, commercial fishing, local accessibility problem);
- Recreational activities (boating, fishing, properties value, local economic impact);
- Cultural, historical and archaeological impacts (exposed artefacts to erosion or human disturbance);
- Aesthetics (natural and man-made landscape features perceived through the human senses).

Any socioeconomic monitoring program should be built and implemented with the input of key stakeholders and regulatory agencies. key stakeholder input on the final project design of dam decommissioning is important.

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9. SELECTED CASE STUDIES

Decommissioning of Dams in Australia

1. **Lake Mokoan - Victoria**

In 2004 the Victorian Government announced the decision to proceed with Australia's largest dam decommissioning project, the return of the 365,000ML capacity Lake Mokoan to a wetland. The storage was constructed by the State Rivers & Water Supply Commission in the late 1960s over the site of the former Winton Swamp and commissioned in 1971.

The lake was a large, shallow, off-stream water storage with a 7.5 kilometre, 1 Million cubic metre earthen embankment. It had a maximum capacity of 365,000 Megalitres with a surface area of 7,890 hectares and a maximum depth of 7.3 metres. The Lake was intended to supply water for irrigation and stock & domestic use. Lake Mokoan was also used to supplement flows in the River Murray.

a. Issues Affecting Lake Mokoan prior to Decommissioning

Blue-green algae and Drought

During the drought of 1982/83, Lake Mokoan was drawn down rapidly to 4 % of its capacity. When the Lake refilled in 1986, mud and silt activated by wind and wave action increased the turbidity of the stored water. This meant that growth of submerged plants was limited and blooms of toxic Blue-green algae (BGA) became more common. BGA blooms occurred regularly at Lake Mokoan after the late 1980s and, for the duration of blooms, the use of Mokoan waters for recreation or irrigation was periodically restricted.

In the summer of 2008/09 the prolonged drought took its ultimate toll with extreme evaporation rates leaving the lake totally dry. This situation repeated in 2009/10 and effectively remained in that condition until decommissioning formally occurred in late 2009.

Dam Safety

An operating level restriction was placed on Mokoan as a result the slope failures and dam safety review, with a maximum operating level of 1 metre below Full Supply Level being imposed, thereby limiting the storage to 78% of capacity. A design review in 2003 identified that embankment stabilisation works were required if the embankment was to be maintained under its current loading at an estimated cost of 20 Million Australian Dollars.

Water Losses

The average annual evaporation loss from Lake Mokoan was assessed at 50,000 Megalitres. Evaporation losses from a decommissioned lake site were assessed to be of the order of 15,000 Megalitres resulting in a net evaporation loss reduction of 35,000 Megalitres once Mokoan was removed from the system.

b. Background to the Decision to Decommission

In 2002 the Victorian Government initiated the Lake Mokoan Study to assess water savings options for Lake Mokoan in the context of seeking the best solution to the prevailing issues associated with Lake Mokoan:

- water loss from evaporation;
- poor water quality;
- the costs of operating the lake, the equitable sharing of those costs; and
  dam safety upgrade costs.

The decision to fully decommission Lake Mokoan was announced in June 2004 and it was expected to provide 44,000 Megalitres of water each year to improve the health of the Broken, Goulburn, Snowy and Murray Rivers. As a result of the removal of the 365,000 Megalitres of storage capacity, a significant reduction in annual supply capacity and removal of direct access to water for approximately 35 irrigation and domestic and stock customers occurred.

Decommissioning of the Lake was also to result in 8,100 hectares of land becoming available for alternative uses and would render obsolete a 7.5 kilometres long, 1 Million cubic metre embankment, 29 kilometres of major supply channels and a larger number of associated water supply infrastructure assets.

The Mokoan Project was to include five broad elements:

- works to provide an alternative supply to direct diverters from the lake;
- water supply offset measures to maintain the reliability of water supply in the Broken system;
- measures to allow some of the water savings achieved to benefit the Snowy River (this element of the project is not addressed further in this paper);
- work to decommission the Lake Mokoan assets;
- rehabilitation of the Mokoan storage site.

The decision to decommission Mokoan resulted in significant community and stakeholder interest and a degree of active local opposition, which was to continue for a period of almost 5 years, throughout the delivery of the project.

c. Decommissioning Timeline and Process

The process of decommissioning from initial studies to identify potential water savings in the Victorian supply system began in 1998 with the final decommissioning including offsets being completed in 2011 with a further program of works to rehabilitate the original wetland ongoing until 2018. This length of time reflects the complexity in decommissioning an active storage with many involved stakeholders.

Asset decommissioning entailed the removal of part of the diversion structure on Holland's Creek, the conversion of 14 kilometres of the Mokoan Inlet channel into a more stable, self-sustaining local drainage depression by raising bed levels flattening batters and removal of the original uncompacted channel spoil banks.

In late 2011 approximately 7 kilometres of this depression had been landscaped and is in the process of being transferred to management by the local municipality with the expectation of development of a recreation access-way between Benalla and the new Winton Wetland development.

Asset decommissioning has also required breaching the former Mokoan embankment. The breach includes a concrete lined section to provide a fixed discharge level from the new Winton Wetlands back into the Broken River. This level corresponds with the overflow level of the original Winton Swamp. The breach width has been sized to provide a balance between natural wetland overflow requirements and flood risk minimisation downstream of the breach area.

Asset decommissioning works were undertaken under several primarily earthworks contracts at a cost of approximately 6 Million Australian Dollars. The progress of the channel decommissioning works in particular was hampered by ongoing wet weather (and floods) which commenced in March 2010 and continued through until February 2011.

