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**ICOLD Bulletin on:**

# Multipurpose Water Storage

## *Essential Elements and Emerging Trends*

*(30 June 2016)*

## ICOLD Bulletin on:

## Multipurpose Water Storage
## *Essential Elements and Emerging Trends*
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## Acknowledgements

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- *Sedimentation management*
- *Water management institutions*
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*The MPWS Core Team dedicates this work to him:*

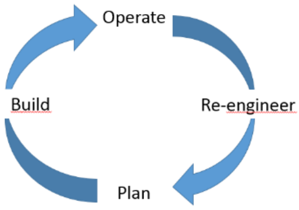
***In memory of John Briscoe who taught us integrity, coherence, and standing for one's principles, even when they digress from what "everybody thinks".***

# *Foreword: key messages for decision makers*

A “multipurpose” use is becoming a recurring key requirement for the development of water infrastructure projects involving dams and reservoirs. In June 2012, during a lunch break in Kyoto’s ICOLD Congress, when the concept of a Multipurpose Water Storage (MPWS) committee was formulated, it was anticipated that the output was going to be an unusual ICOLD Bulletin: it would not add much about dam engineering, but significantly on modern approach to planning, economics, and sustainable development.

The committee believes that the MPWS Bulletin represents valuable information to strategically advise policy makers, decision makers, project developers and planners. We believe that the following five topics, in particular, represent key messages from the study.

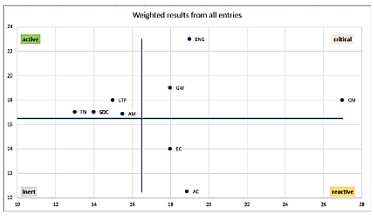
i) Multipurpose storage life cycle



Life cycle of multipurpose water infrastructure is very different from that of other infrastructures primarily due to its longer life span. The history of reservoir development shows that societal requirements continue to evolve over time with varying needs for additional uses of water or storage capacity, mitigation of impacts, and continual evolution of the economics of the infrastructure.

Decommissioning of dams (chapter 5) is a relatively recent happening, which should be regarded as a normal process in countries where dam construction started about a century ago. When dealing with large, multipurpose projects with a very long service life, it is very unlikely that decommissioning or total dam removal becomes the common course of action, rather re-engineering the infrastructure with major rehabilitation and upgrading investments is the obvious alternative.

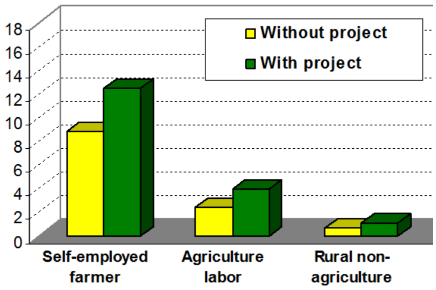
ii) The need for Long Term Planning



Long term planning is an extremely challenging endeavour, but it is essential in the case of multipurpose water infrastructure. Where detailed planning has occurred, the study highlighted that significant benefits to the infrastructure, society and the environment were obtained. Cross-Impact Analysis (chapter 8) is a technique that can assist long-term planning preparation.

Quality dam sites are scarce resources, and how non-sustainable use of these resources impacts society has been often underappreciated in the past. Past dam design and economic analysis paradigms considered benefits and costs over a period of time that often ranged from 20 to 30 years, commonly known as the design life. Nowadays (2016), organisations like the World Bank recommend that the time period used in economic analysis of projects should reflect reasonable estimates of the full duration of costs and benefits associated with the project, rather than be capped at 20 years or some arbitrary cut-off date. Besides, using 3%, as an approximate estimate for expected long-term growth rate in developing countries, the World Bank is considering using a discount rate of 6%. Where there is reason to expect a higher (lower) growth rate, a higher (lower) discount rate should be chosen. Consideration is now being given to the use of a declining discount rate to account for the uncertainty associated with future economic growth.

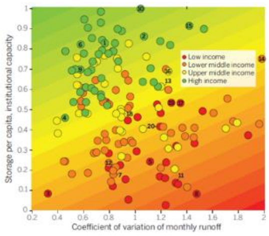
### iii) Economic effects of Transformational Projects



Indirect economic benefits, or economic multipliers, assume particular relevance in the case of “transformational projects”, i.e. projects conceived to cause major changes in regional and national economies (chapter 4). Indirect and induced economic impacts are those that stem from the linkages between the direct consequences of a project and the rest of the economy. Since water investments are not typically “marginal” or small in comparison with the rest of the economy, it is important to capture the total benefits of the project in the context of regional developments. Such considerations of creating employment and regional incomes were the original motivation behind large-scale water and other infrastructure projects built many decades ago in the United States, Europe and other regions and countries. Regional multipliers were precisely the point of such projects as it was expected that water investments would “change the trajectory of regional economies”.

Transformational projects are particularly sensitive to pre-construction delays (chapter 4). Beside obvious economic impacts, such delays have also numerous secondary effects such as the stress on communities, deforestation of project areas, lack of local investment and services, and a disincentive for foreign investment caused by a lack of reliable power supply.

### iv) The “3 I’s” concept



Institutions, Infrastructure, and Information (chapter 2) are the three pillars in water resources development and management and those in decision making positions should ensure that the three pillars grow harmoniously. *Institutions* and governance (including river basin organization, legal systems, national governments, and non-governmental organizations) support proactive planning and development of legal and economic instruments to manage and share risks (water allocation, and property rights, land zoning, watershed protection, water pricing and trading, insurance, and food trade liberalization). Investment in *Infrastructure* buffers variability and minimizes risk (storage, transfers, groundwater wells, levees, wastewater treatment, and desalination). *Information* collection, analysis, and transfer (monitoring, forecast and warning systems, expert know-how, simulation models, and decision support systems) are essential for operating institutions and infrastructure.

### v) The importance of Knowledge Transfer

Information is based on data analysis. Information becomes knowledge through application. Transfer of such knowledge between experienced professionals and young professional is a must for sustaining knowledge itself, and permitting knowledge to evolve into wisdom, the final product of the process. Involving young professionals in hands-on application, teaching the reasoning of past decision-making, listening to their views on societal drivers and the application of knowledge, and working with experienced colleagues, should be the preferred method of knowledge transfer.

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## 1.0 Introduction

This ICOLD Bulletin on Multipurpose Water Storage (MPWS) has been prepared by the Committee using information from 52 case studies representing MPWS projects around the world. It follows the First Final Draft that was circulated in May 2015 to get feedback during the 25th ICOLD Congress in Stavanger (Norway). Before that, several international experts in different areas, relevant to MPWS, provided very useful comments, suggestions, and constructive criticism. Reviewers' contributions have been incorporated in the Bulletin, and their names of are duly acknowledged herewith.

The scope of this bulletin is to provide a view on the dynamics of the MPWS subject. This is achieved by presenting what the Committee regards, today, as "essential elements" and "emerging trends" for planning and managing MPWS projects. The focus of this Bulletin is therefore, not on what should be done, but on what is being done, and how and by whom. That is why the findings and reflections stemming from a review of the case studies are not presented in the form of a guideline, but as recommended "essential elements" and "emerging trends".

Essential elements represent a considered set of checklists for implementation of a MPWS project. Emerging trends are a snapshot of the current "state of the art" of MPWS projects; a state that has been evolving significantly in the recent few decades, and that is expected to further evolve as innovative approaches emerge in search of optimal sustainable solutions. It is considered that presentation of different ways of dealing with planning and management of MPWS projects in different parts of the world will provide useful material to planners, developers and operators of such projects for improving their business and promoting integration with society and the environment.

The Bulletin is structured to present the global and local role of water storage in the modern world and present the basis of multipurpose developments in the context of the hydrological cycle, the water energy nexus, stakeholder engagement and environmental assessments. The Bulletin explores the economic and financial perspectives of multipurpose projects and the need for long term planning including reservoir conservation, and the challenges of envisioning long term scenarios. It discusses the institutional and procurement aspects of the infrastructure development and management, touching also on water governance and how this is interfacing with corporate governance. Building on the case studies, the Bulletin then presents structural and non-structural solutions to improve development, operation and management, and illustrates how water conservation and adaptive management are essential to the societal ‘license to operate’ reservoirs and their ancillary infrastructure. The Bulletin concludes with a presentation of the essential elements and emerging trends, and a technique for evaluating the relative criticality of the essential elements as they change throughout a reservoir’s lifecycle.

The Bulletin was three years in preparation. The authors observed in the study that whilst the infrastructure is static in nature, the changing societal demands are significantly influencing design, operation and management of the infrastructure. They observed that these change processes lead to incorporating multiple uses of reservoirs to provide wider benefits to the society, and progressively improving impact mitigation.

In a wide subject such as multipurpose water storage, it is essential to strike a balance between specificity and synthesis. One has to make sure that breadth and scope of the document is sufficient to cover the subject without entering into too much detail that would take the reader away from the core of the subject. Reviews and suggestions from a variety of international experts in different areas have assisted a lot in seeking that balance.

