WCD Thematic Review

Options Assessment IV.5

Operations, Monitoring and Decommissioning of Dams

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Executive summary[i]

The interpretation of scientific understanding, however limited or conditional, must be translated by the scientists into concrete recommendations designed for the manager. We must make small changes initially. But it should be understood very clearly by the people who are supporting the investigation that more changes will be needed. The need for long-term measurements is the unassailable conclusion of studies made to date. The data collection program should be designed with great care, it should consider a wide variety of data needs, and each part should be installed and operated as soon as practicable even though not all parts. . . . . begin at one time (Leopold, 1990)

Introduction

The World Register of Dams of the International Commission On Large Dams (dams higher than 125 feet) includes more than 22,000 large dams, and there are probably another 23,000 bringing the worldwide total to approximately 45,000. Three quarters of these were built prior to 1980, and over the next 50 years, at the present rate of construction, as many as 15,000 new dams could be added to the total. The design of dams for safety and economy, their safe operation for water and energy management, their decommissioning, and the effects they have on people and nature will continue to be important throughout the world.

The effects from the operation of dams are both direct and indirect. Direct effects stem from the flooded area of the reservoir, the changes in downstream flow regimes, and the outputs such as electricity and water for irrigation and municipal and industrial water supply. Indirect effects include salination and water logging of irrigated areas, regional economic activities, and institutions and regulations that are required to design, operate, maintain, and decommission dams.

Owning dams requires consideration for the policies and legal frameworks that promote them and regulate their operation, the detailed criteria and guidelines that ensure consistency and safety in their operation, and the methodologies and techniques that ensure their efficient operation. Some of these considerations like those affecting the safety and integrity of the dam itself (dam safety), are well established through centuries of engineering practice (though continuing to evolve along with other technologies). Other considerations are newly emerged and immature, like regulating the management of water to minimise adverse impacts on the environment, or to enhance the environment.

As time has passed, new information has become available, technology and techniques have become more sophisticated, and societal priorities have changed. These are signals to revisit water projects to determine how their operation should be revised. Efficient utilisation of existing dams and the dependant infrastructure provides an economical means for increasing project benefits.

Optimising dam operations

Optimal operation of reservoirs requires managing the storage space in anticipation of future inflows and multiple needs for water. Optimisation is a fundamental concept for increasing the efficiency and managing the tradeoffs in dam projects. It is a method that merits consideration at all dams throughout the world. In countries where capital is not readily available for building new dams it offers an affordable method for meeting an increment of needs. The concept of optimising dam operations has become increasingly more important as operating criteria become more complex and requirements for environmental protection have become better understood.

Re-placing the operating criteria

Nam Ngum is a 150 MW hydropower plant near Vientiane, the capital of Lao PDR. Not all power can be consumed in the country and the surplus power is exported to Thailand. The power sales agreement between the two countries foresees that the export tariff is revised every 4 years.

The objective of the study, which was financed by the Asian Development Bank, was to find ways and means by which the operation of the project could be changed to maximize the income for the Lao Government, hydro-electricity being one of the most important foreign exchange income earners of the country.

The study started with a detailed simulation of hsitorical operation to derive the net inflow series into the Nam Ngum reservoir from 1971 when the project was commisioned, to 1990 the year the study was done. By regression with rainfall data, the inflow was extended, including the years 1949-1989.

The study proposed a time-of-day tariff with three time slots: peak, partial peak and off peak hours, with the highest tariff for peak hours and the lowest tariff for off peak hours.

Application of a monthly stochastic dynamic programming model then derived switching curves, depending on the month and the water level in the reservoir. These curves dtermine whether the project should, in addition to covering the local demand in Lao PDR, maximize output for exports during 24 hours per day, during the peak and partial peak hours, only during peak hours, or not at all.

This new mode of operation was successfully negotiated with the Thai authorities. Appropriate software was installed on the project computers to update the data sets for changes in the local demand and new hydrological variation, and to let the operators from day to day know during which hours which turbines had to be run with what capacity. Net benefits are estimated to be approximately US$ 2 million per year.

Assuming the same average tariff, the revenues from power sales to Thailand increased by about 10%.

A prerequisite to optimal water management is a regulatory environment with key environmental objectives clearly stated in a way that provides the dam operator maximum flexibility in determining how to achieve the objectives. In some cases the first step is to improve communications between those who have the data and its interpretation and those who need it. In other cases the very data required to operate effectively may not be available in time to influence decisions.