Embankment Breach, Lake Diverters with Pump Station (foreground), Lake Mokoan dry bed (background)

Embankment Breach and Wetland and showing overflow control structure

d. Rehabilitation of Lake Mokoan Storage Site

The government announcement of the decision to decommission Lake Mokoan in 2004 included reference to an intent to rehabilitate the Winton wetlands system on the decommissioned storage site with a funding commitment of 1 Million Australian Dollars. A steering committee was established to guide the development of a vision and strategy for the future land use, and provide recommendations and advice to the Victorian Government in the form of the Lake Mokoan Future Land Use Strategy.

A series of community information sessions and workshops were held to identify potential opportunities for the site. In addition consultants and various experts were involved and a range of identified land use options. The Lake Mokoan Future Land Use Strategy (FLUS) revolved around a wetland system and recommended other opportunities for land uses on the remainder of site such as agriculture, tourism, recreation and forestry.

The FLUS was endorsed by the Government with a commitment to fund up to 20 Million Australian Dollars (including receipts from land sales) for implementation, a significant increase on the original commitment of 1 Million Australian Dollars (excluding receipts from land sales). Land sale receipts were estimated to be around 3 Million Australian Dollars. A Committee of Management, which included community representatives, was seen as the best way in which to implement the FLUS.

e. Project Estimates

The total estimated cost of the project at the time of the decision to decommission was 60 Million Australian Dollars. This proved to be overly optimistic, with the final project cost being in the order of 107 Million Australian Dollars. A significant component of the increase was the additional 17 Million Australian Dollars provided to support a much higher quality future wetland development than was originally envisaged. Much of the remaining cost differential can be attributed to the level of contingency applied to various project elements for which only rudimentary understanding of concepts solutions was available. The provision of 40% contingency was found to be inadequate, an allowance of 100% would have been more appropriate. Regardless of the cost increase, the project remained a viable water savings project in comparison other alternatives.

Greater detail on the Lake Mokoan decommissioning can be found in reference 22.

2. Crusoe Reservoir – Victoria

Crusoe Reservoir was built in 1873 and had a storage volume at full supply level of 1,500 Megalitres. It was owned and operated by Coliban Water. In 2002, new state-of-the-art water treatment works were constructed at another reservoir which meant that Crusoe Reservoir was no longer required for water supply purposes.

The City of Greater Bendigo expressed interest in using Crusoe Reservoir as a passive recreational facility to Bendigo (population over 75,000) – known as the 'Beach for Bendigo' project for swimmers, fishing, paddle/row boats and walking. To retain the reservoir for this alternate use required a safety upgrade and this was not considered the cheapest option for Coliban Water. The cheapest option was to partially remove the embankment and re-establish the surrounding Box-Ironbark forest (material from breached section of embankment was to be used to cap silt deposits).

The option to upgrade the reservoir and pass ownership on to the State Government under the management of the City of Greater Bendigo was the preferred option and offered a number of key outcomes:

- It provided a community facility;
- Retained the heritage assets and;
- Continued to provide a habitat for wildlife including a nationally significant water bird.

The safety upgrade works required prior to handing over to the new owner for recreation purposes included:

- Permanently reducing the Full Supply level by 2m;
- Enlarging the spillway;
- An embankment toe berm and drain;
- Upgrading a high level outlet conduit and removal of the original outlet;
- Partially filling historic settling ponds at the toe of the dam for safety and preservation reasons.

These upgrade works cost 2.8 Million Australian Dollars, 2003. In addition there were approximately another 0.2 Million Australian Dollars in recurrent costs such as risk assessments, land transfer and documentation production. These activities were funded by Coliban Water as its contribution to the local community. Following transfer Coliban Water has no responsibility over the reservoir with the City of Greater Bendigo being the manager.

A significant component of the decommissioning process was a lengthy consultation process with the community and other key stakeholders the Department of Sustainability and Environment (DSE, the regulating authority) and the City of Greater Bendigo. The process from initial assessment of the reservoir and its function in the Coliban Water Supply system through to eventual transfer of the asset from Coliban Water to the City of Greater Bendigo took around ten years and involved:

- Initial Portfolio Risk Assessment 1997/8;
- Discussions with the Department of Sustainability and Environment & the City of Greater Bendigo (COGB) commencing in 1999;

- Options report in 2000;
- Joint COGB & Coliban public announcement in 2000;
- Memorandum of Understanding signed in 2003;
- Dams Improvement Upgrades completed in 2004;
- Transfer of land in 2006;
- Surveillance training & document handover in 2007.

The administrative costs to the various parties in man hours and other resources required is not included in the dollar totals quoted above.

In addition there were two specific issues that required further evaluation in the decommissioning process. These were:

a. European Heritage

Crusoe Reservoir is on the Victorian State Heritage Register along with the Coliban Water Supply System. It is an historically important engineering system designed to bring water to the City of Bendigo which commenced operation in 1877. The system is one of the earliest water supply systems in the region dating from the early Gold Rush in Victoria.

b. Nationally Significant Bird

Referral was made to Environment Australia due to the presence of a nationally significant water bird. Actions to minimise any impact on the species included:

- Avoid drawing water levels down at the peak-breeding season to discourage breeding at the reservoir and ensuring a nearby reservoir remained untouched to provide an alternate habitat during any works;
- Closely monitor the breeding habitat to ensure that it is protected from the works.

