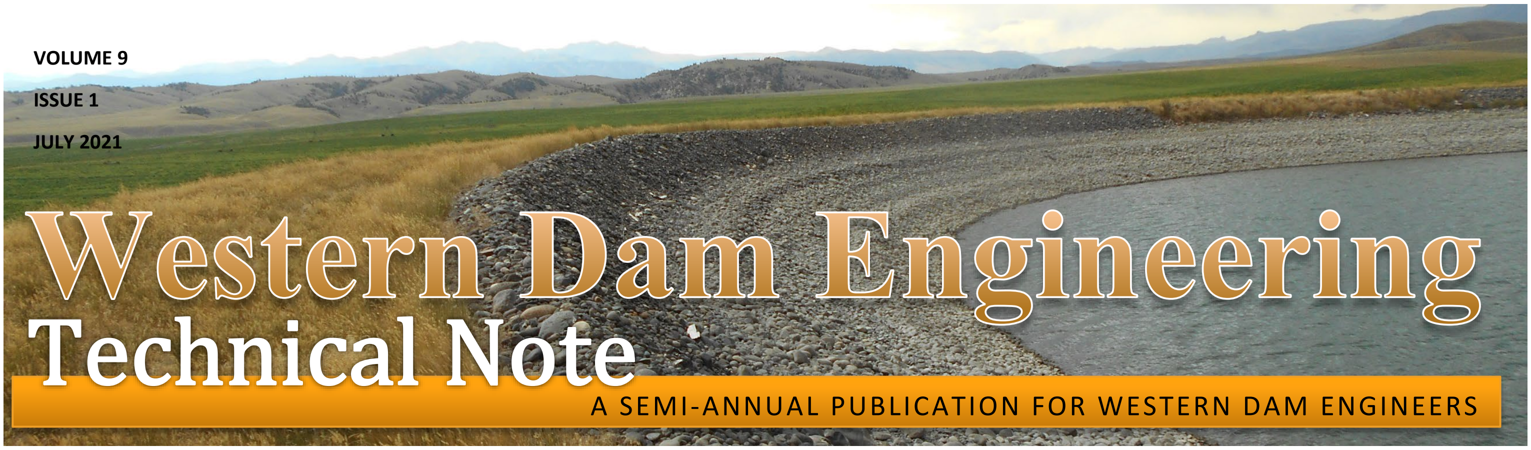

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A SEMI-ANNUAL PUBLICATION FOR WESTERN DAM ENGINEERS

In this issue of the ***Western Dam Engineering Technical Note***, we present articles on **dam decommissioning** and a suggested approach when considering an **alternatives analysis**. This newsletter is meant as an educational resource for civil engineers who practice primarily in rural areas of the western United States. This publication focuses on technical articles specific to small and medium dams. It provides general information. The reader is encouraged to use the references cited and engage other technical experts as appropriate.

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- Colorado Division of Water Resources
- Montana Department of Natural Resources
- Wyoming State Engineer's Office
- New Mexico Office of the State Engineer

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Good to Know

Upcoming ASDSO Webinar Dam Safety Training:

- *Use of Underwater Remote Systems in Dam Safety, July 13, 2021*
- *Uplift and Drainage for Concrete Dams and Spillways, August 10, 2021*
- *Current Trends in the Seismic Analysis of Embankment Dams, October 12, 2021*

Upcoming ASDSO Virtual Technical Seminars

- *HEC-RAS, July 27, 2021*
- *HEC-RAS 2D, August 24, 2021*
- *Design and Technical Specifications Review, October 19, 2021*

Conferences

- *Dam Safety 2021 Conference, Nashville, TN, September 12-15, 2021*

ASDSO Training Website Link

In this Issue

Dam Decommissioning – Considerations and Keys to Success

By: Janeen McDermott, PE

Introduction

Dams have existed in the United States since roughly the mid-1800s when dams were primarily constructed for agriculture, population water supply, or used to power mill wheels. In the ensuing years, dams were constructed for hydroelectric power, flood control, and recreational purposes. Many of the almost 100,000 dams that exist today are over 100 years old, with the average age of our nation's dams being 57 years old [1] with aging structures that may have maintenance/repair issues or a purpose that no longer exists. This can often lead to dam owners being faced with the decision of whether to rehabilitate or remove a dam. This article presents reasons for and against dam removal or decommissioning and lays out keys to success for initial decommissioning through full dam removal.

Why Dam Removal?

There are many reasons dam owners consider dam removal including: *1. Ecological benefits; 2. Dam Safety/Maintenance Costs; 3. Purpose;* and *4. Recreation.*

1. Ecological Benefits

Dams impound water, raising its level and thereby modifying the surrounding ecosystem, preventing fish and other aquatic organisms from passing upstream or downstream of the structure and lowering biodiversity within the stream or river. This impounded water often results in increased water temperatures and changes the river function by altering natural flood regimes and preventing sediment transport to downstream reaches, which negatively alters the stream function [2].

2. Dam Safety

Because many of the dams in the United States were built in the late 1800s or early 1900s and are now over 100 years old, several of these aging structures have exceeded their expected design life. Components of the dam's structure including earthen embankments, concrete spillways, or other structures require maintenance and repair. Deterioration of these components can put the dam at risk of failure.

Additionally, the hydraulic and seismic design criteria for dams has changed significantly since many of these structures were built, such that many dams require significant upgrades to meet the current dam safety standards. Maintenance, repair, and upgrades involve substantial planning, engineering, design, and financial investment; however, without these improvements an aging dam can be a considerable hazard to downstream populations, infrastructure, and environment. The life cycle cost of a dam can be such that dam removal is a more economically feasible option for the dam owner than continuing to maintain or rehabilitate an aging dam. Dam removal often reduces risk and liability that the "do-nothing" option does not recognize or address.

3. Purpose

Often, old dams no longer serve the purpose for which they were originally constructed, including diversions to produce hydroelectric power, powering mill wheels, or for recreation that no longer occurs as it has in the past. Many old instream low head diversion structures create needless dangerous hydraulics that threaten the public. With a lack of purpose or beneficial use, all that remains is risk. It is at this time that dam removal becomes an option to alleviate maintenance costs, mitigate risks to the owner and the public, and/or to repurpose the land.

4. Recreation

Sometimes there is significant local interest in recreational activities such as fly fishing, paddling the river, or additional parkland and trails; therefore, dam removal provides greater benefit to local recreation than a lake does. With support from local recreational organizations and the public, conservation groups can pursue dam removals for the overall benefit of the community.

Why Not Dam Removal?

For as many reasons there are for dam removal, there are just as many considerations for why not to remove a dam including: 1. *Environmental Considerations; 2. Recreation; 3. Navigation; and 4. Flood Control*.

1. Environmental Considerations

There are some instances when environmental hazards associated with dam removal outweigh the benefits of dam removal. Perhaps the dam is impounding contaminated sediment, which if the dam were to be removed would allow those contaminated sediments to travel downstream, thus impacting the downstream ecosystem and population, or becoming dispersed by the wind in all directions if allowed to dry and not be revegetated. The costs to remediate impounded contaminated sediments can be very high relative to the direct costs for removal of the dam structure and clean sediments, , making a dam removal project cost-prohibitive.

There may be threatened and endangered species that are utilizing the habitat the dam has created. Alternatively, the dam could be acting as a key barrier blocking invasive species from passing upstream and downstream. Removing a dam in either of these cases poses a significant environmental impact and would require consideration before decommissioning a dam.

2. *Recreation:*

Depending on the size of impoundment and geographical location, the dam could provide significant recreation including boating, fishing, and swimming. Adjacent property owners and homeowner associations as well as public utilizing park and wilderness areas may enjoy those recreational opportunities, such that dam removal would result in significant public resentment and resistance to the project overall.

3. *Navigation*

Some dams provide water level control on large rivers that allow for navigation by large boats. If a dam were to be removed, navigation could be negatively impacted and, therefore, should be a factor in any dam removal decision.