Software for Stakeholders

The California Department of Water Resources has developed an efficient modeling tool (CALSIM) to assist in the rapid evaluation of changing alternatives. The goal is to empower users to quickly develop system representations and easily to specify or modify operational criteria. CALSIM reflects a fundamental change in the modeling approach used for California water systems, particularly in simulating operation of Central Valley Project and the State Water project. The availability of CALSIM will provide stakeholders with the capability to make independent assessments of the effectiveness of water operations.

Optimal operations requires effective software for forecasting reservoir inflows, from deterministic forecasts in real-time to long range probability based forecasts. The software must also provide guidance for operating decisions. This decision support is required over the various time horizons, from real-time to commitments months in the future.

Sediment and reservoir flushing

Sedimentation is common to all reservoirs and it is widely recognised that each year up to 1-percent of the world's reservoir storage is lost to sedimentation. There are a number of ways to address the problem, ranging from watershed management to minimising erosion, to flushing sediments through the dam. But there is no routine remedy that will remove sediment and extend the useful life of storage at all dams. Case studies show that sediment flushing can be a factor in extending the life of narrow reservoirs if dams have the appropriate facilities to bypass large flows at low reservoir levels. In common with all major changes in operation, the effects of the sediment that is flushed must be considered, which can include water quality changes, and effects on the downstream river channel.

Sediment Flushing

In Japan, Dashidaira Dam on the Kurobe River was constructed in 1985 with sediment flushing facilities in two tunnels beneath the dam. Discharge from the dam goes directly to the ocean. The first flushing after 6 years of operation sent a dark grey and foul smelling fresh water plume over the ocean. After a major inflow of sediment during a flood in 1995, subsequent flushing a few days at a time have reduced the sediment volume stored in the reservoir by approximately forty percent.

Floods

The potential for floods varies seasonally with the climate and with day to day changes in a soil moisture and snow cover. Thus the flood frequency curve and the probable maximum flood are conditional on the time of year and the current state of the watershed. The portion of the total reservoir storage reserved for flood control therefore varies with these factors.

Since the 1960's in the Columbia River of the USA and Canada, the current hydrological condition of the basin has been used each year to revise the allocation of storage for flood control. The goal of this procedure is to maximise the utilisation of reservoirs for non-flood control purposes without sacrificing flood protection for downstream areas or dam safety. Monitoring and modelling is incorporated effectively into the reservoir operations procedures.

Land around reservoirs is normally acquired and dedicated to uses that are not damaged by high water levels. If this is not the case, reservoir operations to control floods must consider the trade-off between damage from downstream flooding caused by large releases, and upstream flooding as reservoir levels rise far above normal.

Hydroelectric operations

Operating decisions are made at different time scales, depending on the circumstances of the moment and the setting in which the generating facilities are operating. Power benefits have been increased by 5 to 10 percent by using operations optimisation techniques with good data in a computer based decision support system.

The objectives change as a utility moves from serving a defined service area towards a competitive electricity market. In service areas the goal is to meet load at minimum cost by efficient use of hydroelectric facilities. In competitive areas the goal is to maximise revenue.

Since 1987 a computerised decision support system (DSS) has been used to guide weekly reservoir release decisions at two hydroelectric plants in the coastal mountains of British Columbia, Canada (www.chal.bc.ca). Studies of 1970-1974 operations (a period before the decision support system became operational) showed that, compared to operation with perfect foresight as determined with a deterministic optimisation model, the rule curve based operation had produced 83.4-percent of the maximum attainable energy compared to 95.1-percent with the full DSS. Without the hydrologic forecast component the optimisation component would have produced 92.8-percent by simply using long-term average monthly inflows in place of the forecast. The actual energy produced by operating with the DSS in each year between 1989 and 1993, compared to the maximum possible, was 100, 93, 98, 94 and 96 percent. The DSS provides accessible data and a consistent framework for improving operating decisions.

Water quality

Reservoirs affect water quality within the reservoir itself and in the downstream river. Temperature stratification within the reservoirs leads to areas of low oxygen (less than 5 ppm) in which animals cannot flourish and to anaerobic conditions conducive to undesirable chemical reactions in reservoir sediments.

The conventional solution to problems stemming from temperature stratification is to use a network of submerged pipes to aerate the reservoir areas that are subject to low oxygen concentrations. Another method takes advantage of the small difference in density in stratified reservoirs and uses mechanical mixing to provide the uniform temperature distribution that supports higher concentrations of oxygen. Releases from upstream reservoirs can be scheduled to provide cooler aerated water to downstream reservoirs at critical times of year.