3. Victoria Dam - Western Australia

This was a 22 metre high concrete gravity dam originally constructed in 1891 that stored 0.86 Million metres of water. The concrete quality had deteriorated to the extent that keeping it in service was no longer viable. However, Munday Brook was a valuable source of water for the city and when the dam was decommissioned it was replaced by a new RCC dam built upstream to a height of 55 metres and storing almost 10 Million cubic metres of water. The decommissioning and reconstruction of the new dam upstream were completed in 1991, 100 years after the original structure was decommissioned.

A range of remedial works had been undertaken over the years. In 1966, the first stage involved constructing a concrete skin on the upstream side. This was largely successful in controlling leaching of the concrete by the aggressive water in the reservoir. The body concrete was found to contain less than 70 kilograms of cement per cubic metre of concrete and there were significant partings on the lift joints which were found to be quite smooth and completely lacking in bond. While the construction of a temporary enlargement to the spillway capacity was achieved in 1987, the solution reduced the operating level resulting in loss of yield. The only real solution available to take advantage of the yield available was to construct the new dam upstream.

The original dam has been retained downstream, albeit with a hole in the middle. The old portion of the reservoir between the two dams has been revegetated and landscaped and the whole area is now used for recreation.

The overall project cost was 40 Million Australia Dollars in 1991. (Note Australia Dollar 10 is approximately equal to United States Dollar 8).

4. Harvey Weir – Western Australia

This was a 14 metre high structure originally built in 1916 as a concrete gravity structure to supply water to the Harvey irrigation district. In 1932 it was raised by 6 metres, with a central concrete gravity spillway and flanking embankments of rock and earthfill. During a major flood in 1964 there were serious concerns about the safety of the structure. In 1970, the dam was post tensioned after the raised section of the spillway split apart from the base.

Designed as a temporary measure, the dam was retained in service for another 30 years until it was replaced by a new large dam downstream. Harvey Weir is normally only exposed when the waters of the reservoir fall to very low levels.

Alternatives to the project, such as an RCC alternative were considered as being less cost effective alternatives. The replacement was triggered by the need to further develop the water resources of the river basin, the total project costing about 75 Million Australian Dollars.

5. Oaky Creek Dam – Queensland

The Oaky Creek Dam was a 10 metre high, 1 Million cubic metres capacity structure that was partially overtopped during Cyclone Steve in February 2000 and only survived because a right abutment training wall failed and acted as an unplanned fuse plug. Approximately 300,000 Australian Dollars was spent providing an interim 50% upgrade to the existing spillway capacity while a court order was sought to decommission the dam. Once received, a further 300,000 Australian Dollars was spent decommissioning the dam and rehabilitating the storage area. The alternative to removing the dam was to significantly upgrade the spillway capacity. However, the dam owner did not have the financial resources to do this and the State had to step in and undertake the decommissioning which was the cheaper alternative.

6. Mount Morgan Dams - Queensland

The Mount Morgan Dams were built in the 1890s for water supply to the Mount Morgan Mine and were progressively contaminated by highly acid producing tailings from the mine site. This lead to deterioration of the weir concrete and concerns over the safety of the structures. The project to decommission the structures also involved the dredging or excavation of approximately 500,000 tonnes of tailings from the dam storages and the storing of this material in the mine pit.

Details of the Mount Morgan Dams are as follows:

Dam 4 4.5 metres high, 30,000 cubic metres

Dam 5 4.5 metres high, 42,000 cubic metres

Dam 6 9.7 metres high, 64,000 cubic metres

The overall cost of the project, including the removal of the tailings in 2004 was 7.3 Million Australian Dollars. Because of the severe state of the dams and because of the contamination in the river, no other alternatives were considered.

7. Wellington Dam - New South Wales

Wellington Dam was built in 1899 and removed in 2002. It was a concrete gravity dam 15 metres high storing 90,000 cubic metres. It was removed for dam safety reasons (severely deteriorated concrete) at a cost of some 1 Million Australian Dollars. Alternatives such as buttressing and lowering were also considered.

Decommissioning of Dams in Italy

1. Disueri Dam

Disueri dam (Sicily) was built on the Gela River for irrigation purposes with public funds soon after the 2nd World War. The 48 metre high dam was constructed of dry stones on a concrete bed and provided with a concrete cut-off located at the upstream dam toe. The waterproofing of the upstream face was provided by concrete slabs.

The need to operate the dam as soon as possible resulted in the underestimation of the reservoir banks stability. As a matter of fact, in 1952, after heavy winter rains a landslide occurred affecting the left dam abutment. The works immediately undertaken did not give the expected results. Additional investigations provided a clearer geological framework but the instability phenomena of reservoir banks continued and the Authorities imposed at the limitation on the water level in the reservoir. Further problems related to the reservoir silting reduced the reservoir capacity to half in less than ten years.

Towards the end of the 1960’s new problems were observed: cracks appeared on the concrete upstream facing probably caused by consolidation phenomena in the foundation and to the additional thrust of sediments. Moreover, updated hydrological studies suggested a further reduction of the water level in the reservoir.

The dam owner (Consorzio di Bonifica del Gela) decided to decommission the dam and to construct a new structure located downstream of the old Disueri dam (**Fig. 1**).