# 2.0 The Role of Water Storage

## 2.1 Water and Development

Before the end of the twentieth century, it was predicted (Keller et al. 2000) that one-third of the developing world would have faced severe water shortages by 2025. Since this prediction, we have observed pressure growing on water resources, key drivers being more people, growing economies, and global warming.

The true renewable water resource is precipitation, be it in the form of rain or snow. Sporadic, spatial and temporal distribution of precipitation rarely coincides with demand. Whether the demand is for natural processes or human needs, the only way water supply can match demand is limiting demand itself to match supply, or through creation of storage to supplement low flow periods.

Storing water plays a critical role in the water- food- energy nexus. Food supply, energy production and other water delivery services all depend on sizable, reliable, continuous and efficient supply of water. Vast amounts of energy are also needed throughout the food supply chain. Water supply services likewise require significant amounts of energy to move, heat, and treat water for human use.

Storage capacity in natural systems (lakes, wetlands, groundwater, snow pack, etc.) and in artificial reservoirs can mitigate extremes in hydrological variability (floods and droughts). The role of reservoir storage can be enhanced by non-structural measures (e.g. decision support systems), by conserving existing storage capacity (e.g. by sedimentation management), and by creating additional reservoir capacity for that function.

The World Register of Dams (ICOLD, 2011) lists 58,266 large dams, i.e. dams higher than 15m. This is the most accurate census of dams structures worldwide; a low estimate of the actual number can be safely placed at 60,000. Statistics about global reservoir capacity are more uncertain, but a reasonable figure for gross storage[1] is in the order of 7,000 km3 (Lemperiere and Lafitte, 2006). Given a world population of around 7 billion people (2013), the average (artificial) storage can be reasonably estimated in the order of 1,000 $m^3$/capita. This value is useful to put other technical characteristics in perspective, but it is meaningless by itself. However, if the figure is disaggregated by volume of the reservoir per capita, amazing figures emerge at country level.

One such study was presented at the ICOLD Congress in Montreal, (L Berga, 2003). The study included data from 82 ICOLD member countries, which represent approximately 40% of the countries in the world and over 80% of the world's population. Relevant data, also referring to the year 2003, were presented at the 4th World Water Forum in 2006 (Grey and Sadoff,. 2006). Both studies showed that the average stored water volume of about 1,000 $m^3$/capita has actually only arithmetic meaning because of the extremely large range of values from country to country. The following graph, from Grey et al. (2006), gives a few indicative examples. Differences are astonishing, yet they do not tell the entire story. The reader is referred to the following section 2.3 on Water Security and the concept of *Seasonal storage index* in particular.

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[1] The value to quote should be active storage, i.e. net of capacity lost to sedimentation; however, that is a moving target, which is difficult to estimate. The subject is dealt with in chapter 5 under "Reservoir Conservation".

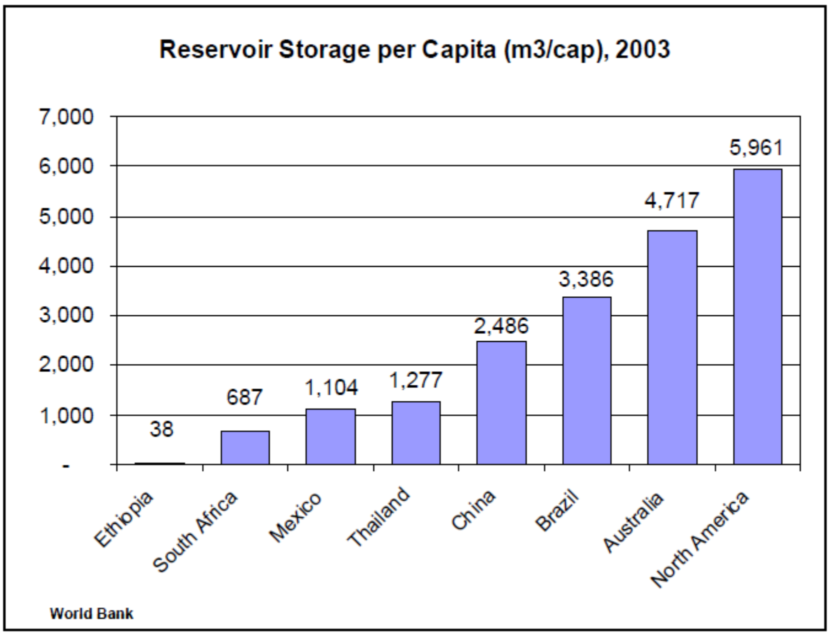
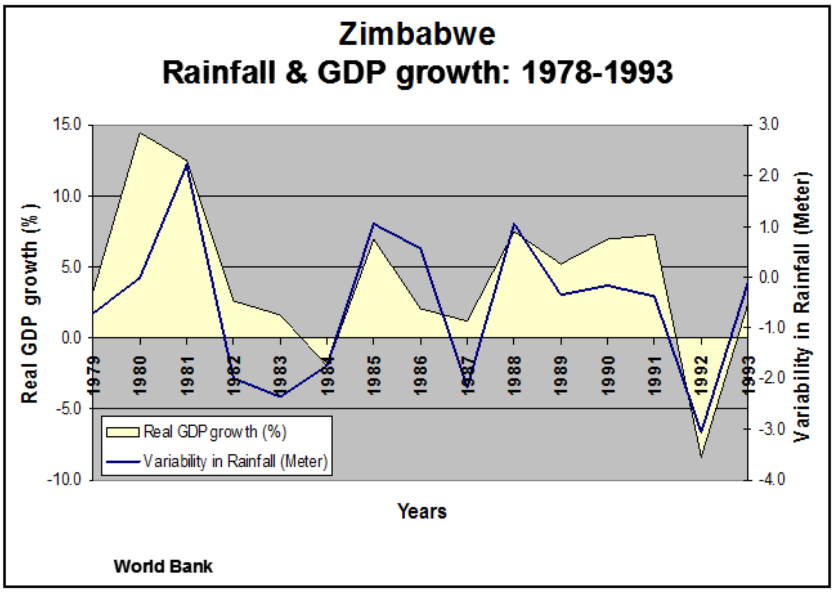


**Figure 1**

While the values in North America and Australia have not undergone significant changes since 2003, the opposite is true for some developing countries. The case of Ethiopia is particularly noteworthy. As a result of the Country's policy in water infrastructure development, water storage per capita has grown, in about 10 years, from less than 40 to more than 200 m3 per capita. That achievement, due to such projects as Tekeze, Beles, Fincha, is particularly noteworthy because of simultaneous population growth in Ethiopia. The index will further increase in the next few years as large storage projects, such as Gibe III and GERD, come in operation.

A relevant factor that also has to be considered is the progressive reduction of storage capacity as sedimentation takes place into reservoirs. The phenomenon exhibits large variability from site to site and, in many cases, albeit not all, can be mitigated by adequate reservoir conservation measures. The subject is treated in Chapter 5 "The need for long term planning".

In least-developed economies, climate seasonality, variability and/or rainfall extremes are often marked, while the capacity, institutions and infrastructure needed to manage and mitigate these potentially major challenges are generally inadequate (Grey et al. 2007). Catastrophic hydrological events such as droughts and floods can have dramatic social and economic impacts with tragic losses of life and declines in annual GDP often exceeding 10%. In countries where climate variability is high and water-related investments relatively limited, such as in Zimbabwe (see Figure 2), there is an apparently strong correlation between hydrology and economic performance, suggesting that the rains, rather than diligent economic management, drive economic performance.  Zimbabwe does not have a single natural lake of any size - all water bodies throughout the country are created by dams. The largest of these reservoirs is Lake Kariba, situated on the Zambezi River at the border with Zambia.



World Bank

**Figure 2**

Where economic performance is closely linked to rainfall and runoff, a particularly true condition in rain-fed agrarian economies, growth becomes “hostage to hydrology” (Grey et al. 2007).

At the other extreme, well-developed countries enjoy a very high reliability of water supply, and water is always available whenever consumers open a faucet. Those consumers have become so accustomed to regular availability of fresh water that they can perceive it as a right. A consequence of this perception is the frequent confusion between the resource (raw water) and the services (water supply).  Access to the resource should always be considered a right, and no person should be excluded from it. At the same time, access takes very different forms; from the faucet in a luxury residence (top class water supply), to a long walk to access muddy water in a remote location (self water supply). Water-related services, and their affordability, make the difference. Such services can be offered by a variety of providers and those who provide that service have the right to get fair remuneration for their work.

## 2.2 Water Demand

Demand for water, and water-related services in particular, changes for many reasons, which are both related to economic growth and to global conditions, such as increasing hydrological variability.

The Food and Agriculture Organization (FAO), AQUASTAT[2] program, publishes data on annual freshwater withdrawals at global level. Data refer to total water withdrawals, not counting evaporation losses from storage basins. Withdrawals also include water from desalination plants in countries where they are a significant source of supply. Withdrawals can exceed 100 percent of total renewable resources where extraction from nonrenewable aquifers or desalination plants is considerable or where there is significant water reuse. Withdrawals for agriculture and industry are total withdrawals for irrigation and livestock production and for direct industrial use (including withdrawals for cooling thermoelectric plants). Withdrawals for domestic uses include drinking water, municipal use or supply, and use for public services, commercial establishments, and homes.