Mercury in flooded soils may be released into more mobile forms that bioaccumulate into toxic concentrations at higher tropic levels. There are no known operational fixes for this problem - fish caught in reservoirs must be monitored to detect high concentrations before they become human health problems.

Water supply and demand forecasting

Dam operations sometimes focuses only on managing water supplies. But water shortages come about when demands for water exceed supplies so both must be determined to develop optimal water management plans.

Water supply reliability has a probability distribution that is determined from the intersection of supply and demand forecasts. The benefits and costs of various levels of reliability are used to determine when to invoke water consumption restrictions.

The key to operations during drought is managing the demand for water. Consumption restrictions are the only methods that will maintain an acceptable level of reliability and prevent a water supply disaster. A hedging strategy based on temporarily curtailing water demands is used to determine storage operation during drought. The goal is to avoid emptying the reservoir for then there would be a complete lack of water available for subsistence.

Planning as well as operations can benefit from demand management. In planning it is a tool for delaying the construction of new facilities and for reducing the present value of costs to meet growth in unrestrained demands for water. A portion of the savings in supply costs is used to finance a continual program of public education. In addition to increasing supplies, the risk of water shortages is controlled by managing consumption and by developing long term cost avoidance strategies in preparation for droughts.

Ageing, maintenance, rehabilitation and upgrading

Dams and their appurtenant structures inevitably are ageing. The International Commission on Large Dams (ICOLD) reported on over 1000 case histories of deterioration of dams. The report discussed the mechanism of the ageing process, how this is detected and the effect of the deterioration on the operation and safety of the dam. Recommendations were made for all types of dams to reduce the rate at which ageing occurs, and to reduce the impact of that which has occurred. Aging is a technical issue that requires ongoing attention to hundreds of details that ensure the longevity and safety of dams.

Dam safety

Although few dam failures occur each year the consequences can be substantial. The main causes are unprecedented floods, which exceed the spillway capacity, or foundation drains that are inadequate to prevent subsurface erosion (piping) that leads to collapse of earth embankments. Careful operation and continuous monitoring are essential to maintain the safety of dams. It is standard practice to instrument dams to detect any significant movements or seepage. Regular inspections supplement the readings of these instruments. As more and better data become available, projections of flood probabilities should be updated, but this has seldom been the case. Dam safety regulations are in place in many countries but enforcement is not uniformly applied.

Emergency warning systems and evacuation plans are required for all dams that may adversely affect human life.

Dam safety in China

The Ministry of Water Resources has broad responsibility for the safety of dams and flood levees throughout the country. There are two National Dam Safety Centers. The centre for concrete dams is located in Hongzhou: the one for earth and rockfill dams is in Nanjing. The Ministry has issued numerous dam-safety guidelines and regulations: Safety Management of Reservoir Dams; Flood Control Criteria; Evaluation Procedures for Reservoir Dams, and the 1991 Regulation of Dam Safety Management. The regulation, Law of Flood Control for China (January 1998), requires that emergency-preparedness plans be established for each dam that is above a certain size. Plans list people to contact and actions to take in an emergency.

Chinese sources describe some notable dam failures in China. In August 1975, a typhoon created a maximum 24-hour rainfall of 1 005mm and a three-day rainfall of 1 605mm in Henan Province. This unprecedented event caused the failure of the Banqiao Reservoir on the upper reach of the Ruhe River. The flood caused by the typhoon combined with the dam failure inundated more than one million ha of land, over 100 km of the Beijing-Guangzhou railway line was damaged, and more than 20 000 lives were lost. In 1993, the Gouhou Dam in Qinghai Province failed when the concrete slab on the rockfill failed and 1 200 people died.

The recent Dam Safety Management and Monitoring Project (1999) recommended the establishment of a Dam Safety Regulatory Agency to assume responsibility for dam safety management. Its proposed tasks include advice and assistance to the Ministry of Water Resources in drafting regulations, taking responsibility for enforcement for dam safety and overseeing the production of guidelines and standards for inspection and safety appraisals. Recommendations included the need for new regulations and guidelines to cover the areas of owners' responsibilities, frequency of inspections, record-keeping requirements, qualification of personnel, etc. Approval of these recommendations is anticipated. The present action plans sets a date of completion of the regulations and institutional arrangements for the end of 2003.