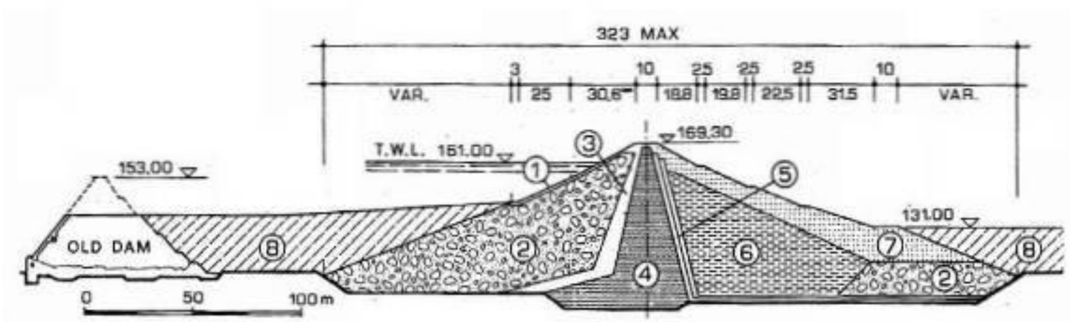


Fig. 1 –Disueri dam: vertical cross section of the new and old structures

The new project was approved in 1979 and the dam was built in the period 1981-1984. The old dam worked as a provisional structure (cofferdam) during the construction of the new dam. The old dam was breached in 1994 to allow the continuity of the reservoir when the new dam was completed (**Fig. 2**).

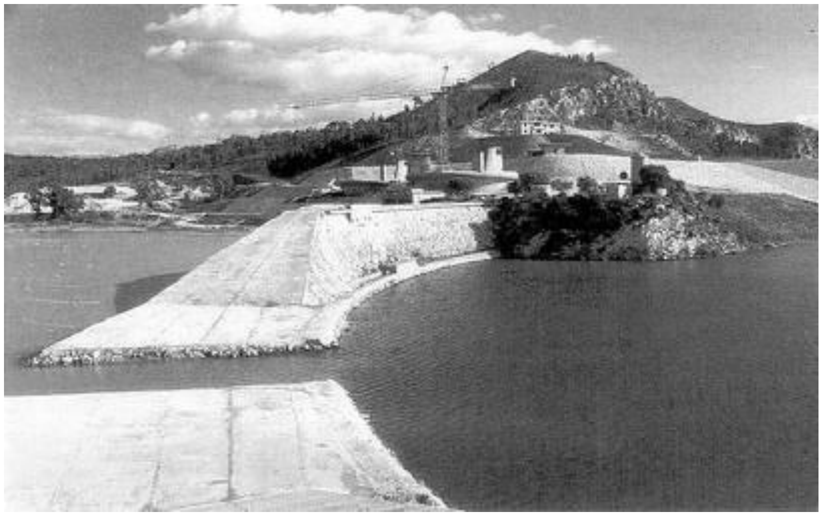


Fig. 2 –Disueri dam: view of the breach built on the central part of the dam

2. **Isollaz Dam**

The compensation reservoir created by the Isollaz dam, high 16.3 metres, (**Fig. 3**) was located in Val d'Aosta, North-West of Italy.

The embankment dam was built in the period 1941-'42. The inner faces were waterproofed by concrete slabs; the outer faces were protected by stone masonry. A concrete bed, integrated with a drainage system, was built to prevent leakage from the reservoir.

Fig. 3 – Isollaz reservoir before the decommissioning

Fig. 4 – View of the actual state of the works

In 1998 the operation of the dam was stopped because of the progressive increase of leakage in different areas of the reservoir.

Repair works were estimated to be too high by the owner (ENEL) compared with the income and the decommissioning of the dam was decided.

The decommissioning design included (**Fig. 4**):

- re-profiling of the dam shells in order to reach the slopes established by the current Italian Law for embankment dams;
- demolition of the discharge outlet;
- construction of a 6 m wide breach in the same location of the demolished outlet, protected by a reinforced concrete bed and containment walls.

The decommissioning project was started in 1998, submitted to the National Dam Service in 2000 and approved in 2002. The works were carried out between October 2002 and April 2003.

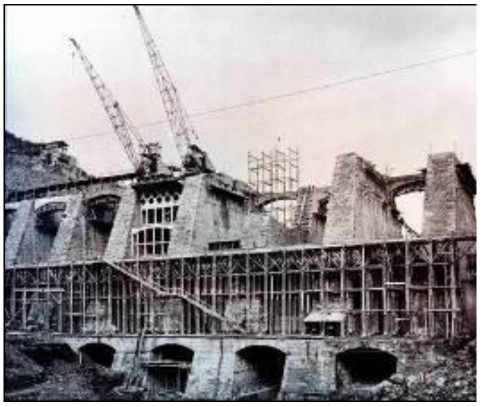
3. Santa Chiara d'Ula Dam

Santa Chiara d'Ula dam (Sardinia), built on the Tirso River in the period 1918-1924 as a multipurpose plant, was a reinforced concrete multi-arch structure with masonry buttresses. The dam height was 70 metres and the reservoir storage was 400 Million cubic metres (**Fig. 5**).

The dam was bombed by the Allied Air Forces during the 2^{nd} World War but was repaired and put in operation again. In 1968 the presence of cracks on several buttresses suggested a reduction of the reservoir water level. The capacity was reduced to 150 Million cubic metres. Subsequently, the construction of a new dam located downstream was decided by the owner (Consorzio di Bonifica Oristanese).

The new concrete gravity structure, named La Cantoniera (**Fig. 6**), is 100 metres high with a reservoir capacity of 780 Million cubic metres.

The decommissioning of the old structure was carried out by the partial demolition of two vaults (among the highest) to allow the free water flow in the new reservoir. The civil works necessary to channel the water through the vaults to be demolished (during the normal operation of the new dam) were carried out without empting the reservoir (**Fig. 7**). The demolition of the vaults was performed using a diamond wire saw system when the water level upstream and downstream the dam was the same.