Other important water demands, such as those for ecological services, navigation, and hydropower are not included in AQUASTAT because they represent non-consumptive water withdrawals. As such, those demands do not affect the balance of renewable resources. It should be noted, however, that for large reservoirs evaporation losses are significant (e.g. High Aswan Dam where 10 to 15 $km^3$ of water are lost annually, representing approx. 12-18% of the annual reservoir inflows (although not 100% of the evaporation losses are to be linked to hydropower).

Growing populations, changing societal demands (e.g. meat production) and evolving social priorities (e.g. recreation, aesthetic, environmental integrity) also lead to shortages and issues with water security.

## 2.3 Water Security

*Terminology and the unique quality of water*

The terms “food security” and “energy security” generally mean reliable access to sufficient supplies of food or energy, respectively, to meet basic needs of individuals, societies, nations or groups of nations, thus supporting lives, livelihoods and production. The term “water

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[2] www.fao.org/nr/water/aquastat/main/index.stm

security” has been used in the literature with an equivalent meaning. A striking difference, however, is that unlike food or energy, it is not just the absence of water but also its presence that can be a threat. This destructive quality of the resource in its natural, unmanaged state is arguably unique. In consideration of that, Grey and Sadoff (2006) introduced the following definition of “water security”:

“The availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environment and economies”.

Scarcity of water can be physical or economic.  Physical water scarcity is when demand outstrips physical availability.  Economic water scarcity exists when a population does not have the necessary monetary means to utilize an adequate supply of water and is closely related to governance.[3]

*Water security and GDP – rainfall amount, variability and economic growth*

The following two figures (Brown and Lall, 2006) address the water security concept at a global scale. Hydrological parameters are shown on the X-axis (Mean Annual Rainfall, in *centimeters*) and on the Y-axis (Monthly Rainfall Variability- *coefficient of variation*), each bubble represents a country and the size of the bubble is proportional to GDP per capita in that country. Figure 3 singles out a window of wealthy nations (large bubbles), such nations share favorable climatic conditions (moderate rainfall of low variability).

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[3] https://thewaterproject.org/water_scarcity_2

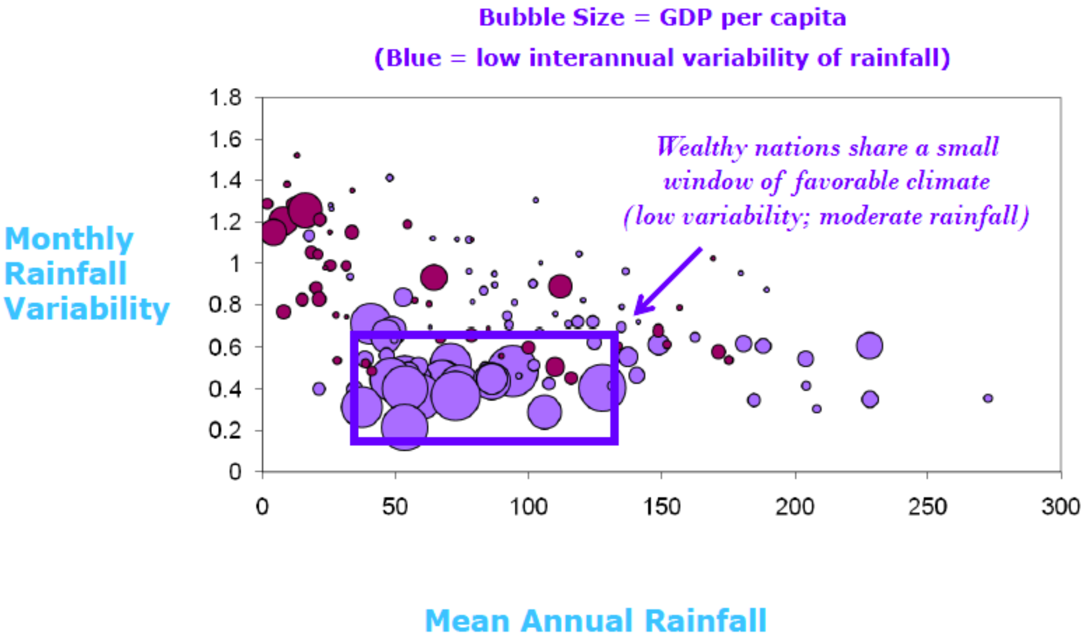

**Figure 3**

Figure 4 highlights two areas where small bubbles correspond to developing countries; such countries have either excessive rainfall or high rainfall variability. The three nations with high rainfall variability, very low annual rainfall, and high GDP (large bubbles in the upper left of both diagrams) are the small oil producing states of Kuwait, Oman, and United Arab Emirates.

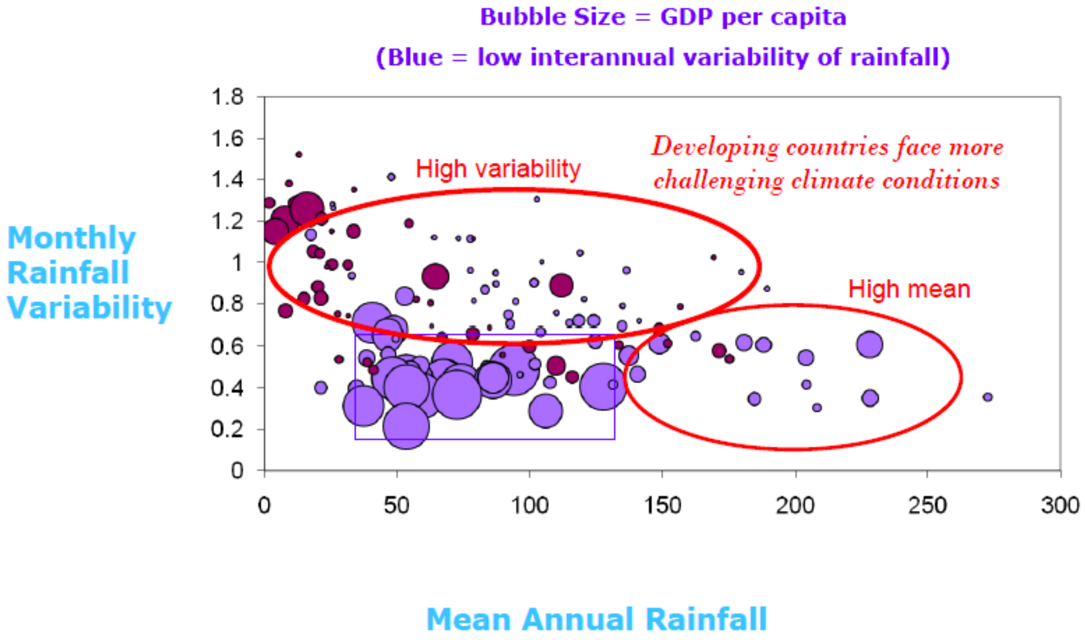

**Figure 4**

Comparing the two figures, it is evident that rainfall amount and variability are strongly associated with economic growth. Achieving water security is related to how countries manage rainfall amount and variability; in general, water security is a major challenge for most developing countries, certainly for those largely relying on rain fed agriculture.

Where the cause of water shortage is intra-annual variability, storage is needed to transfer water from wet seasons to dry seasons. Alternatively, where water shortage is due to lower than needed mean annual precipitation, efficiency gains or alternative water sources, including the importation of virtual water[4], are the preferred option.

### *Seasonal storage index*

Brown and Lall (2006) also developed a useful parameter, i.e. the seasonal storage index (SSI). This index asks the question how much storage would be needed, to smooth out the variability, to meet the food demands of the country (i.e. "food security"). Their data show that GDP/capita of countries lacking adequate storage, in comparison to the SSI, are notably low.

Countries have little control over their hydrologic endowment: when and where it rains and how much water evaporates, infiltrates and runs off. Countries that have managed to grow economically, notwithstanding complex hydrology, have invested heavily to reduce risk. In river basins where there has been low investment to cope with complex hydrology, economic output is overwhelmingly low, as shown in Figure 5 (Hall et al. 2014), lower right part.