4. *Flood Control*

Some dams are built for flood control; however, others may not have originally been constructed for flood protection and could be unknowingly providing flood reductions for downstream areas. In this case, removing the dam would cause a rise in flood waters to downstream areas and could impact cities and infrastructure. Before dam removal, it is important to analyze the hydraulic impacts the structure might be having on the stream or river on which it was built and, if necessary, complete an attenuation study to evaluate the specific impact to the peak flood flows and stages. **Figure 1** provides a visual of the impact a dam can have on the discharge in a river. The natural hydrograph, or rate of flow in relation to time past a specific point in a river, hits a high point (peak) higher and faster than the dam-influenced hydrograph. The dam=influenced hydrograph results in a muted hydrograph with reduced river channel flows and water levels downstream of the dam. Removing a dam in this case could result in increased flooding downstream.

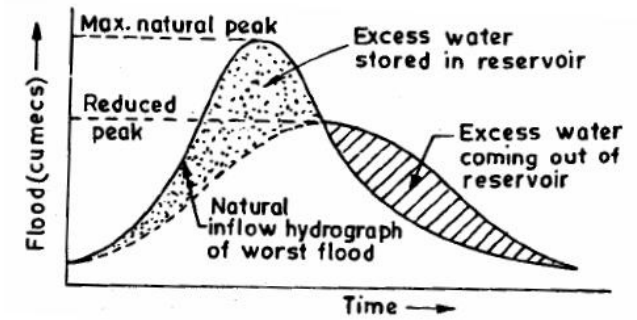

Figure 1: With and Without Dam Hydrographs

Site Specific Examples

Every dam is unique in the factors that lead to dam decommissioning or rehabilitation. The table on the following page presents selected examples for which dam decommissioning was considered, including the factors that went into the decision to decommission or rehabilitate the dam. It is during this decision-making process that risk is characterized and weighed against the rewards to prioritize the factors influencing the decision to remove or rehabilitate a dam

Table 1: Examples of Dam Projects Considered for Decommissioning

Dam Name	Factors in Decision to Decommission or Keep Dam in Place	Relevant Photos
Basin #2: This western Montana significant hazard dam has several deficiencies that will be costly to address. Decommissioning is likely the most cost-effective option; however, the reservoir provides important sediment collection, which is critical to the downstream water treatment plant. Despite decommissioning being most cost effective, the owner is evaluating rehabilitation alternatives that leave the structure in place. **Fate of Dam:** Rehabilitation is actively being pursued.	**Environmental Considerations/Purpose**: The reservoir provides important sediment collection that is critical to the downstream water treatment plant. The trees in the drainage area above have been decimated by pine bark beetle, increasing the risk of wildfire and associated sediment laden runoff.	 Existing Conditions
Boardman Dam: This northern Michigan high hazard dam with a height under 40 feet was constructed in 1894 and completely rebuilt in 1930 to provide hydroelectric power. The dam was built on the Boardman River, a blue-ribbon trout stream, and is located approximately 4 miles upstream from a highly populated area. **Fate of Dam:** Dam decommissioning was completed.	**Ecological Benefits:** Removal of the dam would restore cold water habitat. **Dam Safety:** The dam structure was an aging high hazard dam. Ongoing maintenance and repairs were anticipated to be costly, with dam removal being the most cost-effective option. **Purpose:** Hydroelectric power generation was terminated after 2000. **Recreation:** Although the reservoir provided some recreation, the surrounding area and the nature of the Boardman River offered added recreation benefits of fly fishermen and river paddlers were a greater benefit to the community with removal.	 Pre-Dam Removal  Post-Dam Removal

Mighty Mouse Dam: Built in 2005 to capture water produced during the production of coal bed methane (CBM). The dam was classified as a low hazard dam and was 34 feet tall with a 39-acre-foot storage area. **Fate of Dam:** Dam decommissioning was completed.	**Lack of purpose:** CBM production largely ceased in 2010 and the reservoir no longer had a purpose. Dam Safety: The Wyoming State permit required removal or a decrease in storage potential < 20 acre-feet.	 Pre-Dam Removal  Post-Dam Removal
Missile Silo Dam: This central Montana dam did not have a responsible party and defaulted back to the State of Montana, which owned the land under the dam. In spite of the reservoir's popularity with locals for fishing, the presence of a heavily traveled unlighted road downstream was concerning. The State decided to decommission the dam, as the risk and consequences of failure were determined to exceed the benefits. **Fate of Dam:** Dam decommissioning was completed.	**Lack of Purpose:** No responsible party and no readily apparent purpose. **Dam Safety:** The dam had several deficiencies and even though small, a failure could cause debris to cover a heavily traveled unlighted highway located downstream. Due to the speed and lack of lighting, it would be difficult for motorists to see any debris at night, which could potentially cause accidents.	 Pre-Dam Removal

Dam Removal Keys to Success

Once the decision has been made to remove a dam, multiple considerations need to be included in the design process to support a successful project. A dam removal is never just simply a dam removal. **Social**, **Ecological, Care of Water/Dam Safety**, **Sediment Management**, and **Management of Risks and Expectations** are five key considerations of dam removal projects we'll discuss in a success dam removal project. Additionally, you can reference "Guidelines for Dam Decommissioning Project" at USSD (ussdams.org) [3] for a more detailed outline of considerations and steps in the design process.

From the concerns of adjacent property owners and local public interests, environmental impacts and dam removal logistics, to determining which structures will be left behind after removal and managing risks and expectations throughout the process, there are many facets that need to be considered. To focus on one and not the others leaves the owner at risk for unforeseen impacts, costs, risks, or delays to the project. The remainder of this article will focus on the components of a dam removal project, grouped as *Social, Ecological, Care of Water/Dam Safety, Sediment Management, and Management of Risks and Expectations*. These five pillars of dam removal vary in their degree of importance and proportion in any given dam removal. It is important to consider the unique characteristics of each project including the construction of the dam and its history, the local watershed characteristics, surrounding land use, and public interest in the project overall.

The following sections are meant to be a guide for consideration and planning for dam removal, but it should be noted that each site needs to be individually evaluated and the five keys to success be weighted and prioritized to fit the project.

Social

Water has always been vital to our survival, but has also been a means of transportation, recreation, and inspiration. Throughout our history, people have been drawn to water, whether that be a large lake, a roaring river, a lazy stream, or local pond. We can get quite emotional about these bodies of water that we pass by every day or have fond memories of as a child, and people often are sensitive about dam removals. Gauging the social implications to dam removal is important to inform the future course of the project. Public input is often an important consideration for dam removal and is best incorporated into a project from inception to end, reaching out to the public for input during planning, design, and pre-construction phases. It is crucial to bring all of the stakeholders to the proverbial table early so there are no surprises later in the process. Some items that often arise at public input sessions include the purpose of dam removal, recreational desires (lakes vs. river), angler concerns, aesthetics, and design analysis. These public input sessions can be used to calm any fears or misconceptions the public might have, such as the probability of downstream flooding, and to request input from the end users as to site features post-dam removal (e.g., river access, parks, trails, etc.). Often, stakeholders have competing interests; therefore, costs and benefits need to be weighed with a clear decision-making process outlined and communicated effectively to the stakeholders.

Public buy-in on dam removals is frequently a make-it or break-it deal and, unfortunately, is sometimes overlooked, causing scheduling and cost implications to the owner as the project is delayed or meets significant opposition (i.e., lawsuits).

Ownership of the dam and whether it is publicly or privately owned will greatly influence the level of public input considered into a dam removal project. Property ownership of not just the dam itself but also the bottomlands, or land area underwater, impacts both private and public projects. With many of the dams in the United States over 100 years old, property ownership issues can arise purely because old land deeds exist, or the transfer of properties are not well detailed. The dam owner needs to consider not only who owns the land on which the dam sits but also who owns the land currently under impounded water in the reservoir. Some deeds might state the property extends to the edge of the impoundment or might predate the dam and state to "the centerline of the stream or river". Both types have implications to the project and need to be investigated at the beginning stages of a dam removal project to identify any property ownership issues early on to provide time for discussions with adjacent owners, easement negotiations, or land acquisition, as applicable.