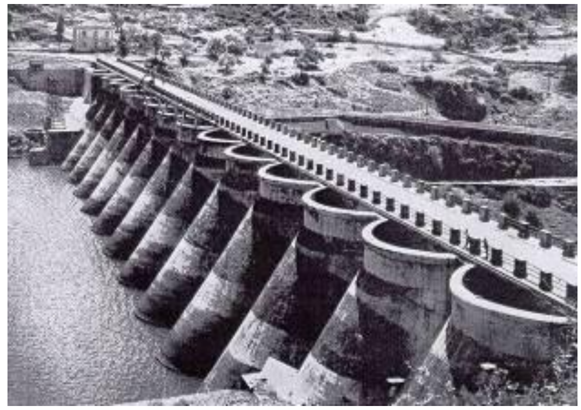


Fig. 5 – Santa Chiara d'Ula dam during construction (left) and the view from upstream

Fig. 6 – La Cantoniera dam seen from the right bank

The impoundment of the new reservoir formed by La Cantoniera dam has almost completely submerged Santa Chiara d'Ula dam (**Fig. 8**) that was declared decommissioned on 2001.

4. Rio Salita Dam

The dam, a gravity masonry rectilinear structure with a height of about 15 metres, was built in the 1940's (**Fig. 9**).

Fig. 7 – Civil works (in progress) to channel the water through the buttresses of the vault to be demolished

Fig. 8 – Downstream view of the dam: in the foreground the new Omodeo bridge that connects the lake banks

The hydrological studies carried out according to updated standards have indicated the inadequacy of the outlet capacity. Moreover, the dam owner (ENEL) decided to update the hydropower system.

According to the former hydraulic scheme, the very small reservoir formed by the dam (only 21,000 cubic metres), in connection with the surge tank (located at about 2 kilometres of distance from the dam), provided damping of the hydraulic oscillations caused by the hydropower operation.

The refurbishment of the hydraulic machinery by the dam owner allowed relying solely on the surge tank. Therefore, the reservoir was no longer required.

It was decided to demolish most of the dam by forming a wide breach in the central part of the dam.

A diamond wire saw system was used to cut both the 45° inclined surfaces and the horizontal one.

Only limited parts of the structure close to the abutments and the facing of the banks already present in the reservoir area remain. All the surfaces of the remaining works were lined with sandstone recovered from the demolition (**Fig. 10**).

At present the structure is a debris dam without any water retaining capacity.

Fig. 9 – The Rio Salita dam before the demolition

Fig. 10 – The dam after the demolition

5. Corongiu Dam

The Corongiu water supply system (Sardinia) was formed by three old dams to supply drinking water to Cagliari.

The first dam, 20 metres high and with a reservoir capacity of 900,000 cubic metres, had been in service since 1867. The second one, constructed upstream the first dam in 1915, is 15 metres high and has a reservoir capacity of 440,000 cubic metres. The third one, built upstream the second dam, has been in operation since the 1930's. It is 34 metres high and has a reservoir capacity of 4.3 Million cubic metres.

Hydrological studies carried out in the 1990's have indicated the inadequacy of outlets and the need to revise the whole project. Moreover, the first dam had been suffering from stability problems caused by inadequate filters in the dam body and leakage from the downstream dam face.

The new project included the upgrading of the second dam's spillway. The dam body was cut on its left side (**Fig. 11**) to accommodate a new spillway which is equipped with two hydraulically operated flap-gates (8 metres wide x 5 metres high). Some minor works were performed on the third dam, in particular to restore the equipment of the control room.

Finally, the oldest Corongiu dam was completely demolished.

Fig. 10 – The diamond wire cuts and the demolition of the left side of Corongiu dam II to accommodate the new spillway

Decommissioning of Dams in the United States

1. Saeltzer Dam - California

The dam was completed in 1912 at the site of an older masonry dam. Saeltzer Dam was a composite gravity structure consisting of a reinforced concrete wall anchored to a timber crib structure, ranging in height from about 3 feet to 20 feet (average 15 feet), with a crest length of about 185 feet.

By 1997, the owner and its shareholders reported the demand for water diversions at the dam had significantly diminished and that a more efficient means of diverting and conveying water was desired. The physical condition of the dam was very poor, with extensive concrete deterioration and cracking visible, and evidence of numerous leaks and concrete repairs.

In 1992, the Bureau of Reclamation was authorized and directed under the Central Valley Project Improvement Act (CVPIA), to implement a program that would increase the anadromous fish populations in the Central Valley rivers and streams within 10 years.

The Saeltzer Dam Fish Passage and Flow Protection Project was established to meet the following project objectives:

- Provide fish passage;
- Protect instream flows;
- Provide sediment transport;
- Improve aquatic and terrestrial communities;
- Maintain water supply;
- Improve public safety;
- Eliminate dam failure potential.

Various dam removal and fish passage alternatives were the subject of separate technical studies performed in 1997. In January 2000, Reclamation issued a reconnaissance report for dam removal and for several structural alternatives to improve fish passage while maintaining agricultural diversions at the site. Federal, State, and local agencies agreed that optimum accessibility to upstream spawning and rearing habitat would only be achieved with dam removal.

The proposed project included the excavation and removal of sediments and other fluvial materials that were deposited behind Saeltzer Dam over the years. Some of the fluvial materials may have been previously exposed to mercury used to separate gold-bearing minerals during historic mining and dredging activities in late 1800s and early 1900s. An extensive sampling and testing program of the sediments upstream and downstream of the dam was performed concurrently with the environmental compliance activities.