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[4] The subject is discussed in section 7.2 “Non-Structural Solutions”

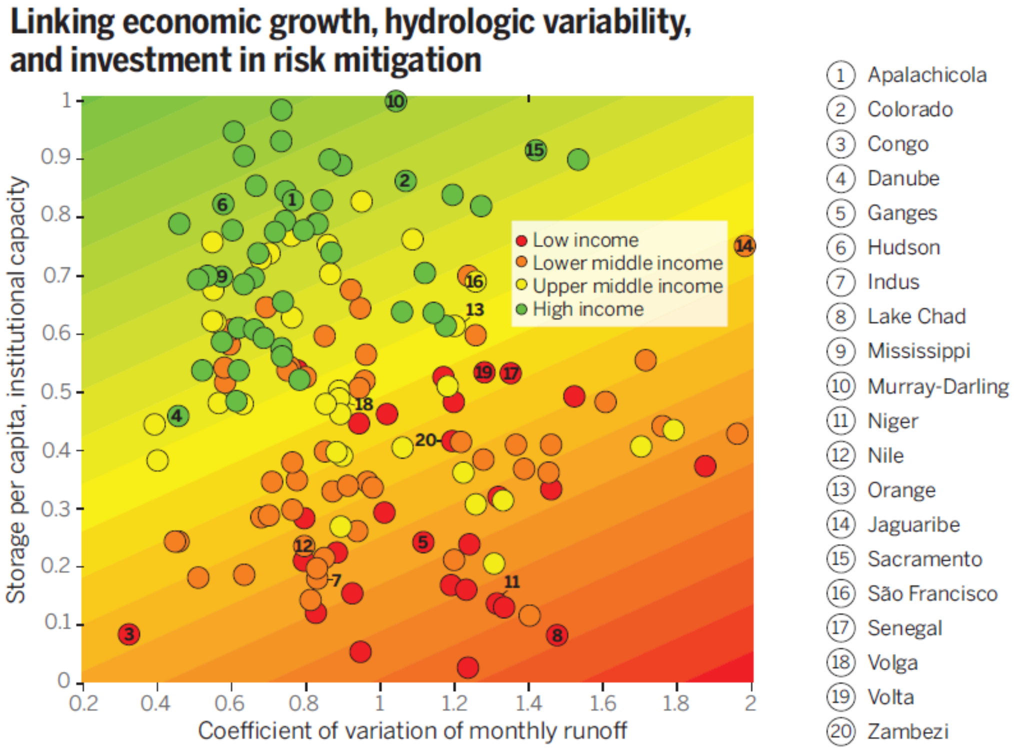

**Figure 5**

By contrast, countries along river basins with benign hydrology are often wealthier, even though investments in water management have sometimes been quite modest (see chart, left side). Additional investments required to transition from water-insecure to secure is greatest in river basins with highly variable hydrology (see Figure 5, right side). This is least affordable and hardest to deliver in the poorest countries.

*River flow variability, storage and reliability of supply*

One of the greatest challenges to supply fresh water from rivers, in a reliable manner, is to figure out how to adapt to or manage flow variability (seasonal and inter-annual). If the demand is greater than the minimum flow in a river, it is not possible to supply enough water during times when the flow is low. In order to overcome this problem a solution is to use storage space.

River flow variability can be expressed by the coefficient of variation of stream flows Cv, i.e. the ratio of standard deviation and mean value of annual flow (MAF) ( McMahon et al. 2007). If Cv is negatively correlated to flow reliability it is an indicator that the river might experience long, multiple-year droughts.

Figure 6 shows the level of storage required to achieve a specific reliable yield, at a given level of hydrological variability. The figure was developed for a reliability of water supply of 95%[5] and relates reservoir yield divided by MAF (on the vertical, y-axis) to the annual coefficient of variation of river flow (on the horizontal, X-axis). The four curves refer to different ratios (Tau) of storage capacity to MAF.

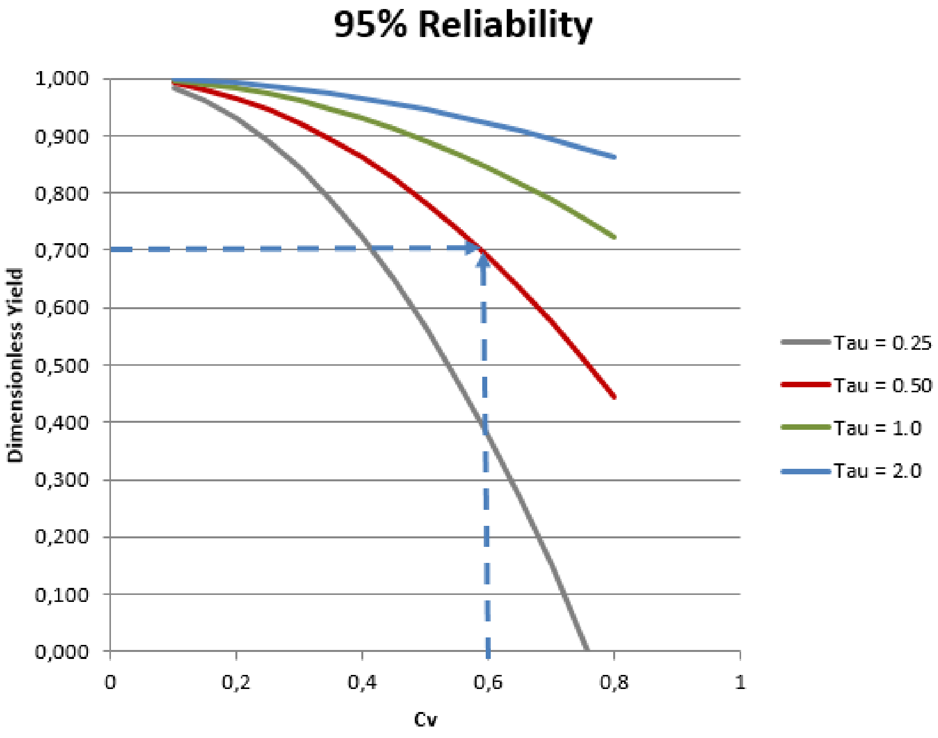

**Figure 6**

With Cv =0.6, a yield of 70% MAF would require a regulating storage capacity not lower than half the MAF (Tau=0.5). In absolute terms, this example would translate as follows:

- Decide the size of a regulating reservoir to guarantee an annual water yield of 70 million m3, with a reliability of 95%.
- The river has a mean annual flow (MAF) of 100 million m3; coefficient of variation of annual stream flows, Cv, is 0.6.
- Entering the diagram with Cv= 0.6 and dimensionless yield 0.7 (70/100), the red curve of Tau=0.5 is intersected.

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5 i.e. there is 5% probability, during the period under consideration, that water yield will be lower than the water demand.

- The size of the regulating reservoir should be 50 million m3 (0.5*100).

Should a 99% reliability be required (curves not shown), still with Cv= 0.6, the same dimensionless yield of 0.7 would require a storage capacity of about 80% the MAF.

The simplified analysis based on Fig. 6 demonstrates that when faced with greater levels of variability, there are larger gains to enhanced storage capacity (in terms of reliable yield).

Figure 7 shows a histogram of the annual coefficient of variation for about two thousand rivers from all over the world (Annandale, 2013).

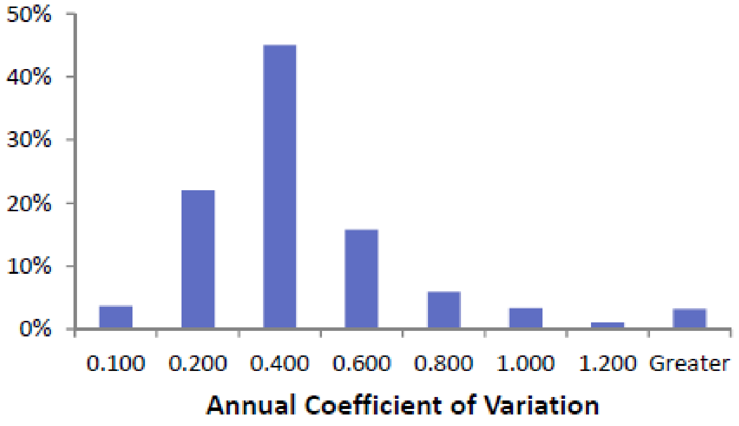

Figure 3.1. Relative frequency of hydrologic variability of river flow for more than two thousand rivers worldwide (current climate conditions).

**Figure 7**

About half of the surface area of the earth is characterized by rivers where flow varies significantly from year to year. These regions are characterized by multiple-year droughts that can last anything from two to seven or even more consecutive years. Integration of information contained in the two figures, reveals that providing adequate storage to regulate those rivers would be a daunting task. This is particularly the case if associated with irrigation, which requires the largest volumes among water using sectors. However, the task becomes more reasonable for domestic /industrial water, and some, strategically selected, high value irrigation demands. This is expected to be the trend in the near future.

Technologies such as desalination and reuse will play an important role, nonetheless matters of scale and multipurpose capacity (e.g. flood management) will forcefully require storage. As society demands evolve, together with their welfare, water storage becomes more and more strategic for its capacity to adapt to society’s needs. Concerns on the impacts of global warming call for increased hydrological resilience. No alternative to water storage can fully perform such a critical function.

## 2.4 Climate Variability and Hydrological Resilience

Resilience of a system determines how quickly it recovers from failure (Hashimoto et al. 1982).

The above considerations make it clear how climate variability, largely attributed to global warming, makes storage of increasing value in the long term.

Many regions of the world are experiencing significant stress on water resources, and it is now recognized that global warming might exacerbate this stress. Even though many elements to be considered in planning and operation are specific to any water resource project, three key elements are usually present, they are:

- Water availability,
- Hydrological extremes (floods and droughts),
- Seasonal and inter-annual variability.