Another social factor that can arise regarding removal of old dams is the question of whether the dam is "Historical" or "Historic". Historical means the dam is old, while Historic means the dam serves as an important structure in history. The State Historic Preservation Officers (SHPO) can be a helpful resource to dam owners to determine if their dam is considered historic and protected for preservation. [State Historic Preservation Offices - National Register of Historic Places (United States National Park Service) (nps.gov)](https://www.nps.gov). SHPO has a process for determining historic places and structures and, if designated a historic structure, removal will need to follow a specific process or may be halted all together depending on the designation of the historic significance.

Ecological

We won't discuss ecological considerations in too much detail in this article, as it could be a topic for an article all by itself. However, it is important to touch on what will be left in place once a dam is decommissioned and removed. Depending on the size and characteristics of the dam and river/stream on which it was built, sometimes dams can be removed and the stream channel allowed to passively restore itself. This process involves removing the dam and letting the stream determine its own channel through impounded sediments, establishing a new channel alignment, slope, and bank characteristics. This process leads to sediment transport downstream and often bank erosion as the channel seeks to find its equilibrium. This is the most cost-effective method to complete restoration; however, is not appropriate for all cases. Passive channel restoration should be avoided, for example, when there are hundreds of thousands of tons of impounded sediment that could be washed downstream or if there is critical infrastructure nearby that could be impacted by headcutting of the stream upstream or erosion adjacent to the project area.

The alternative to passive channel restoration is completion of an engineered analysis, design, and construction. This type of restoration is frequently necessary to stabilize the site post-dam removal. This can range from stabilizing just the river channel in the immediate vicinity of the former dam location or constructing a completely restored river channel at the former dam and through the former impoundment. To complete this level of design, the channel and floodplain geometry, alignment, and profile are the critical design items to determine. There are a multitude of methods to do this, ranging from the Rosgen Stream Classification Method, Stream Functional Pyramid, matching reference reach characteristics, etc. However, the general process for channel design involves understanding the normal flow and flood flow conditions at the site, completing a HEC-RAS model to analyze the hydraulics of a proposed design, and fine tuning the design to meet the guidance of whichever method is being utilized to complete the channel design. Hydraulic models can include energy, shear, and power calculations to pinpoint areas of the channel design prone to erosion and the need for specific bank and channel stabilization or grade controls.

Other considerations include defining channel bank treatments for habitat and stability, revegetation of the former impoundment, and providing bi-directional fish passage through the project area. Bank treatments can range from using large logs, boulders, or cobbles to utilizing stabilized soil banks (**Figure 2** and **Figure 3).**

Figure 2: Soil encapsulated channel banks with live stakes installed along the bank and floodplain bench are utilized to stabilize the stream banks.

Figure 3: Reinforced logs are being used to stabilize a sluffing riverbank.

Revegetation of the former impoundment can, similar to channel restoration, take an active or passive route – either providing for a planting plan and native seeding and plantings placed as part of construction or allowing the impoundment to revegetate via any native seedbank that might remain in impounded soils. The more robust the revegetation plan, the better aesthetics a project will have in the first five years post-construction (**Figure 4**). However, left to its own devices, Mother Nature will often take over. The cost/benefit associated with revegetation plans should be considered as it relates to soil erosion control and risk of the overall project. If the soil characteristics are such that vegetation is unlikely to establish itself, then some revegetation plan should be considered.

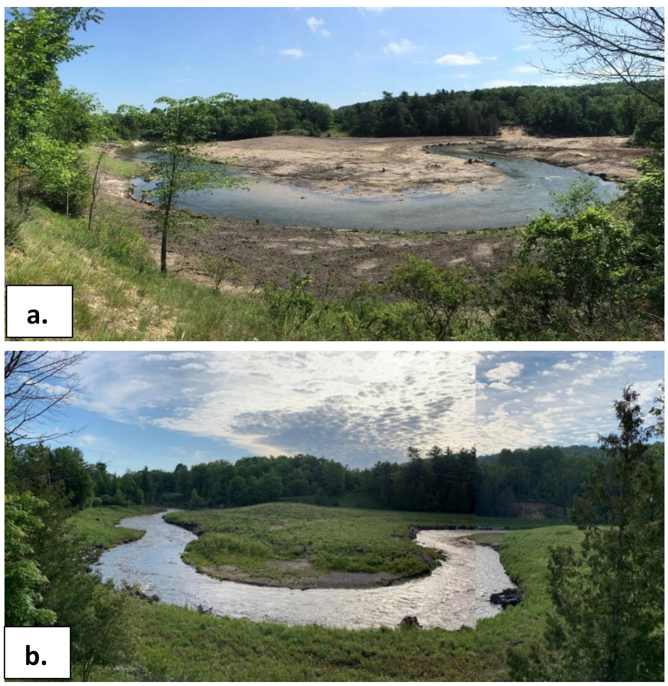

Figure 4: Revegetation of former impoundment area. (a.) Photo taken during construction. (b.) Photo taken 2-years later.

Bi-directional fish passage can also be a significant consideration, especially if the project goals for dam removal are directly related to ecological benefits. To confirm fish passage, a hydraulic model would be used to check designed channel velocities to allow native fishes to swim upstream. Fish passage is most often a consideration in the design of in river structures such as riffles (**Figure 5**) or other grade transitions and is an important piece of a complete ecosystem restoration project.

Figure 5: Engineered riffle with rock boulders to provide grade control on impounded sediment and design to allow fish passage.

Every project is different in application of these considerations and truly can range from completing dam removal only to design and construction of a fully new channel, floodplain, and planting the entire former impoundment area. Ultimately, what typically guides this decision is future use desires and cost. Owners can anticipate spending as much or more on design and construction for channel and restoration as on the dam removal itself.

Care of Water / Dam Safety

Every dam is unique in construction, location, and risk. It is essential to evaluate the hazards and risk associated with each dam removal. Areas for investigation, analysis, and consideration include *dam construction, watershed hydrology, and the upstream and downstream impacts*.

Taller dams, those with higher hydraulic heads, and those with high hazard levels present higher risk during a breaching and dam removal operation due to the potential downstream impact if a sudden uncontrolled release were to occur. There are exponential increases in impact if a 6-foot wave of water were to uncontrollably release compared to a 20-foot wave of water. Breaching operations for dams with higher risks should consider a calculated dewatering approach and a multi-phase incremental breaching plan to lower the risk of an uncontrolled breach.

The construction of the dam also influences the breaching and removal plan. For example, a dam with a solely earthen embankment or one with a clay core of unknown condition might require a more engineered approach for breaching and dewatering to improve control during the operation, while a dam with an existing concrete spillway might just use incremental demolition of the concrete to dewater the impoundment and breach the dam over the structure.

Watershed hydrology should also be considered when developing a dewatering and breaching plan. Watersheds in urban areas, deserts, or land with poorly draining soils will likely have a runoff hydrograph that is quick to peak even for small rainfall events. This type of watershed is considered “flashy”, where runoff is high and river stages tend to rise quickly after onset of rainfall. These types of watersheds present complex considerations when it comes to dewatering and dam breaching operations. The engineer should consider multi-stage incremental breaching plans or a process to complete primary dewatering before breaching the dam to provide controlled dewatering and lower risk of an uncontrolled release of impounded water or dam failure in the case of a sudden, unexpected rain event. **Figure 6** illustrates such a multi-phase incremental breaching approach that utilized a combination of a siphon dewatering system with a lower elevation temporary armored spillway to complete the dam breach and dewatering approach.

Figure 6: Dam removal in process utilizing multi-stage siphon and spillway dewatering system.

An example of statistical or probabilistic watershed analyses that should be considered would include evaluation of the inflow hydrograph peak and flow volumes, study of stream or river gauge data over a long period of time to understand typical peak flows in the river, as well as determine recurrence interval flow events by completing a Log Pearsons Type III evaluation. The United States Geological Survey (USGS) Water Resources division manages streamflow gauges across the country (USGS Current Water Data for the Nation) that can be utilized for the purposes of determining typical river flows and recurrence interval events on gauged or ungauged watersheds. Some state agencies also will provide this type of information upon request. HEC-HMS and HEC-RAS modeling of the watershed hydrology may be necessary and helpful.