The sediment characterization study also provided estimates of the total volume and gradation of sediments within the reservoir pool.

Removal of the dam and reservoir sediment required the construction of a temporary diversion channel that would completely bypass the reservoir area.

The reservoir sediments were excavated from the main stream channel and from a smaller side channel from October 5 through October 19, 2000. During this period, 12,500 cubic yards of material was removed and hauled to an onsite disposal area above the floodplain to the south of the reservoir area.

The entire project from design through construction was completed within 8 months for a total cost of about 3.5 Million United States Dollars. The costs included 2.8 Million United States Dollars for the construction contract, 309,000 United States Dollars for the sediment characterization and sampling contract, and 400,000 United States Dollars for non-contract costs (engineering design, contract administration, construction management, and environmental compliance). An additional 2.5 Million United States Dollars was paid to the owner for their water rights and property interests.

Additional details on the project can be found in reference 20.

2. Chiloquin Dam - Oregon

Chiloquin Dam was located on the Sprague River in south central Oregon. The dam consisted of a concrete gravity weir about 10 feet high and 130 feet long and an embankment section on the left abutment about 21 feet high and 90 feet long. Other project features included a canal headworks structure, two sluiceways, one active fish ladder and two abandoned fish ladders. It was determined that the dam effectively blocks passage for endangered sucker fish to about 80 miles of potential spawning range. Federal legislation passed in 2002 required a study of the feasibility of providing adequate upstream and downstream passage of the endangered species. The study was to evaluate various fish passage alternatives, including dam removal, and determine the preferred action which maintains water deliveries to the dam owner.

Removal of Chiloquin Dam would require the construction of a downstream pumping plant to supply irrigation water to the canal. In addition the point of diversion would have to be legally transferred from the Sprague River to the new pump diversion site downstream on the Williamson River. The pumping plant would result in increased operating costs over the existing gravity diversion system. Partial dam removal options were not considered due to the concern for public safety and potential for legal liability.

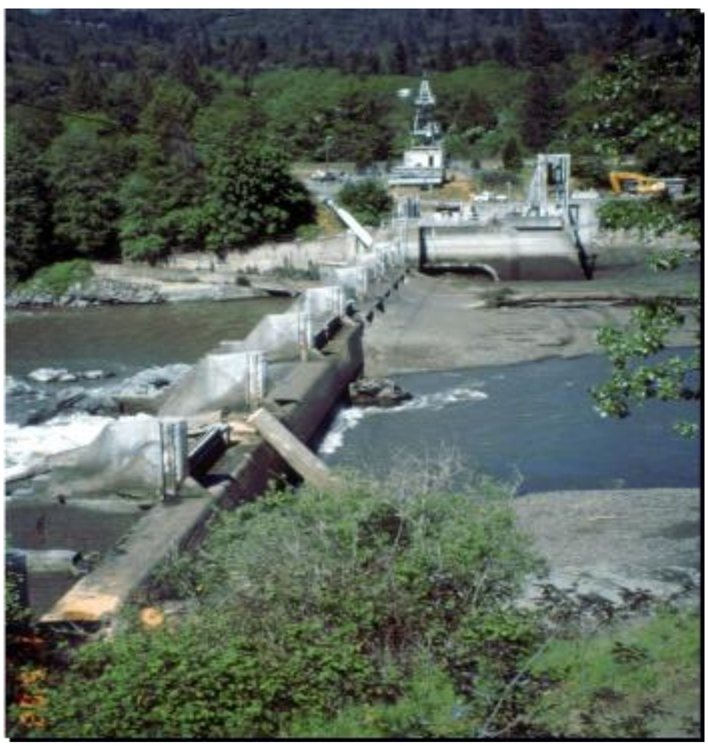
Two structural alternatives were evaluated which would replace the existing concrete overflow weir a gated section that would permit lowering the reservoir level during critical fish migration periods. The two gate options considered were three radial gates or a single Obermeyer crest gate. The existing right ladder would be retained. These alternatives would maintain gravity diversion to the canal but a pumping station would be required on the Williamson River for use during the early summer when both fish migration releases and irrigation diversions may be required.

In 2003, the dam removal alternative was selected as the best solution for fish passage, requiring a new pumping station about mile downstream to provide irrigation flows to the irrigation canal. Detailed feasibility studies and environmental compliance activities were performed in 2004. The owner signed a cooperative agreement in 2006 to remove the dam.

The construction contract was awarded in February 2007. Construction of the pumping plant was completed by April 15, 2008 to allow sixty days of operational testing before the dam removal could begin. The dam removal was completed by December 2008 at a total cost of 18 Million United States Dollars for design, construction, environmental compliance (including permitting and monitoring), and mitigation. The project costs include nearly 9 Million United States Dollars in construction contract costs for removal of the dam, construction of the new pumping plant and conveyance systems, and compensation for future operation and maintenance of the pumping plant.

Additional details on the project can be found in reference 14.

3. Savage Rapids Dam - Oregon



Savage Rapids Dam was located on the Rogue River in southwestern Oregon. The dam was a combination concrete gravity and multiple arch diversion facility. The facility consisted of the north fish ladder and pumping plant on the right abutment, a multiple-arch reinforced concrete overflow spillway through the main river channel, river outlet works, concrete gravity overflow spillway, headworks for a gravity fed canal, and south fish ladder on the left abutment. The dam had an overall length of 465 feet and the overflow section had a structural height of 33 feet. The overflow section is 394 feet long and is divided into 16 bays separated by piers or buttresses. An additional 11 feet of head was developed during the irrigation season by installing stoplogs on top of the spillway crest.