Storage plays a key role in increasing hydrological resilience of a water resource system, but its effectiveness and its economic feasibility depend on several factors. The following qualitative diagram (Figure 8) examines trends of the same two parameters used in section 2.3 “Water Security”:

- Mean Annual Flow (MAF), and
- Coefficient of Variation (CV) of stream flow.

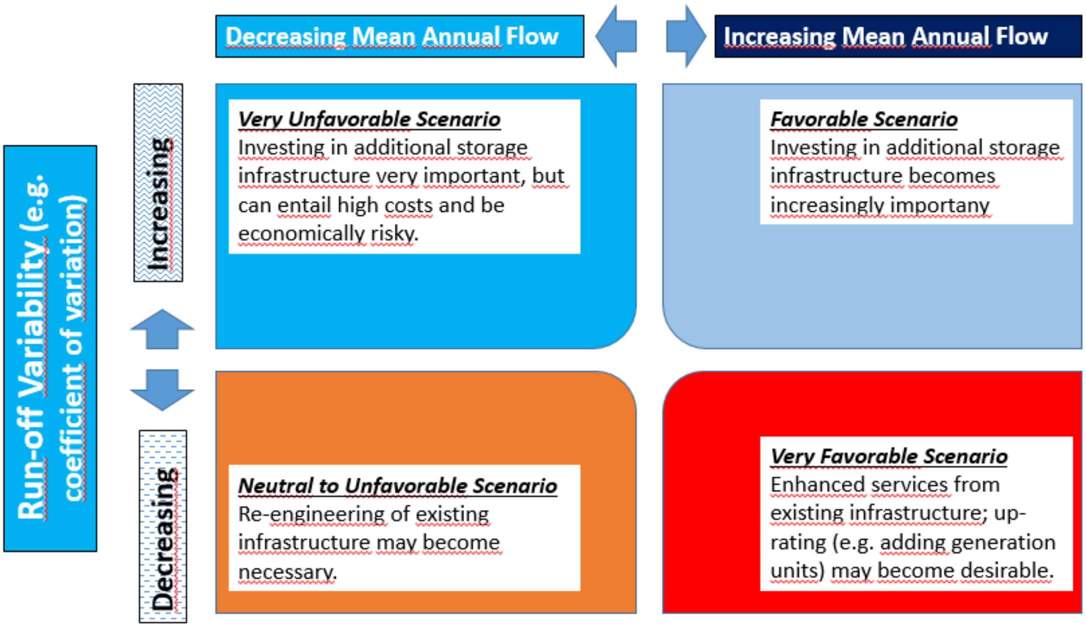

**Figure 8: Climate variability scenarios and indicative management actions**

The four sectors of the diagram can be associated to climate scenarios characterized by different water resource criticality. The diagram also indicates management actions that are likely to be desirable in each scenario. The indicative nature of the desirable actions is underlined; actual management decisions will have to take into account several other elements such as: existing level of infrastructure in the country/ region, demand for water-related services, required water supply reliability, etc.

Many countries, notably in Sub Saharan Africa, but also elsewhere, have undergone the punishments of high climate variability for a long time. It is desirable that renewed concerns over the effects of global warming lead to addressing that painful legacy with measures aimed at increasing hydrological resilience. However, when action is required, the reader will discover that there is a lot of literature dealing with awareness, much less about “what to do”, and very much less on “how to do it”.

### *Global Circulation Models and uncertainty in down-scaling*

One of the main reasons for this situation is that the gap between available predictive models and decision making on water resources management is still very large today. Available Global Circulation Models (GCM) were designed to model global scale atmospheric changes and, in particular to predict temperature rise. Therefore, they were never intended to produce local level run-off estimates and, as such, their use for water resource assessments is questionable. Some progress has been made in the most recent years on reducing the scatter of GCM temperature predictions. However, going from temperature to precipitation, from precipitation to run-off, and the need to downscale results, still leads to levels of uncertainty that frustrate meaningful decision making.

### *Adaptive Resource Management*

Rydgren et al. (2007) carried out a study on emerging global practice in adapting hydrological predictions to increasing uncertainty, and how results are reflected in project planning. The main conclusion of the study was that until models are improved beyond current limitations, the most appropriate way forward is to incorporate Adaptive Resource Management (ARM) in water resources management, especially in planning new projects.

This would entail regular monitoring, evaluations and reviews, with possible redesign of the management program, as found necessary. Most importantly, ARM needs to be based on a solid set of indicators. Chapter 7 “MPWS Problem Solving” contains elaborations on available methods to inform and implement ARM at both structural and non-structural levels.

### *Uncertainty and Real Options Analysis*

Decision making under uncertainty becomes unavoidable due to current doubts about future climate and hydrological scenarios. Real Options Analysis (ROA) is an economic tool to inform decision making under uncertainty. ROA applies option valuation techniques to capital budgeting decisions.  A real option itself, is the right — but not the obligation — to undertake certain business initiatives, such as deferring, abandoning, expanding, staging, or contracting a capital investment project. Real options analysis, as a discipline, extends from its application in corporate finance, to decision making under uncertainty in general, adapting the techniques developed for financial options to "real-life" decisions.

Jeuland and Whittington (2013) apply ROA for planning new water resources infrastructure investments and their operating strategies under climate uncertainty. The approach incorporates flexibility in design and operating decisions, i.e. the selection, sizing, and sequencing of new dams, and reservoir operating rules. The value of the ROA framework is that it can be used to identify dam configurations that are robust to poor outcomes and sufficiently flexible to capture high upside benefits if favorable future hydrological conditions arise.

### *Reservoirs and greenhouse gas emissions*

The subject of greenhouse gas (GHG) emissions from reservoirs has been the subject of much debate since the early 2000's. Some organisations have campaigned to portrait reservoir as greenhouse gas emitters and, consequently, contributors to global warming. The following summary of current knowledge is based on a work by R.Liden (2013).

Much research on the subject has been conducted in the last decade and recent studies have indicated corresponding global estimate to be less than 1 percent. However, these studies still have limited coverage of ecosystems and geographical areas and, more critically, almost none of them have measured the long-term change in GHG emissions over the years.

A fundamental concept for accurate description of GHGs from reservoirs created by biochemical processes is the difference in gross and net fluxes. Rivers are major conveyors of carbon from terrestrial areas to lakes and the sea. Terrestrial areas are generally net carbon sinkers and aquatic systems are net carbon emitters. Changes in GHG fluxes to the atmosphere because of the  introduction of reservoirs in a river system must therefore be viewed from a catchment perspective. Net GHG emissions created by the reservoir are the difference between total fluxes for the whole river basin before and after the reservoir is constructed.

Unfortunately assessement, let alone measurement, of net emissions is extremely complex and not yet achieved today. The results from and understanding of gross, not net, GHG emissions measurements during the last 15 years have led to the following key conclusions.

- Reservoirs with significant GHG emissions are associated with high methane ($CH_4$) emissions because of the gas's strength as GHG.
- The likelihood of significant GHG emissions, especially CH4, increases with the number of variables contributing to GHG emissions that work in combination. No single variable, for example, latitude ot reservoir size, should be used on its own to estimate GHGs from a specific reservoir.
- The key for assessing GHG emissions lies in understanding the availability of carbonstock and the reservoi's water quality conditions, especially the temporal and spatial extent of anoxic conditions.

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# 3.0 The Multipurpose Water Storage Project (MWSP)

## 3.1 Definition

Water storage projects designed and/ or operated to serve two or more purposes are defined as multipurpose. A project designed for a single purpose that produces incidental benefits for other purposes should not be considered multipurpose. A single-purpose project can become multi-purpose during its planning stage, during operation, or in the long term when re-engineering becomes necessary.

*Functions*

The best-known functions that Multipurpose Water Storage Projects (MWSPs) can deliver are:

| |
|---|
| Water supply (domestic/ industrial) |
| Irrigation/ soil leaching |
| Hydropower and energy storage |
| Navigation |
| Flood mitigation |
| Maintaining and managing stream flow |
| Recreation and tourism |
| Fishery/ aquaculture |
| Power pool cooling |

Depending on local context, less usual purposes include:

| |
|---|
| Sediment management in the downstream river course |
| Prevention of ice jam formation |
| Protection from upstream outburst floods (glacial lakes, barrier lakes, etc.) |
| Fire fighting |
| Artificial wetlands |
| Barrier to saline water intrusion |

Micro-climate around reservoirs

*Benefits*

Multi-purpose dams are very robust producers of major streams of benefits as economies develop, as circumstances change and as societal values evolve. At the same time, the decision making process to realize a multipurpose water project is very often a challenging one.

There are several reasons for detailed consideration of multipurpose objectives:

a) dam sites, particularly storage sites, are scarce national resources, and so it makes sense to consider how to extract maximum benefit from them;

b) since civil works may last for 100 years or more, they represent a genuinely long-term investment in the future, and so should be viewed from this long-term perspective, which argues for flexibility in use over time;

c) as global warming contributes to increasing variability in rainfall, agricultural production, floods, etc., storage becomes more valuable, and dam projects need to be designed with this in mind.