Additionally, since dams can provide for flood storage even if not initially constructed for that purpose, it is important to evaluate the downstream risk to a change in flood hydrograph and, if necessary, complete an attenuation study of the dam to be removed. **Figure 7** presents the results of such an analysis in which the inflow hydrograph into the impoundment was compared to the dam outflow hydrograph.

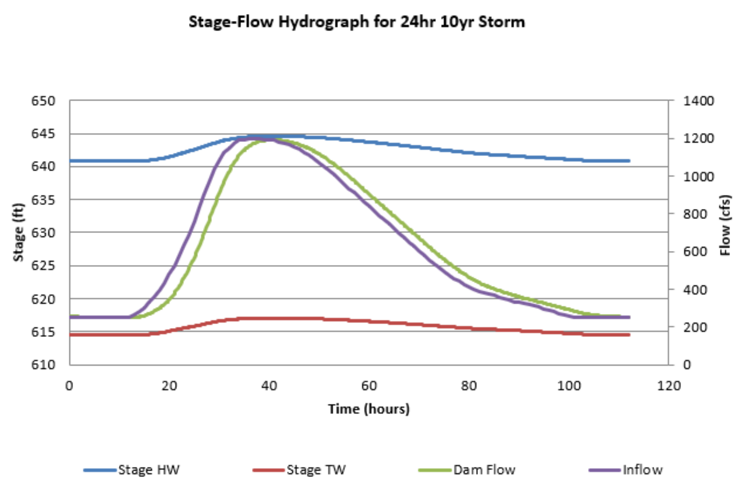

Figure 7: Attenuation analysis for dam prior to removal.

In this case, you can see that the dam outflow hydrograph nearly matches the inflow hydrograph, indicating that the dam provided insignificant attenuation of a flood event. Additionally, the headwater and tailwater stage followed a similar pattern of rise and fall.

Determining the design storm event for construction is also key to confirm the dewatering and breaching designs are meeting an acceptable flow event. Determination of the design event should occur in conjunction with local regulatory agencies including dam safety officials and the lead agency permitting the dam removal. Depending on the watershed, the dam being removed, and the risk associated with the project, using the 10-year recurrence interval storm event may be appropriate. In other cases where there are high risks associated with an uncontrolled breach, for example, when loss of life may be likely, designing for a larger recurrence interval such as a 100-year event or greater is prudent. The implications for the design flow event considered during design are incurred in the cost of construction. Being able to plan for and design to a lower recurrence interval event allows for less engineering and lower material costs vs. designing a breaching operation to a 100-year or larger event. Ultimately, the hazards and risks associated with the dam itself, the watershed characteristics, length of time the dam will be under construction and use of temporary flow control measures, and the possible impacts to upstream and downstream areas will determine the appropriate design flood event that will be utilized to inform the design and construction approach to the dam removal.

Dam breaching sequencing, operation, and timing within the year should utilize a risk-based approach that considers specific hazards and risks associated with the site, incorporates site-specific solutions, and integrates sediment management. Incremental dam removal should be utilized whenever practicable as this practice allows for a slow and controlled dewatering process, and allows the contractor to stabilize slopes and accommodate efficient sediment management.

The site should specifically be analyzed to determine the locations of the river channel, construction access, and dewatering, and the possibility of locating the dewatering operation separate from the future river channel or together – significantly affecting sequencing.

Most significant and high hazard potential dams likely have an Emergency Action Plan (EAP); however, it is important for any dam removal project, big or small, to have some level of emergency preparedness and response be considered during construction and specifically during the breaching operation of the dam. Generally, this consists of outlining materials that should be kept on-site during construction (e.g., a large stockpile of riprap/boulders or extra bull-dozer or track-hoe) in case of an uncontrolled breach, laying out the list of emergency contacts, and coordinating with emergency response groups regarding the project schedule and plan.

Sediment Management

Sediment Management is going to differ depending on the dam, location, watercourse, sediment quantity, and quality. However, to define the role sediment management should have in a project requires some level of sediment data collection and analysis, and modeling may be required. The United States Department of the Interior Bureau of Reclamation's Dam Removal Analysis Guidelines for Sediment (usbr.gov) [4] provides a thorough overview of considerations to include in sediment data collection and design.

The natural river process includes transport of sediments into streams and rivers through runoff. Once in the water column, sediment is transported downstream until flow conditions are such that the particles settle out on the falling limb of the hydrograph and deposit on the surface of the channel or floodplain. Dams halt this process by blocking river flow and creating an impounded water area that slows flow and results in deposits of sediment in a concentrated area. This can leave hundreds of thousands of impounded sediments behind large dams. Removal of the dam reintroduces natural sediment transport; however, without management of the impounded sediments during dam removal, large flow events can pick up massive quantities of the sediment within the former impoundment and transport it downstream until it deposits elsewhere. This can have significant harmful impacts to downstream river reaches when essentially the annual sediment load for a stream or river gets moved in one flow event. Road/stream crossings can become clogged, wetlands filled, and channel features such as riffles or pools can fill, causing havoc on the stream function, hydraulics, and geomorphology of the river system. Thus, sediment management is a key consideration during dam removal.

For the control of sediment quantity that gets transported downstream, there are different approaches that can be utilized to control transport of impounded sediments downstream. Sediment traps, or large excavated holes upstream of the dam, can be utilized to allow for larger particles to settle out before leaving the project area and allow for the construction contractor to actively manage and excavate sediment out of the stream channel at one designated location. Another approach is to tie sediment management directly to the care of water or dewatering plan for the dam removal. By dewatering the impoundment in small increments while incrementally mitigating revegetation, sediment transport can be reduced. Couple that approach with active channel excavation in the upper project reaches, removing accumulated sediments from the proposed flood area until the contractor arrives at the proposed channel/floodplain geometry and elevation, minimizing sediment transport to the maximum extent possible. **Figure 8** shows a sediment spoil pile from a project that indicated the excavation of over 200,000 cubic yards of impounded sediment from the proposed river channel and floodplain area.

Figure 8: Sediment spoils pile mid-construction.

Similar to the restoration approaches presented under Ecological considerations, the approaches to sediment management range from good, better, best, and have corresponding increases in cost. The most successful approach will incorporate some degree of each of the methods - sediment traps, incremental dewatering, and active sediment management.

The quality of the impounded sediment will impact the sediment management approach. Sediment characterization should be completed prior to dam removal and ideally is conducted in the early phases of the project to identify contamination concerns, management strategies required, and disposal costs. Clean sediments can often be spoiled on-site, thereby contributing to substantial cost savings to the project. However, contaminates such as PCBs or metals may be common in some regions or river systems and incur significant project costs for management, remediation, and disposal. Therefore, it is critical to a successful project that sediment characterization be completed early to determine quality and quantity before design moves forward.

Management of Risks and Expectations

Managing risks associated with dam removal specifically related to breaching and the occurrence of high flow events is a key consideration during the design phase of the project. The design team, owner, and stakeholders should agree on the level of risk each entity is willing to assume as well as the overall level of acceptable risk for the project. This will vary for each project and is tied to the dam construction, height, hydraulic head, and condition, as well as the watershed hydrology.

Flooding during construction is a risk and should be planned for in the design flow event as we discussed in the Care of Water section.

Permitting dam removal projects can be complex and frequently require years of previous studies including considerations for environmental impacts and development of feasibility studies and alternatives. The permitting process itself varies from state to state but often requires coordination with the United States Army Corp of Engineers (USACE) and the state environmental and/or natural resources agencies, as applicable. Aspects of the project that require permitting include dam removal, floodplain impacts, wetland impacts, and soil erosion and control consideration. Dam removal projects frequently require public comment periods to complete the permitting process, and the process can take a year or more to complete. As such, it is important to hold coordination meetings with regulatory staff early in the project so that the permitting requirements and schedule are clearly stated, understood, and included in the overall project design and schedule.

Management of expectations for the owner, stakeholders, and the public is also important, particularly during discussions about the project in design, but also during construction. Dam removals are messy - the water within the river or stream will turn black or brown as sediment and organic material is churned up through dewatering and construction within the former impoundment. This results in increased turbidity in the water, sometimes miles, downstream of the project area. Communicating the conditions and logistics of the river aesthetics ahead of construction helps manage the expectations of the public and alleviates or at least calms some of the initial fears that often occur when someone sees a usually clear river flowing brown.