Monitoring

A review of the world literature showed that monitoring of dam operations to determine their actual benefits is not a normal practice. It should be. Monitoring provides data for improving operations as well as information for measuring how effectively dams and the related facilities are being utilised. Many dams are operated without the comprehensive hydrometric data and analysis software that could be used to improve operations at a fraction of the cost of the monitoring. No wonder then that monitoring to verify or to improve instream and reservoir environmental benefits and to minimise adverse impacts is even rarer. In 1997 Japan initiated an experimental program that requires dam performance reviews every 5 years. The reviews cover every aspect of benefits, costs, and safety associated with the operation of dams.

Some countries have re-licensing requirements that provide opportunities for a comprehensive review and revision to operating criteria. There is no consensus among countries on the elapsed time, which is up to 70 years, between such reviews. Hungary and Vietnam do have re-licensing requirements. They require inspections at periodic intervals, average approximately ten years.

Updating master plans

As river basin development proceeds over time, operational changes are required at existing dams. The planning process for new facilities must anticipate this by re-optimising the operations of existing facilities at each step as development proceeds.

A functional balance should be achieved through dam operations which serve more than one purpose. For example, slight changes in the reliability of power generation from a dam (rely more on thermal generation or demand management) can free up storage for irrigation, municipal water supply, or for nature. Regulatory mechanisms, public participation, and market forces have led to operating criteria that improve benefits and reduce the harm from existing dams.

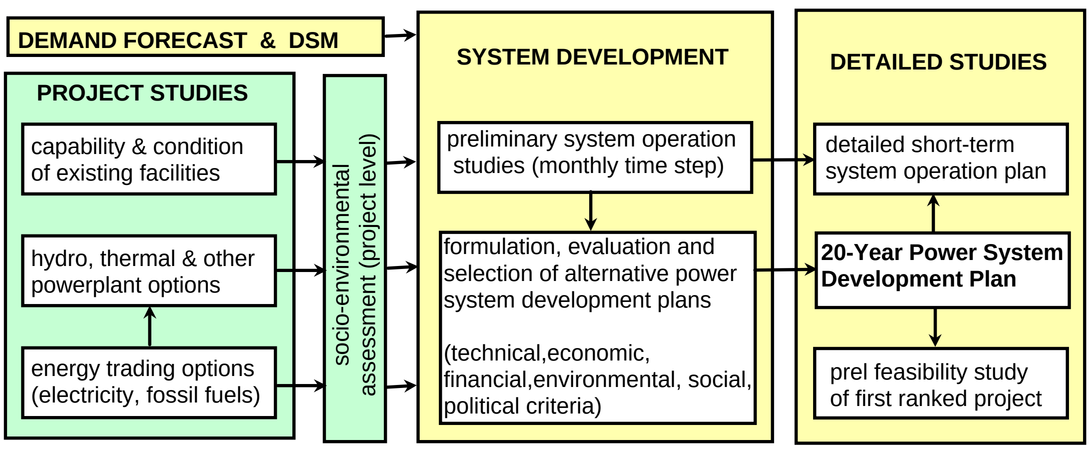
A win, win Case

In Seattle, USA, the dam constructed in 1904 on the Cedar River for municipal water supply now is managed to provide municipal and industrial water supply, hydroelectric power and fish. Through cleanup of Lake Washington and careful regulation of flood flows when eggs are incubating in the gravel, the sockeye salmon spawning run increased from 67,000 in the late 1960's to over 600,000 by the mid-1980's. All this with no loss of power benefits or water supplies to the city. Complex River systems with several dams may offer opportunities to improve the operation of the overall system by fine tuning the criteria and methods for operation of the individual dams.

Malawi Masterplan for Power System Development – 1998

The World Bank funded study had the following objectives:

- to determine the most attractive long-term development plan for the power system of Malawi for the period until 2020, taking into account technical, economic, environmental, social, political and risk considerations
- to identify the first major measure required after completion of Kapichira Phase I and to carry out a draft feasibility study for the selected project
- to carry out detailed operation studies for the system, aiming at minimum cost and maximum reliability of the power supply
- to transfer skills required for power system planning and provide ESCOM with the facility and capability to regularly update the expansion plan.



The study concluded that interconnection to the Cahora Bassa plant in Mozambique would be of top priority to make the system more reliable. Other important measures identified were rehabilitation of the older parts of the Nkula and Tedzani hydropower plant, and the rehabilitation and expansion of the HV transmission and distribution networks. As a result, besides the completion of the Kapichira hydropower plant, no further hydropower plants need to be constructed in the next 15 to 20 years.