Each of these arguments points towards a serious consideration of multipurpose project design.

ICOLD publishes a World Register of Dams that contains data from about 100 member countries. The latest published version of the register, which is widely recognized as the most accurate data basis on dams worldwide, is dated 2011, and contained data on 58,266 large dams. A continuously updated version is also accessible on line[6]. In April 2015 the register contained 53,572 dams. The last figure is different from the one contained in the 2011 Register, and may change again because the register is automatically updated as data come from member countries, while the Register is published every 10 years or so. Figure 9 shows how the dams are subdivided across different purposes.

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[6] www.icold-cigb.org/GB/World_register/world_register.asp

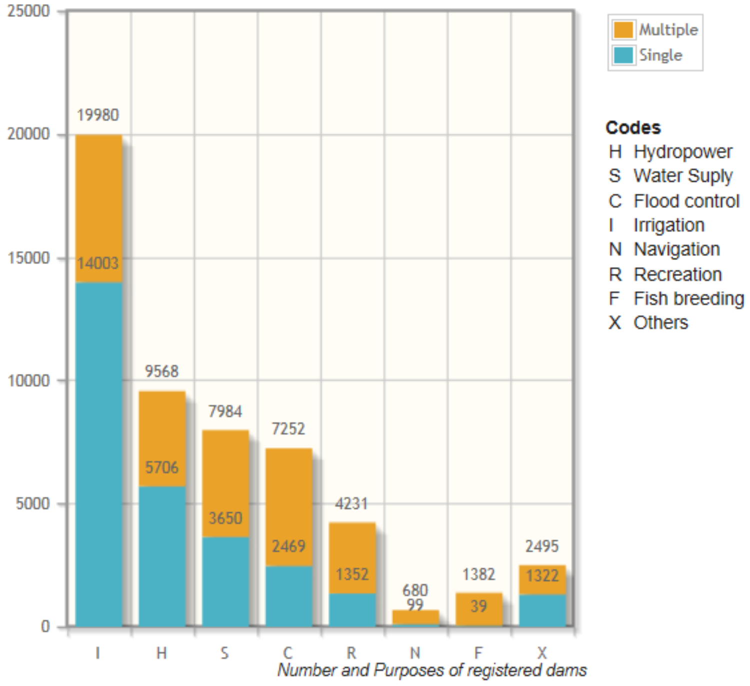

**Figure 9**

- Single-purpose dams (28,640) or 53%, and
- Multipurpose dams (24,932) or 47 %.

## 3.2 Surface water and groundwater

*Conjunctive use and its limitations*

Often renewable groundwater is looked upon as a separate source as compared to renewable river flow. It is however elementary that, in a catchment context, renewable groundwater is generally part of the basin’s hydrological cycle. It feeds the dry season base flow in local rivers; and groundwater-fed wetlands depend upon the natural outflow from aquifers.

Conjunctive *use* means actively managing the aquifer systems as an underground reservoir. During wet years, when more surface water is available, surface water is stored underground by recharging the aquifers with surplus surface water. During dry years, the stored water is available in the aquifer system to supplement or replace diminished surface water supplies. As such, conjunctive water use primarily changes the timing in the flow of existing water sources by shifting when and where it is stored and does not result in new sources of water. Conjunctive use is often incidental as water users intuitively shift between surface water and groundwater sources to cope with changes and shortages. While conjunctive use may prove successful for an individual or group of water users to manage an immediate situation, it is also possible for conjunctive use to unintentionally harm the groundwater basin and other groundwater users who are not involved in conjunctive use but are reliant on the same groundwater basin.

### *Conjunctive water management*

An alternative to conjunctive water use is conjunctive water *management*[7]. The latter engages the principles of conjunctive water use, where surface water and groundwater are used in combination to improve water availability and reliability. However, conjunctive management also includes important components of groundwater management such as monitoring, evaluation of monitoring data to establish and enforce local management policies. Scientific studies are needed to support conjunctive water management. They provide relevant data to understand the geology of aquifer systems, how and where surface water replenishes the groundwater, flow directions and gradients of groundwater.

Conjunctive management occurs when system administrators control ground and surface water simultaneously. It may be achieved by modifying the configuration of the surface system and its operating procedures. Promotion of improved conjunctive use and management often requires significant strengthening, or some reform, of the institutional arrangements for water resource administration. It can be challenging in transboundary context. Important examples of conjunctive management exist in various parts of the world, for instance Argentina, Australia, Mexico, Peru, United States, to mention a few.

The following box presents an example of long lasting program of conjunctive management in Southern California (Metropolitan Water District of Southern California, 2014).

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[7] www.glenncountywater.org

**Groundwater conjunctive management in Southern California**

The Metropolitan Water Districts (MWD) of Southern California has promoted and encouraged use of groundwater management strategies within its service area since the 1970s. In the mid 1990s, MWD developed a regional “Integrated Water Resources Plan” that recommended expanded use of the storage and conjunctive use of the groundwater basins within Southern California. The July 2010 update of MWD’s Integrated Water Resources Plan recommends an adaptive management strategy that includes expanding groundwater storage and recovery throughout Southern California. To ensure that the region has reliable supplies with the uncertainties of imported water from the Colorado River and northern California, groundwater basin management in Southern California will become increasingly important and cost effective. Utilization of new technologies for aquifer recharge and recovery of stored water will be a critical investment decision for the region. However, institutional collaboration is seen as the biggest challenge to implementing these programs and to enhance groundwater storage and recovery.

*Hydrogeological setting influence for use vs management*

Conjunctive management of groundwater and surface water resources for both irrigated agriculture and urban water supply is primarily, but not exclusively, of relevance to large alluvial plains, which often possess major rivers and important aquifers with large storage reserves in close juxtaposition (Foster et al, 2010). However, conjunctive use potential can arise in a wider range of hydrogeological settings. Besides improving water availability, a second important feature is that conjunctive use is often the best way to confront some of the serious problems of groundwater salinization and soil waterlogging of alluvial plains.

## 3.3 Projects on Shared Rivers

*The challenge of shared rivers*

Some 60% of global freshwater flows are contained in the world’s 263 international river basins. Hence, much of the world’s freshwater is contained in catchments shared by two or more countries.

Basin management presents a significant challenge to the countries involved when a basin is intersected by one or more political boundaries, introducing an additional level of complexity. Interventions for diverting water and constructing dams require constructive cooperation, which may be difficult to achieve due to differences between riparian States in economic development, infrastructure capacity, political orientation and institutional and legal set-up (United Nations Environment Programme, 2007).

ICOLD Bulletin 132 “Shared Rivers – Principles and Practices” (2007): summarized relevant information from the United Nations and other international organizations; reviewed agreements, including judicial and arbitral decisions, pertaining to technical aspects.

Implementation of river basin projects in developing countries, notably in Africa, inevitably involves shared rivers and the issues associated with that are certainly a trend. Possibly not an emerging trend, because the subject is not new, but certainly a subject that is bound to require increasing attention in the future.

### *Indirect multipurpose projects on shared rivers*

Projects on shared rivers introduce indirect types of multipurpose whereby:

- the same “purpose” is shared between two different stakeholders, or
- the “purpose” of an upstream stakeholder generates effects on a downstream stakeholder.

In the first case, the particular “purpose” may acquire specific features, reflecting the different needs of the various players, generating variants of the same purpose. The second case is represented by upstream storage projects built on a river, which flows downstream in a different country. The case of water infrastructure in the Aral Sea Basin and its challenging management following the collapse of former Soviet Union is a relevant example (see box below).

### Water Resource Infrastructure in the Aral Sea Basin

After the break down of the USSR, the problem of interstate distribution of water resources became vital. Water resources originate mostly in Afghanistan, Tajikistan and Kyrgyzstan, and water shortages are experienced in Kazakhstan, Turkmenistan and Uzbekistan. The latter three Republics are more concerned with irrigation and environmental issues, whereas Kyrgyzstan and Tajikistan see their future in the development of hydropower. The potential for achieving fair and sustainable water allocation depends on successful resolution of existing tension among Central Asian republics and prevention of regional conflicts.

*Water as an agent of cooperation*

While the propensity of freshwater to strain relations between countries frequently makes headlines, the other side of the coin – *water as an agent of cooperation*- rarely receives sufficient attention. Research has shown much more historical evidence of water playing the role of catalyst for cooperation than acting as a trigger of conflict (United Nations Department of Public Information, 2006; Sadoff and Grey, 2002).

## 3.4 The Water Energy Nexus

In June 1999, in its address to the Polish National Committee on Large Dams, the ICOLD Secretary General, (Lecornu J, 1999) envisioned two developments pertaining to hydropower development, especially in Europe:

i) Greater interest in hydropower dams controlling a storage reservoir, and

ii) Gradual extension of existing hydroelectric generation plant, and even more pumped storage schemes.