It is also quite common for fish and other aquatic species such as turtles to become trapped during dewatering and dam removal. An aquatic organism rescue plan, or at least consideration, is a good resource to manage stranded fish and animals. **Figure 9** presents construction staff equipped with a net to rescue any stranded fish in an off line water course.

Figure 9: Construction staff rescue stranded fish during dewatering and transport fish back to the main channel.

Conclusion

Owners considering dam removal should reflect on the reasons for and against it as well as considering the benefits and costs of each condition. Reasons for dam removal include benefits to the local ecosystem, dam safety concerns and high maintenance costs, a lack of purpose, and creation of new recreational opportunities. Reasons against dam removal include harmful environmental impacts, negative impact to recreation, navigation, and flood control, as well as social concerns. Every dam is different, and considerations of all stakeholders should be weighed recognizing that stakeholder wants and desires are often competing.

If dam removal is chosen as the preferred option, then the five keys to success (*Social, Ecological, Care of Water/Dam Safety, Sediment Management, and Management of Risks and Expectations)* need to be considered in the project from inception to construction.

There are nearly 100,000 dams in the United States, each with varying degrees of impacts and benefits. Our job as owners and engineers is to weigh those costs and benefits to determine the fate of these structures and how some dams could and should be removed cleanly and safely for all stakeholders.

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Complex Decisions Don't Require Complex Tools - Alternatives Analysis using a Multi-Criteria Decision Tool

By: Christina Bennetts, PE and Paul Perri, PE

Introduction

As children, we used a form of alternatives analysis to decide what toy to purchase, what game to play, who to play with, and even who to invite to a birthday party. As we got older, the alternatives analysis process became more complex as we evaluated which life path to take, university to attend, classes to take, and even possibly what to do on a Friday night. As adults, the focus shifted to careers, vehicles, spouses, and homes. Comparing different alternatives is a natural step in the decision-making process and doing so in a systematic framework can be a powerful tool when evaluating several potential outcomes and considering numerous influential factors.

There is never only one solution to any engineering problem, but there is a "best" solution. Multiple alternatives need to be considered to select the preferred alternative - the one that meets the majority of important **goals** of all **stakeholders**. That isn't always easy as goals, or their perceived importance, may vary amongst the stakeholders. Goals of dam rehabilitation projects often include things like cost, risk reduction (dam safety and public protection), constructability, loss of resource (operational impacts), and social and environmental impacts. Stakeholders will include owners, regulators, engineers, and other interest parties. Evaluating competing tradeoffs among alternatives for complex engineering projects needs to be systematic, collaborative and transparent. A multi-criteria decision analysis is a valuable tool when performing an alternatives study because it provides a framework for logical discussion amongst a group of diverse stakeholders, provides a consistent evaluation to be used for the alternatives, and communicates the reasons for a decision.

This article will discuss the timing, data needs, process, and interpretation of a systematic alternatives analysis.

Why Perform an Alternatives Analysis?

There are always multiple alternatives to solve any problem. Looking at only one solution, or presuming to know the best solution without considering factors in a systematic thought process, can lead to a design that is inefficient and potentially challenged later by other stakeholders. For this reason, an alternatives analysis is a required step early in the design process for most federal agencies such as the Natural Resources Conservations Service (NRCS), National Park Service (NPS), Federal Emergency Management Agency (FEMA), U.S. Army Corps of Engineers (USACE), and Bureau of Reclamation when requesting project funding.

An effective alternatives analysis compares alternatives using a systematic and unbiased approach to evaluate the strengths and weaknesses of the various alternatives in meeting different decision criteria, which may include safety, design, risk, standards, principles, and cost. With rehabilitation costs increasing and resources for projects becoming more difficult to acquire, it is more and more important to examine all of the available choices.

An alternatives analysis is performed using a multi-criteria decision tool to take what could be a complex decision-making process with potentially conflicting stakeholder opinions and break the process down into smaller parts, allowing more focus on what is most important to the decision makers. Discussing the relative advantages and disadvantages of the various alternatives will result in a more informed decision that may lead to effective combination of alternatives.

When is the Right Time to Perform an Alternatives Analysis?

An alternatives analysis is not the first step in the design process. The design needs to be progressed to a point that will sufficiently inform the assessment. The timing to complete an alternatives analysis depends on the answer to the following questions:

1. Have all stakeholders been identified and their requirements and opinions been captured? These requirements and opinions become the criteria against which the alternatives are evaluated.
2. Is there sufficient information to clearly describe the intent or objective of each alternative?

3. Can the alternatives be developed to a level that will provide project cost and duration information for consideration?
4. Will additional data collection or progression of the design significantly increase the confidence in the results?

Approaching an Alternatives Analysis

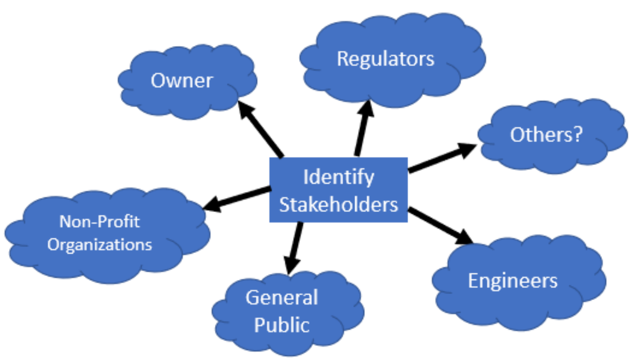
This article presents a general approach to performing an alternatives analysis that has been used for numerous projects with successful results. This approach can be tailored to each specific project. The general steps are as follows:

1. Identify stakeholders.
2. Identify and develop alternatives
3. Identify the alternative analysis team.
4. Select decision criteria and weighting.
5. Perform the alternatives analysis.
6. Discuss and Interpret the results and document a preferred alternative.

Each of these identified steps are summarized in the following sections.

Stakeholder Identification

The early identification and engagement of all stakeholders is an important step. Typical stakeholders include:



Owner

The owner of the project is at the top of the list as a key stakeholder for the following reasons. Owners have specific operational or modification objectives that need to be met. Owners are financially responsible for the design, construction, and safe operation of the project. Owners will be intimately involved throughout the process.

Regulators

Regulators exist at the local, state, and federal levels. Regulators provide minimum regulatory standards that all alternatives need to meet. Regulator guidance is often published and readily available for reference and incorporation into design. It is extremely beneficial to proactively coordinate with the appropriate regulatory agency to gain their perspective, interpretation of regulations, and guidance that may help to streamline a design element. The complexity of the project will determine the level of involvement by a regulator through the alternatives analysis process.

Engineers

Design engineers are key stakeholders in the alternatives analysis process. Design engineers that will be responsible for the successful design, construction, and effectiveness of the solution will have their own goals and priorities. Engineers may also provide subject matter expertise on technical goals of other stakeholders. Design engineers will identify initial alternatives that are then presented to other key stakeholders during the early development phases for input and collaboration, at which time additional alternatives may be identified. It is important for design engineers to stick to the facts, including precedents and known case histories, but avoid personal bias.

Nonprofit Organizations

Often in dam projects, nonprofit organizations become a stakeholder that adds a level of complexity in the alternatives analysis process. Early engagement of these stakeholders to identify their priorities will assist in the development of alternatives and selection criteria. Nonprofit stakeholder involvement is sometimes limited to the initial coordination to identify their goals that are most important and but can continue throughout the duration of the alternatives analysis.

General Public

Although not directly involved with the decision-making process of an alternatives analysis, the general public is a stakeholder that can provide opinion as to potential impacts the project may have that they perceive as either advantageous or objectionable. Some funding sources may require that a particular project have an effective public outreach process. For example, public involvement can be important in the development of selection criteria for high-profile projects in more urbanized settings. Public opinion is captured during an informational session or open house, during which the project alternatives are presented followed by an open forum for public questions and comments. Typically, the public does not actively participate in the alternatives development or analysis; however, the comments provided are considered as part of the analysis.