Decommissioning

Many dams have been decommissioned but most have been small, less than 15 meters in height, and the environmental improvements have been tangible. As far as known, there has never been a dam exceeding 40 meters in height decommissioned. Decommissioning is an economical option if it is determined that the costs of further operation outweigh its ongoing benefits - that is, the dam has gone beyond its useful life. Decommissioning, however, refers to a range of possible actions, from ceasing operations of a dam, breaching it to allow fish passage and navigation, and to the full dismantling and removal of structures. The effects from decommissioning a large dam are yet to be determined.

Dams removed in France

Dam	**River**	**Height (m)**	**Year Built**	**Year Removed**	**Removal Cost (Million US$)**
Kernansquillec	Leguer	15	1920	1996	1.0
Saint-Etienne du Vigan	Allier	12	1895	1998	1.1
Maisons-Rouges	Vienne	4	1922	1998	2.3

Submission: European Rivers Network 2000/OPT136

Dams are potentially finite, and thus decommissioning is likely to become more of an issue throughout the world in the future. But the costs and mechanics of dam decommissioning or removal are major and have not usually been considered as part of the life cycle costs, nor included in overall benefit-cost ratios when deciding on the feasibility of new dam projects. It seems reasonable that future dam projects will be required to include a fund for decommissioning and a mandatory decommissioning methodology. What should be done about existing projects remains unclear.

Conclusions

Most dams can be operated better than they are at present. Regulatory mechanisms, public pressure, and market forces have proven to be effective in motivating dam owners to improve operations to increase benefits and reduce the harm from existing dams. As the values of society change and new opportunities are recognised, the operating criteria for dams have been successfully revised to meet them.

Large dam projects can bring extensive benefits and economic prosperity to regions. But these benefits usually are estimated based on assumptions and the information available at the time of the design. There are few instances where the operations of the dam were analysed several years after implementation to ensure that these benefits actually were achieved.

The key to improved management of regulated rivers is in the collection of data and the interpretation and conversion of this data to knowledge. Despite the potential adverse impacts of large dams, there appears to be no systematic methodology for monitoring the ecological responses to dams. Monitoring could justify the original investment, develop knowledge that could be used in other projects, and could adapt operational rules to minimise adverse impacts and to maximise benefits.

Technology can play a major role in adaptive management. Real time computer models, remote sensing of meteorological data through satellites and other technology can assist in management decisions. If the interested parties can agree on the technology and predictive ability of the models, then the models can lead to actual operations that reflect the policies and priorities of the decision group.

Dams are built to manage water but they cannot mange the demands for water. Together with the operation tools for the dams there must be a commitment to a contingency strategy to manage situations which develop during draughts and extreme floods. Demand management warning and evacuation systems must be part of the package.

Dam Performance Assessment

- Monitoring for performance assessment
- Data and development of information to support decisions
- Validation of design assumptions
- Achievement of benefits that were predicted during design
- Assessment of predicted impacts during implementation
- Assessment of predicted post-implementation impacts
- Documentation of any unforeseen consequences
- Flexibility in operation rules to account for changing physical or socio-economic conditions
- Adaptive management by direct feedback from monitoring to operation on a real-time basis.
- Accountability for dam operation safety and maintenance
- Mandatory decommissioning methodology.
- Use of institutions and technology to minimise public safety risks
- Optimise the long-term comprehensive performance of the project.

There also is need to incorporate a decommissioning strategy in the planning of dam projects. The estimated cost of decommissioning should be included in the life cycle costs. For existing dams some form of "sinking fund" arrangement might be implemented now to prepare for the inevitable future.

The following recommendations may be made:

1. A functional balance that serves more than one purpose should be achieved through dam operations. For example, slight changes in the reliability of hydroelectric power generation by relying more on thermal generation or demand management, can free up storage for other uses such as irrigation, municipal water supply, or for nature.

2. Dam operations can be improved significantly. Monitoring and post-evaluation is required to provide the information needed for improving the economic performance of existing dams and for identifying and implementing mitigation for adverse environmental effects, dam aging, reservoir sedimentation and unanticipated factors that emerge with time and experience. Japan is developing a model program that should be considered for application in other countries.

3. Decision support systems centered around real-time data and computer models provide opportunities for consistent operating decisions based on agreed upon policies, current data, and optimisation techniques. Modern software and hardware make such systems easy to implement and to use, at costs far less than the benefits they bring.

1.The report was synthesised from reports and reviews by the consultants and staff of the World Commission on Dams, and from submissions by interested professionals around the world.