About 20 years later, it can be said that both visions have progressively emerged. The role of storage, as outlined in chapter 2, has increased in value mainly in consideration of increasing hydrological variability. Wind and solar energy will play an increasingly important role in meeting future electricity needs; however, both wind and solar are intermittent and sometimes pose challenges to load schedulers who manage the transmission grid system. Because of reliability problems, intermittent power supply must be supported by more reliable sources of generation, such as hydroelectric, coal-fired, nuclear, and natural gas. Hydroelectric generation is the most effective and efficient method of shaping or firming intermittent renewables because of the storage capability of reservoirs.

The extensive development of intermittent “non-programmable” renewable energy is increasing the need for pumped storage plants. This is clearly evidenced by a survey on the European market for pumped storage plants (Ecoprog, 2011). As shown in Figure 10, more pumped-storage plants will be constructed in Europe in the next 10 years than in any other previous decade. Most of the largest plants will be built in countries with large shares of wind energy, or in neighboring countries with appropriate topographical conditions.

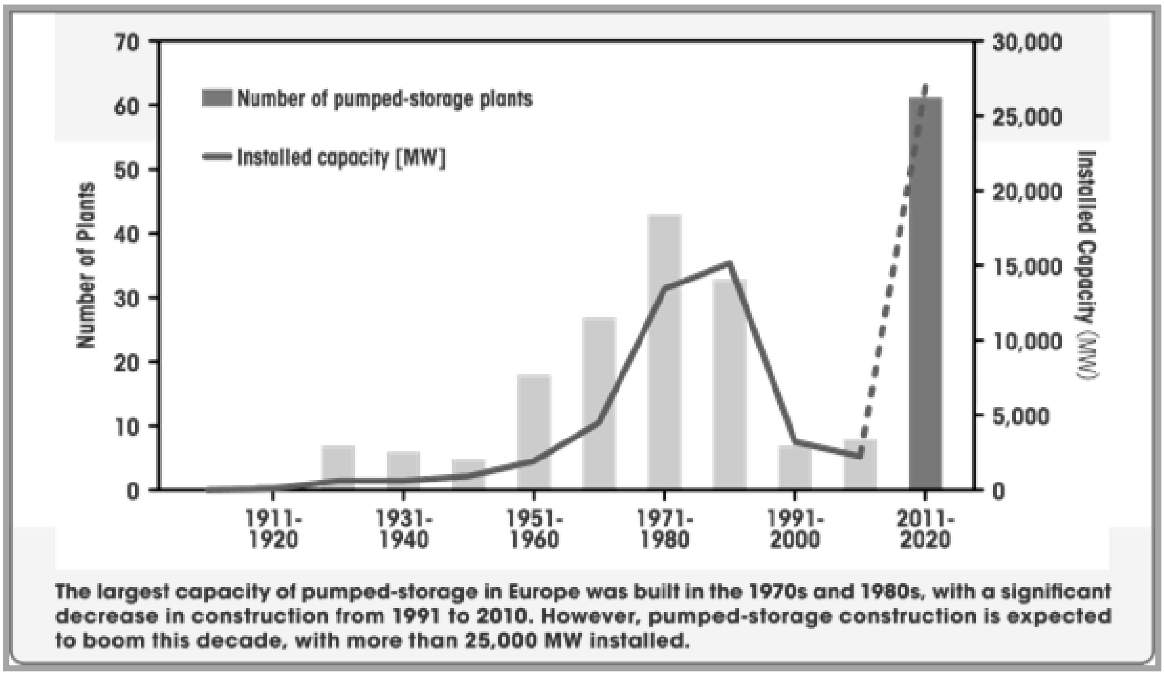

**Figure 10 : Pumped Storage Construction in Europe, by decades**

Ecoprog, 2011 *“The European Market for Pumped Storage Power Plants”*

Pumped storage and 'green battery' type concepts in Europe are developing very rapidly, notably between Norway and Denmark, and between Norway and the Netherlands, with the potential of further development including Germany and Great Britain. The trend is particularly strong in Germany where many wind plants have been added to the system.

The following box exemplifies the concepts.

### German State Eyes 13 Pumped-Storage Sites Totaling 5,130 MW

ERFURT, Germany 12 December 2011 (PennWell) -- Germany's Thuringia State announced it has identified 13 potential sites, including three existing dams, for constructing pumped-storage plants that would total 5,130 MW.

The two largest existing pumped-storage plants in Germany are 1,060-MW Goldisthal in Thuringia and 1,050-MW Markersbach in Saxony.

Over the next 10 years, most of the new pumped-storage plants in Europe are expected to be constructed in Germany, Austria, and Switzerland.

Of the 13 sites, the sponsors, municipal utility network Trianel GmbH and water supplier Thuringer Fernwasserversorgung have formally announced only one.

The 400-MW Schmalwasser pumped-storage project is proposed to be built using the existing Schmalwasser Dam for a lower reservoir. A new upper reservoir would be constructed with an underground tunnel system, pump station, and powerhouse.

The utilities said the estimated 500 million euro (US$666.2 million) Schmalwasser project is expected to go on line in 2019.

For information, see the Thuringia ministry's Internet site, www.thueringen.de/de/tmwat.

According to NVE, The Norwegian Water Resources and Energy Directorate, the total storage volume in Norwegian reservoirs is 62 billion $m^3$ – 85 TWh in energy. The Norwegian geology and rock composition is very old and hard, so erosion and sedimentation are very low. NorNed is a 580-kilometre long, 700MW capacity, HVDC submarine power cable between Norway and the Netherlands, being in operation since 2008. It is the longest submarine power cable in the world. The Norwegian government has recently approved the license for constructing a 1400 MW interconnector from Norway to Germany to be in operation by 2018 and a 1400 MW interconnector from Norway to the UK be in operation by 2020.

The research center CEDREN (www.cedren.no) has conducted a pilot study showing that it is possible to increase the capacity in the hydropower system of southern Norway with 20 GW additional power capacity with the use of existing reservoirs. About 10 GW can be installed as new capacity and 10 GW as new pumped hydro without constructing any new reservoirs and staying within the regulation limits of the existing reservoirs.

### Norway wants to be the "Green Battery" of Europe

Norway's hydropower reservoirs make up nearly half of Europe's energy storage capacity. European grid operators need energy storage to cope with an ever-mounting, always-shifting torrent of wind power.

The 240-kilometer cable across the Skagerrak Strait separating southern Norway and northern Denmark is Norway's first new power link to Denmark since 1993. Called Skagerrak 4, its high-voltage direct current (HVDC) converters—the electronic units at either end of the line that transform AC into high-voltage DC and vice versa—are also the building blocks for more ambitious cables from Norway to wind-power heavyweights Germany and the United Kingdom.

The existing Skagerrak interconnection, three HVDC cables with a combined 1,000 megawatts of capacity, is already showing the world just how well wind and hydropower complement each other.

Norwegian hydropower turbines throttle down as Norway consumes Danish wind energy instead, leaving an equivalent amount of energy parked behind dams. And when the weather shifts and becalms the North Sea winds, the reservoirs and Skagerrak's cables feed that stored energy back to Denmark.

Re. http://spectrum.ieee.org/green-tech/wind/norway-wants-to-be-europes-battery

Such relatively recent developments represent emerging trends of multiple purpose use of storage reservoirs, and the trend is not limited to Europe. Organisations like the IRENA (the International Renewable Energy Agency- www.irena.org) stand as example.

Increasing reliability of renewable energy resources significantly contributes to reducing consumption of fossil fuels. Besides, synergy among renewables plays an important function of adaptation to global warming effects.

It must be observed that highly integrated systems, as those exemplified, require adequate transmission systems, which is often missing in developing country contexts. Such countries are primarily focused on adding generation capacity, which they currently lack, and to upgrade transmission systems accordingly.

It is easy to forecast a rapid spread of the tendency at international level, with energy storage assuming increasing relevance in the hydropower sector. Planning of future multipurpose reservoirs should consider such trends.

## 3.5 Project Sustainability

*Requirements for a viable project*

Achieving project sustainability is a pre-requisite for implementation, together with a project's technical and economic viability. A recurrent message is that "the project cannot be implemented because of a lack of financing". While that is true in several cases, it is equally true that, in many instances, financing could be available with good project preparation and a robust financial architecture.

So what does it take to prepare a "good project"?

The strictly economic aspects of the question are dealt with in the following chapter (Economic Assessment of MPWS Projects). In the following, the focus is on the management of externalities[8].

*Principles and tools for environmental and social sustainability*

Over the years, the threshold of environmental and social acceptability for large projects has significantly raised and environmental standards are getting stricter. A group of international financing institutions has set out minimum requirements for a project to be financed. These principles, referred to as the "Equator Principles," were first designed in 2003 in conjunction with the International Finance Corporation (IFC – the private sector arm of the World Bank); the most recent version, named Equator Principles III, is dated 2013 (for details see www.equator-principles.com).

In June 2011, the International Hydropower Association developed an enhanced sustainability assessment tool to measure and guide performance in the hydropower sector. The IHA's Hydropower Sustainability Assessment Protocol can be accessed at www.hydrosustainability.org.