Despite having a fish ladder at each abutment, the dam was considered a major impediment to fish migration. The recommended least-cost alternative to improve fish passage and maintain irrigation diversions was to construct a new diversion facility and remove a portion of the dam. The new diversion facility consists of a new pumping plant on the downstream left abutment and a new pipe support bridge to fulfill irrigation demands on both sides of the river. Construction of the new pumping plant and pipe support bridge began in 2006. Removal of the dam began in April 2009 and was completed by November 2009.

The contract cost for construction of the new diversion facility and removal of the dam was approximately 28.3 Million United States Dollars. The total estimated cost for the project was about 39.3 Million United States Dollars.

Additional details on the project can be found in references 17 and 18 and at http://en.wikipedia.org/wiki/Savage_Rapids_Dam

4. Elwha River Restoration Project – Washington

Elwha and Glines Canyon Dams are located on the Elwha River on the Olympic Peninsula in Washington State. The dams were built by private interests for power production but have been acquired by the Federal government as part of an agreement to remove both dams to improve fish passage.

Elwha Dam, located at river mile 4.9, is a 108-foot-high concrete gravity dam that forms Lake Aldwell with storage of approximately 8,000 acre-feet. In addition to the dam that was constructed in 1913, the site includes, gated spillways on both abutments, an upstream stabilizing fill (200,000 cubic yards), multiple buttress intake with three high-level penstocks, and a powerhouse with four units (12 Megawatts).

Elwha Dam

Glines Canyon Dam, built in 1927, is located about 8.5 miles upstream of Elwha Dam. The dam is a 210-foot-high concrete arch dam that forms Lake Mills with a current storage capacity of about 28,500 acre-feet. Also at the site is a gated spillway on the left abutment, a concrete thrust block on the left abutment, embankment dikes on both abutments, a mid-level penstock intake, and a powerhouse with one 16 Megawatts unit. Glines Canyon Dam and Lake Mills are located within the Olympic National Park.

Glines Canyon Dam

The Glines Canyon Hydroelectric Project was originally licensed by the Federal Energy Regulatory Commission (FERC) in 1926 for a period of 50 years, and received annual license renewals from 1976 until it was acquired by the U.S. Department of Interior in 2000. The Elwha Hydroelectric Project was never issued a FERC license.

The Elwha River Ecosystem and Restoration Act, enacted in 1992, suspended the FERC's authority for the projects and required the Secretary of the Interior to propose a plan to fully restore the Elwha River ecosystem and native anadromous fisheries.

A 1994 study determined that removal of both dams was feasible and necessary to meet the river restoration goals. The report described four options for dam removal, nine sediment management scenarios, and a process for analysis of a full range of project alternatives.

Both projects were purchased by the Department of Interior in February 2000 for 29.5 Million United States Dollars.

Over 20 Million cubic yards of sediment are estimated to have collected in both reservoirs. Several sediment management alternatives were evaluated including: 1) mechanical removal of all reservoir sediments for offsite disposal, 2) relocation and stabilization of all reservoir sediments within the reservoir area, and 3) allowing the river to naturally erode and transport the sediments downstream.

Mitigation measures for water quality protection during dam removal included the construction of a new surface water intake and new downstream water treatment facilities for municipal and industrial water supplies at a cost of $71 Million. In addition, a new water treatment plant was constructed for the City of Port Angeles at a cost of 25 Million United States Dollars.

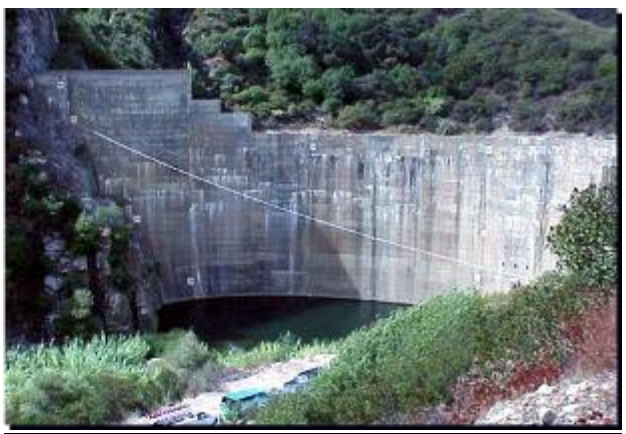
The dam removal solicitation was issued by the National Park Service in March 2010. The contract specifications provides the minimum requirements under the contract for structure removal limits, demolition sequence, reservoir drawdown rates, work restrictions, permit requirements, and use of the site.

All dam removal activities resulting in reservoir drawdown must be suspended during specified “fish windows” from May 1 through June 30, from August 1 through September 14, and from November 1 through December 31 of each calendar year to minimize release of reservoir sediments during critical fish migration periods. This limits drawdown activities to 6 ½ month each year and results in a 3 year contract duration. Reservoir drawdown increments and rates were specified for a full range of reservoir levels for both dams.

The contract for the dam removals was awarded in August 2010 for 27 Million United States Dollars. Site mobilization and preparatory work began in March 2011 with the completion of the downstream levees and Tribal fish hatchery. The powerhouses will be decommissioned prior to dam removal. The dam removal construction activities are planned to start on September 15, 2011 and take 3 years. The total estimated costs for the project are approximately 350 Million United States Dollars, including project acquisition, water treatment facilities, new levee, dam removal, Tribal fish hatchery, and site restoration.

Additional details on the project can be found in reference 19 and at http://www.nps.gov/olym/naturescience/elwha-ecosystem-restoration.htm.