Others

Each project is unique and may involve stakeholders specific to that project. It is important to document all initial stakeholders and to revisit once alternatives are developed.

Identifying and Developing Alternatives

Identifying Alternatives

Prior to initiating development of conceptual level alternatives, a brainstorming session is usually performed where project stakeholders attend with the objective of developing a list of potentially viable alternatives that meet their respective design goals. Parameters that should be considered during the brainstorming session are specific to each project. For example, a brainstorming session for a new spillway design might consider location and elevation, crest structure types, chute types, energy dissipation structure types, discharge channel types, etc. The alternative analysis team can further refine the list by later discussing the anticipated viability of each identified alternative.

It is important to consider all possible alternatives that satisfy the design objective and for the alternatives team to have an open mind to combining alternatives. Alternatives to consider depending on the scope of the project and may include variations of: Do Nothing; Dam Removal; Dam Rehabilitation; and New Dam alternatives. During the brainstorming session, the analysis team may want to consider a potential failure mode analysis (PFMA) to identify where relative risk reduction measures should be incorporated and how sensitive variables and assumptions are to the conclusions.

The feasibility of each alternative should also be evaluated on a high level by the team during the brainstorming session. Typically, between three and six alternatives may be carried forward and further developed. The following questions can be considered when evaluating the feasibility of an alternative:

1. Does the alternative meet the design objective?
2. Does the alternative meet all mandatory regulatory requirements?
3. Can the design be feasibly constructed?

The answers to the above questions may have some uncertainty at this early of a design stage. If the feasibility of the alternative is highly influenced by the existing data gaps and uncertainty, then the feasibility of reducing the uncertainty should also be considered in the screening stage. It's important to document all brainstormed alternatives and the process used to identify which alternatives were selected for further development. This initial step is important because moving forward with too many alternatives or not enough alternatives can negatively affect the outcome.

Developing Alternatives

Each identified alternative carried forward by the analysis team needs to be developed to a level commensurate with the desired confidence in the final result. The level of development needed is dependent on the level at which the project currently stands (e.g., if the project is in feasibility stages or conceptual level design). It is possible the project could be in later design stages such as 30% design when the team realizes the design is not feasible and alternatives need to be reevaluated. There is a balance involved for the level of development necessary to perform an alternatives analysis. If the alternatives are not developed sufficiently to properly inform the assessment, there is greater uncertainty in the results of the analysis. The development of each alternative takes time and effort. The level of effort required to develop each alternative can quickly compound based on the complexity of the alternatives being considered.

For each alternative, the following information is developed at a conceptual level:

- Layout (plan view, profile, sections)
- Cost
- Construction Approach and Schedule

Layout

Design layouts for alternatives need to be detailed and clearly illustrate the physical geometry of each alternative. Poorly developed layouts can impair the understanding of an alternative and lead to ill-informed decisions.

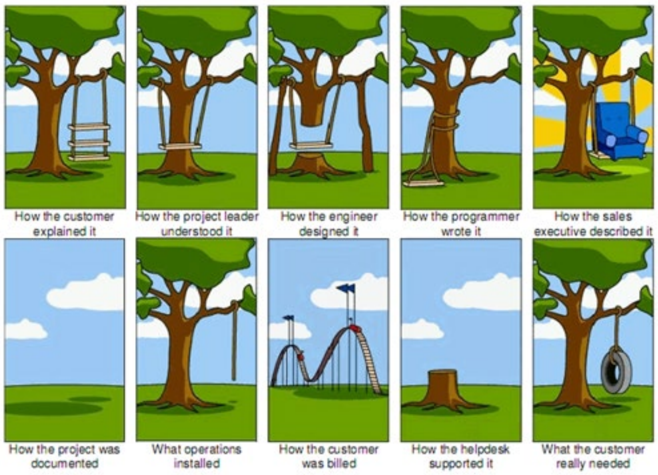


Image Source : http://www.projectcartoon.com/cartoon/1111

Cost

An estimated construction cost should be developed for each alternative. The Association for the Advancement of Cost Engineering (AACE) defines a Study or Feasibility cost estimate as a Class 4 with an accuracy range of -30% to +50% of the estimate cost. https://web.aacei.org/

Construction Approach and Schedule

The anticipated construction approach and schedule for each alternative being considered is often an influential factor. The construction schedule should consider all components of the project including design, permitting, potential regulatory review/approval, and construction duration.

Identification of the Analysis Team

The identification of a diversified and balanced analysis team sets the stage for a successful alternatives analysis. Alternatives analysis teams may include the following:

1. Facilitator (typically independent of the subject matter expert team)
2. Recorder
3. Subject matter experts representing key technical disciplines associated with design, operations, impacts, and construction.
4. Owner/Owner representative
5. Key regulators
6. Other stakeholders

The size of the analysis team depends on the size and complexity of the project. Keep in mind the larger the team the more complex the task of completing the alternatives analysis becomes. A typical size of an analysis team is between 6 to 10 individuals.

Decision Criteria Selection

Each alternative is evaluated based on a series of decision criteria groups. The alternatives team needs to select the decision criteria against which each alternative is scored. Within each criterion, several sub-criteria categories can also be identified to facilitate the scoring of the overall criteria group. An example list of decision criteria groups and potential sub-criteria categories often used in dam rehabilitation alternatives analyses are discussed in further detail below; these should be tailored to the specific project being evaluated.

Planning and Design

A Planning and Design criteria group is used to evaluate the level of effort required and confidence level achievable for the design of each alternative. The criteria sub-categories may include:

Vulnerability to Unknowns: The sensitivity of the design to uncertainties related to lack of information available such as subsurface or abutment conditions.

Design Robustness: The confidence that the alternative will produce acceptable performance throughout the intended lifespan and loading conditions and will perform without unwanted defects or drawbacks.

Design Complexity: Complexity of the alternative or alternative systems and the number of components dependent upon the success of other alternative components.

Degree of Risk Reduction: This is typically a qualitative assessment of risk reduction based on assumed effectiveness of the alternative to address potential failure modes of the existing and remediated dam. It can also be informed by a separate quantitative or semi-quantitative risk reduction analysis. A minimum amount of risk reduction is typically required in the feasibility screening step such that all alternatives carried forward to this step meet the minimum risk reduction to make the residual risk within tolerable limits.

Permitting: An assessment of potential permitting requirements and the amount of coordination required for the alternative.

Regulatory Compliance: The likelihood of regulatory acceptance and compliance with existing regulatory requirements and guidelines. Additionally, the alternative's vulnerability to future regulatory compliance changes is also considered.

Precedent: Design, construction, and performance precedence for the construction method under similar site conditions.

Operational Impacts

An Operational Impacts criteria group is used to evaluate an alternative's impact on the facility operations during construction and its potential impact on the ability to meet the intended purpose of the facility (e.g. water supply, generation, recreation, flood control, etc). The sub-categories may include:

Operational Impacts: The potential to maintain the intended facility purpose during construction of the alternative. If the facility provides multiple purposes, then this may be broken into several sub-categories to allow prioritization of the most important operational goals (e.g. water supply, generation, recreation, flood control, etc).

Environmental Impacts: This is an assessment of the potential impacts an interruption of operations would have on the environment, wildlife, historical artifacts, etc.

Construction

A Construction criteria group is used to evaluate how efficiently the alternative can be safely constructed with limited impact to the public and the environment. Some of the sub-categories are similar to the Operational Impacts criteria group, but this group considers impacts induced specifically by the construction and not the interruption of facility operations. The sub-categories may include:

Dam Safety Risk during Construction: Assessment of potential for dam safety-related items to occur during construction and the relative ease with which to provide a safe work environment during construction.

Constructability: The relative ease with which the alternative can be constructed. This considers overall construction requirements, borrow availability, needs for specialized equipment, waste disposal requirements, dewatering, construction efficiency, and site setting constraints.

Public/Social Impacts: Transportation interruptions, noise disturbance, adjacent property impacts, the need to temporarily or permanently displace residents, and other potential impacts that may be noted by special interest groups.

Environmental Impacts: Potential for construction to induce environmental impacts such as surface and subsurface water quality, air quality, impacts to endangered plant and wildlife species and/or historical artifacts. This may also consider impacts noted by special interest groups. This typically includes both the construction/borrow site and haul routes.