5. Matillja Dam - California



Matilija Dam is located on Matilija Creek, a tributary to the Ventura River, approximately 18 miles inland from the coast near Ojai, California. The dam is a concrete arch structure, 200 feet high and 600 feet long, with a thickness varying from 50 feet at the base to 8 feet at the crest. The dam was constructed in 1946 for water supply and incidental flood control. The reservoir originally had a storage capacity of approximately 7,000 acre-feet but is now 90% filled with 6 Million cubic yards of sediment.

The dam has been notched several times to address deteriorating concrete near the crest, but the crest is still above the level of the impounded sediments. Sediment transport modeling has been performed in order to predict the response of the stabilized sediments in the reservoir to water flow after the dam is removed and how the sediments will be transported downstream to the coast.

Steelhead within the Ventura River system were listed as an Endangered Species under the Endangered Species Act in 1997. Removal of Matilija Dam, in conjunction with the recent provision of fish passage at Robles Diversion, would re-establish access to prime steelhead spawning and rearing habitat.

In 1999, the owner proposed removing Matilija Dam in anticipation of complete sedimentation of the reservoir. Several options have been identified for managing the sediment: permanent stabilization in the reservoir, mechanical removal and natural flushing.

Uncontrolled release of impounded sediments following removal of the dam could adversely impact downstream infrastructure including roads, bridges, flood control and water diversion structures and residential properties.

The preferred alternative entails full removal of the dam and phased transport of the impounded sediments downstream.

Estimated cost of the preferred alternative is 130 Million United States Dollars.

Additional details on the project can be found in reference 3 and at
http://www.matilijadam.org/facts.htm.

6. San Clemente Dam - California

San Clemente Dam is located at the confluence of the Carmel River and San Clemente Creek, approximately 18.5 miles inland from Carmel-by-the-Sea, California. The dam is a concrete arch structure, 106 feet high and 300 feet long, with a thickness varying from 50 feet at the base to 8 feet at the crest. The dam was constructed in 1921 for water supply and incidental flood control.

The reservoir originally had a storage capacity of approximately 2,150 acre-feet but is now over 90% filled with 2.5 Million cubic yards of sediment. The dam is owned and operated by California American Water (CalAm).

The California Department of Water Resources (Division of Dam Safety) has determined that San Clemente Dam would not withstand the seismic loading from a Maximum Credible Earthquake (MCE). The Probable Maximum Flood (PMF) of 81,000 cubic feet per second would overtop the dam by about 14 feet and potentially fail the dam.

CalAm funded studies to evaluate options including strengthening, notching and removing the dam. CalAm proposed strengthening the dam which was the least costly alternative.

Steelhead within the Carmel River system were listed as a Threatened Species under the Endangered Species Act in 1997. The dam was constructed with a fish ladder, but the current steelhead run of zero to several hundred fish represents a decline of over 90% of historical runs. Removal of the dam is viewed as one of the most effective ways of restoring access to steelhead spawning and rearing habitat.

In response to the Draft Environmental Impact Statement (EIS), the California Department of Fish & Game and National Marine Fisheries Service questioned the viability of the dam strengthening project.

The Draft EIS identified four possible alternatives for dealing with the dam: 1) dam strengthening and in-place sediment stabilization; 2) dam notching with partial sediment removal; 3) dam removal with total sediment removal; and 4) dam removal with in-place sediment stabilization and rerouting of the Carmel River.

Dealing with the 2.5 Million cubic yards of sediment in the reservoir is the major challenge for the project. Portions of the lower Carmel River have been developed with a variety of residential, commercial and recreation uses which are subject to periodic flooding. The flood hazard could be increased by release of the sediment behind San Clemente Dam. Fine sediments could impact steelhead spawning and rearing habitat in the lower Carmel River.

Mechanical removal of the sediments and hauling by trucks was ruled out due to the traffic impacts and cost. Two options are being considered:

1. **Off-Site Storage Option**: Approximately 2.5 Million cubic yards of sediment would be excavated from the reservoir and transported less than one-half mile by a conveyor belt system to a small canyon with no active watercourse. The reservoir would be de-watered by diverting the Carmel River to San Clemente Creek. After removal of the sediments and the dam, the river channel would be restored and natural flows directed through the reservoir site. Sediment removal would take place over three years during a five-month construction window from June through October to avoid the rainy season. The entire project is expected to take seven years. Estimated cost of the off-site storage option is 188 Million United States Dollars.

2. **By-Pass Option**: Approximately 2,500 feet upstream of the dam, a portion of the Carmel River would be permanently bypassed by cutting a 450-foot-long channel to San Clemente Creek. The dam and fish ladder would be removed. The bypassed portion of the Carmel River would be used as a sediment disposal site. Approximately 380,000 cubic yards of sediment in the San Clemente Creek arm would be relocated to the Carmel River arm of the reservoir. The project is expected to take four to five years to complete. Estimated cost of the by-pass option is 75 Million United States Dollars.

CalAm funded studies to evaluate options including strengthening, notching and removing the dam and proposed strengthening the dam which was the least costly alternative. The California State Coastal Conservancy is working with CalAm to implement dam removal. CalAm would fund dam removal up to the cost of the dam strengthening option. The Coastal Conservancy would secure additional funding to cover the remainder of the cost of dam removal.

Additional details on the project can be found in reference 3 and at

http://scc.ca.gov/webmaster/ftp/pdf/sccbb/2011/1105/20110519Board09_San_Clemente_Dam_Construction.pdf