Contractor Experience and Sophistication: Considers whether the alternative requires specialized contractors or equipment.

QA/QC Effectiveness: The ability of a well-executed QA/QC plan to identify and correct construction deficiencies. May be influenced by the complexity of the design and contractor sophistication required for construction. May also consider whether the alternative will be constructed above or below ground, which will influence direct or indirect QA/QC methods.

Seasonal Flexibility: Ability of construction to occur during different seasons.

Schedule Duration: The overall length of the construction schedule is the primary driver for this sub-category. Consideration can be given to the relative complexity required for sequencing/coordination with other work. The sensitivity of the schedule to site conditions such as subsurface obstructions including large boulders, hard rock, or other similar obstructions, and unknowns can also be considered.

Long Term Performance

A Long Term Performance criteria group is used to evaluate if the alternative will perform as intended for the design life of the dam. Potential sub-categories may include:

Confidence in Long Term Performance: The degree to which the alternative is expected to provide satisfactory service without requiring significant maintenance or modernization. Will not lose its effectiveness over time. This may include risk of construction defects and the impact the potential defects have on long-term performance.

Surveillance and Monitoring: The effectiveness of visual surveillance and instrumentation monitoring to identify potentially developing failure modes.

Maintenance Requirements: New routine maintenance requirements resulting from implementation of remediation alternative and addition of capital costs and annual operating costs.

The Long-Term Performance criteria group may also consider project-specific opportunities that the identified alternatives may provide. For instance, if one alternative includes the construction of a low-level outlet (if one currently does not exist), while other alternatives do not, a sub-category may include the improved ability to manage reservoir levels for long-term operational considerations. This example may also be considered as a risk-reduction advantage under the Planning and Design criteria group.

Financial

A Financial criteria group is used to evaluate relative construction cost comparisons between alternatives can be developed based on conceptual or more refined cost estimates. The relative cost comparisons can then be used to evaluate each alternative from the perspective of cost and cost risks. The sub-categories may include:

Bid Risk/Cost Estimate Certainty: The relative ease with which to accurately estimate cost and the sensitivity of the construction methods to contractual risk. These risks may include change orders, insurance, liability, damages, etc. This category would also consider the contractor's perceived exposure to potential losses (financial, reputation, etc.) based on the contractor's ability to recognize, assess, and manage identified risk.

Contractual Risk: The relative probability of successful contract performance. Considers whether standard contract terms can successfully protect against claims and litigation.

Latent Conditions: Costs associated with modifying the design and construction to contend with unforeseen changes such as subsurface obstructions or changes in site conditions.

Construction Cost: The base costs associated with mobilization, installation, site reclamation, and general project requirements of the construction option.

Long-Term Financial Risk: Additional monetary responsibilities of the dam owner resulting from implementation of the remediation alternative (e.g., adding maintenance items, additional efforts related to surveillance and monitoring, etc.).

Conducting an Alternative Analysis

To perform an alternatives analysis, a workshop is generally held and attended by the alternatives analysis team. The primary objective of the workshop is to evaluate each viable alternative based on the set of decision criteria groups and sub-criteria categories previously established by the team.

A multi-criteria alternatives evaluation matrix should be developed to facilitate the evaluation of the alternatives according to the established decision criteria groups and sub-criteria categories. An example of such a matrix that has been used successfully is shown in **Figure 1** in which the different alternatives are presented across the top and the decision criteria groups and sub-criteria categories are listed in the rows of the matrix. When the analysis team scores each alternative, as described further below, the scores are documented in this matrix. Additional discussion about the scoring and weighting is described in the following sections.

				Ranking Scores							
				Alternative 1		Alternative 2		Alternative 3		Alternative 4	
Group Weighting (%)		Selection criteria	Individual Criteria Weighting	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
15%	Planning & Design	Vulnerability to Unknowns									
		Design Robustness									
		Degree of Complexity									
		Quantum of Risk Reduction									
		Permitting									
		Regulatory Compliance									
		Precedent									
		Weighted Sub-Total									
10%	Operational Impacts	Operational Impacts									
		Environmental: wildlife, historical artifacts									
		Weighted Sub-Total									
20%	Construction	Dam Safety Risk during Construction									
		Constructability									
		Public/Social Impacts									
		Environmenta Impacts									
		Required contractor experience/sophistication									
		QA/QC effectiveness									
		Seasonal Flexibility									
		Schedule Duration									
		Weighted Sub-Total									
25%	Long Term Performance	Confidence in long-term performance									
		Surveillance and Monitoring effectiveness									
		Maintenance Requirements									
		Weighted Sub-Total									
30%	Financial	Bid Risk / Cost Estimate Certainty									
		Contractual Risk / Disputes									
		Latent Conditions									
		Construction Cost									
		Long-term Financial Risk									
		Weighted Sub-Total									
100%		**Weighted Grand Totals**									

Note: Example matrix adopted by that developed by Richard Davidson, Chris Dann, and Neil Jacka

Figure 1: Example of Multi-Criteria Selection Matrix

Scoring System

Each alternative should be given a raw score for each of the established sub-criteria categories. There are two typical scales that are often used to score, or rank, alternatives: A Relative Scale or an Ordinal Scale.

Relative Scale: Each alternative is rated relative to the others in satisfying a particular interest. For example, if four alternatives are being considered, assign each a 1, 2, 3, or 4 depending on which satisfies the interest: the best = 4; second best = 3; third best = 2; and the worst at satisfying the interest = 1.

Ordinal Scale: Using a scale of your choosing (e.g. a 5-point scale, or a 10-point scale) assign each alternative a rating for how well it satisfies a particular interest: an example ordinal scoring scale is presented in Figure 2. If several of the alternatives are perceived as equal for a certain sub-criterion they can be assigned an equal raw score in this system.

*Raw Scores for Each Alternative	
5	This alternative is the best for satisfying the criteria.
4	This alternative is better than others but is not the best.
3	This alternative is average for satisying the criteria.
2	This alternative is worse than others at satisfying the criteria, but is not the poorest.
1	This alternative is the poorest at satisfying the criteria.

Figure 2: Descriptors to Help Assign Raw Scores

In the authors' experiences, scoring of the alternatives has been completed successfully in a couple different ways. The scoring can be performed by the analysis team as a whole during the evaluation workshop where all participating stakeholders agree upon a score following discussion of advantages and disadvantages of the different alternatives. Due to time constraints, an in-depth investigation of all alternatives may not be feasible in a workshop team setting.

Alternatively, scoring can be completed by workshop attendee sub-groups or even individually, and then the analysis team can reconvene to discuss the various scores assigned. An advantage to smaller sub-group scoring or individual scoring is that it is more likely that all project stakeholders will have a chance to contribute. In larger group settings, it is somewhat common that a few opinionated team members can dominate the discussion and scoring assignments. If the various scores, or ranking, of the alternatives differ amongst the smaller groups, then the team has several options as presented in the **Discussing and Interpreting the Results** section below.

Regardless of the approach, the small groups or the recorder in a group setting, should document factors that led to the selected raw scores.

Weighting the Selected Decision Criteria

While there are multiple methods of assigning weighting factors to the decision criteria groups and sub-criteria categories described in the above section, a double weighting process is presented herein that considers the relative importance of various decision criteria groups to the project as perceived by the stakeholders. Each of the decision criteria groups and sub-criteria categories selected to be evaluated should be assigned a group weighting according to their relative importance to the project. The weighting for each of the criteria groups should be a percentage representing the importance of the criteria group relative to the others wherein the combined percentages sum to 100 percent, with the most important criteria group having the most points and the least important having the least points. For example, if five criteria groups are selected for the evaluation, as described in the above section, the following example group weighting percentages may be selected by the analysis team: 15% to Planning and Design, 10% to Operational Impacts, 20% to Construction, 25% to Long Term Performance, and 30% to Financial. This example weighting would reflect that the Financial criteria group is the most important and the Operational Impacts criteria group the least important, relative to the other criteria. The fact that they all made the list for evaluation criteria is a reflection that all selected criteria are important.

Within each decision criteria group, the sub-criteria categories selected to be used for the analysis should be assigned individual criteria weighting factors. Individual weighting criteria should range from one to four with one being of minor importance and four being of critical importance. The descriptors summarized in **Figure 3** below can be used as a guide when assigning individual weighting criteria to each of the sub-criteria.

*Sub-Criterion Weighting	
4	This criteria is of critical importance. A potential "deal breaker."
3	This is an important criteria.
2	This criteria is of average importance.
1	This critiera is of minor importance.

*How important is this criteria in determining a preferred solution?

Figure 3: Descriptors to Help Assign Individual Weighting Factors to Sub-Criterion

An alternative to the above sub-criterion weighting scale, is to assign a weight to each sub-criterion ranging between 0 and the value assigned to the associated criteria group, based on the perceived importance of the sub-criterion. With this approach, for the example above, a sub-criterion under the Planning and Design group would range between 0 and 15.

A raw score given to a particular sub-criterion for an alternative is multiplied by the individual weighting factor to establish a weighted score for each sub-criterion. The weighted scores for all sub-criterion are then summed and the total is factored based on the assigned percentage weighting of the criteria group.

Discussing and Interpreting the Results

Identifying Potential Additional Data Needs

The alternatives analysis process results in several valuable findings. Going through the process of scoring the alternatives can result in identifying potential data gaps. There may be influential data gaps that become apparent to the analysis team when assigning scores for some of the criteria groups. The team should consider how having the additional data could affect the assigned scores. If confidence in the assigned score is low due to unavailable data that could significantly alter the outcome, then the analysis team should consider reevaluating once additional data is gathered.

Identifying Potential Refinements

Another valuable result of the evaluation process may be the further refinement of developed alternatives; this may allow for score changes in particular criteria categories, thereby re-ranking the alternatives. During the workshop, the analysis team will have in-depth discussions about the advantages and disadvantages of the various alternatives being considered. Through these discussions, potential refinements to the alternatives may be brainstormed. A potential outcome is the analysis team may decide to include these refinements into that alternative for the evaluation. Otherwise, the analysis team could consider adding another alternative to those being evaluated that is a refinement of an existing alternative or potentially a combination of multiple alternatives. The workshop discussions leading to score assignments can provide information just as valuable as the identification of a preferred alternative itself.

Identifying the Preferred Alternative

Using the results of the selection matrix, a preferred alternative is usually identified as the alternative that scores the highest weighted grand total. A figure similar to Figure 4 can be created to visually portray the results of the alternatives analysis.

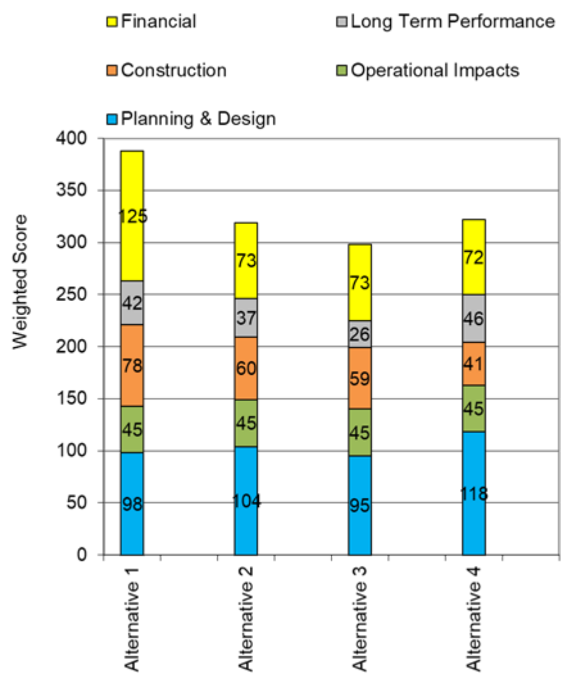


Figure 4: Example Histogram Portraying the Results of an Alternatives Evaluation

The team should critically study the resulting weighted grand totals and the differences between the various alternatives. The following questions can be used when assessing the preferred alternative from the completed selection matrix:

1. Do the weighted grand totals reflect the sensitivity and discussions held about the disadvantages and advantages of the alternatives?
2. What is the overall difference between the various alternatives?
3. Did the highest scoring alternative score significantly higher than the others, resulting in a clear preferred alternative, or are the scores similar to one another? (Note: It is recommended that the analysis team understands the sensitivity of the raw score assignments as they play into the overall weighted grand total [e.g., How many points difference is 'significant'?].)

In the event that grand total scores resulting from the independent or small-group estimation approach differ amongst the stakeholders, then several discussions could take place to agree on a preferred approach.

- If one alternative is rated lowest or second lowest by all of the small-groups, then it can be eliminated from further consideration.
- Alternatives with close scores should be discussed in more detail. Team members can compare and discuss their rankings, and perform sensitivities by assigning higher or lower weights to different sub-criterion or modifying their raw scores based on hearing group discussion. This experimentation may yield some insights and lead to agreement.
- Raw scores of the top-ranked alternatives can be expressed as a range rather than a single number to reflect the degree of uncertainty or disagreement in the value. Monte Carlo statistical analysis can be completed using the selected range of raw scores, for instance using an Excel add-on program such as @Risk (Pallisade).
- Discussion and sensitivity analyses will often lead to agreement on a preferred alternative.

Costs for Completing an Alternatives Analysis

The cost to complete an alternatives analysis for a dam owner could potentially range from $10,000 to $100,000 depending on the complexity of the project, number of alternatives being evaluated, and the number of stakeholders participating. This is a fairly large range and a potentially expensive endeavor; however, when done correctly, this alternatives analysis could end up saving the owner a significant amount of time and money that could have otherwise been wasted if project objectives were unmet, significant changes were required later in the design, and backtracking was needed during project progression. For a typical small-to mid-sized dam project evaluating a potential spillway upgrade or outlet works replacement, the cost for the alternatives analysis would be closer to the $10,000 to $50,000 range. Data collection, evaluation, preparation, and participation are required in order to be confident that the end result is the best path forward for the project. The bottom line is you get out of it what you put into it.

Common Pitfalls and Lessons Learned

There are some common pitfalls and lessons learned in performing alternatives analyses about which one should be aware.

Stakeholder Identification and Involvement

As an engineer developing the alternatives, you want to make sure all stakeholders have been identified and requirements and opinions have been identified early in the process.

Facilitating an Alternatives Analysis

As a facilitator, your primary job is to present the alternatives and walk the evaluation team through the analysis. It is important to focus on being impartial and not provide personal opinions of one alternative over another. Consider engaging a facilitator that has no ties to project to avoid conflicts of interest.

Costs

Costs at this level of development typically have an accuracy range of – 30% to +50%. Costs are often conservative because there are many unknowns. If the range in costs of the various alternatives are within the accuracy of the estimate, consider not including cost as one of the selection criteria. Of course, understanding costs and cost constraints is important and needs to be part of the alternatives analysis. Consider performing the alternatives analysis without the cost of each alternative being evaluated as a sub-criterion. Once the preferred alternative is selected, reveal the cost of each alternative. The workshop group will then have the opportunity to engage in discussion that includes cost.

Analysis Team Size

The size of the analysis team varies from project to project. In selecting people to participate in an alternative's analysis, keep the following in mind.

1. Owner – There are often various departments within an organization that have different responsibilities (environmental, maintenance, operations). Input from all applicable departments is necessary, and the identification and inclusion of key individuals from each department will better inform the analysis.
2. Regulator– The identification of key agencies that will provide input on the permitting

challenges for a given alternatives will be beneficial to the team.

3. Engineer – Include key experts in the applicable design disciplines to answer questions that may arise during the analysis. Keep in mind that these experts are just observers and a resource to the analysis team to request clarification on design intent.

Conclusion

An alternatives analysis using a well-defined multi-criteria decision framework is a powerful tool to gain consensus on a particular alternative that involves input from multiple stakeholders. It provides the framework for people to consider and talk about complex trade-offs among alternatives. This collaborative approach to evaluating alternatives should provide an owner with the results and supporting documentation to make a final decision on the most efficient way to complete their dam improvement project.

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