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[8] An externality is the cost or benefit that affects a party who did not choose to incur that cost or benefit. From a water resources perspective, typical externalities are the indirect costs arising from environmental degradation if water abstractions are pushed beyond their naturally sustainable limits.

ICOLD has been addressing environmental aspects of dams and reservoirs since 1973. Since then, several congress questions have addressed the subject (Q47-1976, Q54-1982, Q60-1988, Q64-1991, Q69-1994, Q77-2000).

More recently, several ICOLD bulletins and questions at ICOLD Congresses have covered topics pertaining to environmental and social sustainability of dam projects.

| **Bulletin** | **Year** | **Title** |
|---|---|---|
| 159 | 2012 | Dams and the Environment from a Global Perspective |
| 149 | 2010 | Role of Dams on the development and management of river basins |
| 147 | 2009 | Sedimentation and sustainable use of reservoirs and river systems |
| 146 | 2009 | Dams and resettlement- Lessons learnt and recommendations |
| 128 | 2004 | Management of reservoir water quality - Introduction and recommendations |
| 116 | 1999 | Dams and fishes - Review and recommendations |

| **Congress** | **Year** | **Question** |
|---|---|---|
| 24th Kyoto | 2012 | Q92: Environment friendly techniques for dams and reservoirs |
| 23th Brasilia | 2009 | Q89: Management of siltation in existing and new reservoirs |
| 22th Barcelona | 2006 | Q85: Management of the downstream impacts of dams operation |

The reader should refer to the above literature for a broader coverage of methods for managing environmental impacts. In the following, we will focus on a couple of subjects that are particularly relevant to multipurpose water storage projects:

- Stakeholder Engagement, and
- Strategic Environmental Assessment.

## 3.6 Stakeholder Engagement

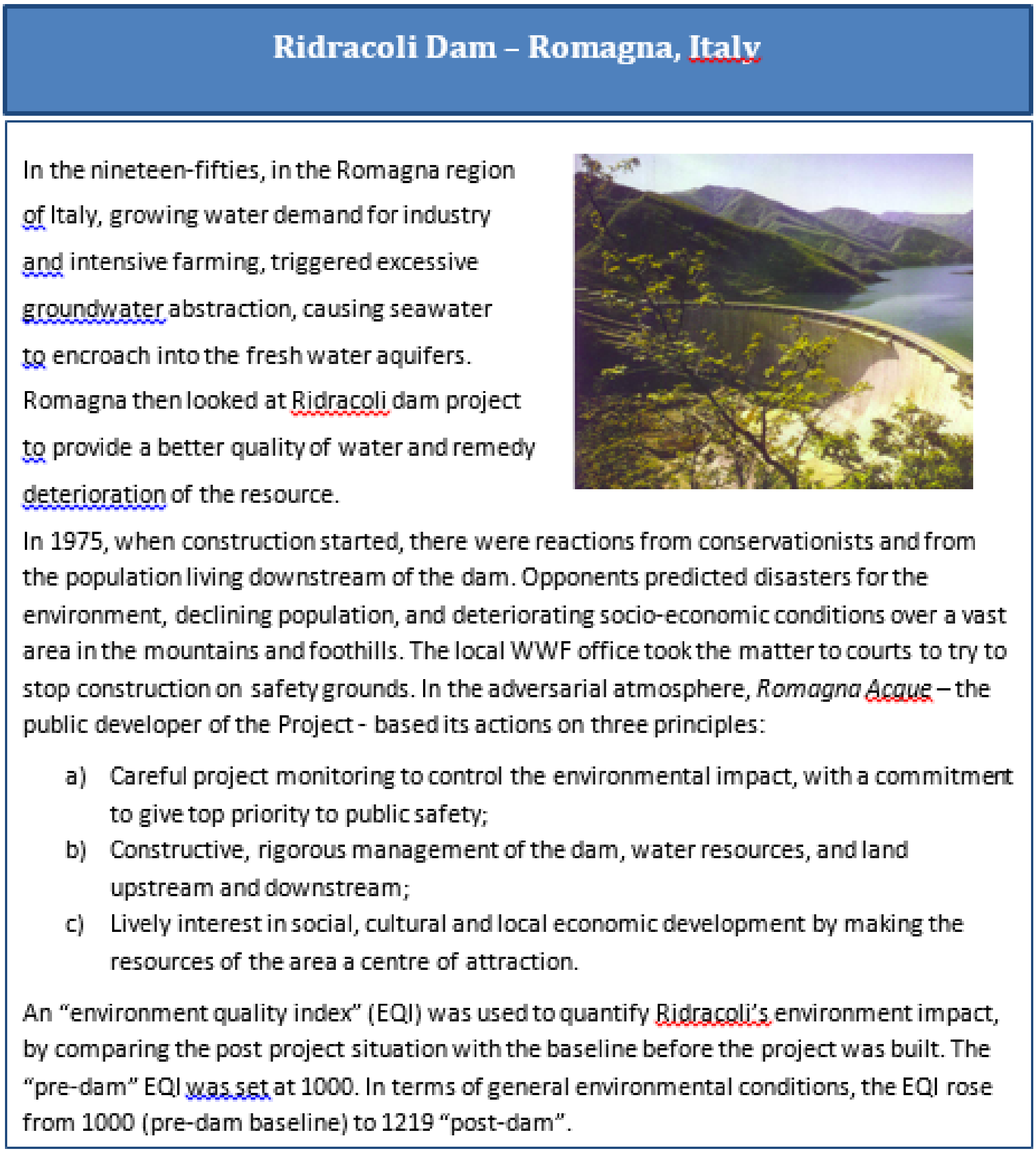
The subject of governance is very relevant in this context and it is dealt with in section 6.1 “Water Governance”.

*Early engagement*

A large-scale project has the capability and the means to generate benefits at both local and national scale. That opportunity should not be missed. River basin committee are often established and/or entrusted for that purpose. The first, essential step to balance local and national benefits consists in engaging local populations, starting with those directly impacted by the project (resettlement, land acquisition, change of livelihood systems, etc.). If their voices are not heard in the early planning stages, many stakeholders will become concerned about the process; when large stakes are at risk, which is inevitable in large-scale projects, concerns rapidly turn into opposition. Controversy about dams and man-made reservoirs if frequently lively, with both sides tending to speak a different language. Water is a unique resource, which must be carefully preserved and used rationally. It that means building water infrastructure, it is unjust to consider them blindly as causes of damage and disaster. Proper design, careful construction, careful sensitive operation can have outcomes that improve environmental balance in all areas, beginning with the human sphere.

The case of Ridracoli Dam, in Italy is a concrete positive experience of such open minded approach to water storage development and management (see box on following page).

The lesson to learn from cases like Ridracoli is to examine environment issues not sectorially – i.e. addressing only one aspect or need while disregarding or leaving aside the other issues – but seeking wider, unifying relationships and programmes, which must always guide decision making.



## Ridracoli Dam – Romagna, Italy

In the nineteen-fifties, in the Romagna region of Italy, growing water demand for industry and intensive farming, triggered excessive groundwater abstraction, causing seawater to encroach into the fresh water aquifers. Romagna then looked at Ridracoli dam project to provide a better quality of water and remedy deterioration of the resource.

In 1975, when construction started, there were reactions from conservationists and from the population living downstream of the dam. Opponents predicted disasters for the environment, declining population, and deteriorating socio-economic conditions over a vast area in the mountains and foothills. The local WWF office took the matter to courts to try to stop construction on safety grounds. In the adversarial atmosphere, *Romagna Acque* – the public developer of the Project - based its actions on three principles:

a) Careful project monitoring to control the environmental impact, with a commitment to give top priority to public safety;
b) Constructive, rigorous management of the dam, water resources, and land upstream and downstream;
c) Lively interest in social, cultural and local economic development by making the resources of the area a centre of attraction.

An "environment quality index" (EQI) was used to quantify Ridracoli's environment impact, by comparing the post project situation with the baseline before the project was built. The "pre-dam" EQI was set at 1000. In terms of general environmental conditions, the EQI rose from 1000 (pre-dam baseline) to 1219 "post-dam".

There are often cases in which populations living in the reservoir catchment area adopt land use practices that are conducive to intense soil erosion and, consequently, sedimentation problems. In such cases, stakeholder engagement becomes a two-way exercise whereby project promoters seek incentives for catchment population to improve their land use practices, and farmers shift to more productive and sustainable cultivation methods. In such context, the Loess Plateau Watershed Rehabilitation Projects (World Bank, 1997-2010) represent a very successful example.

**Successful Large-Scale Erosion Control– Loess Plateau (China)**

*www.worldbank.org/projects/P003540/loess-plateau-watershed-rehabilitation-project*

The Loess Plateau is approximately the size of France, encompassing 640,000 km2 in the upper and middle reaches of the Yellow River. The Yellow River gets its name from this yellow silt that it carries and the constant degradation gradually changed the river as the silt raised the riverbed and made it easier for the river to flood. Erosion control interventions in large watersheds are characterized by very rare success. However, in this specific case, the very fine nature of the soils determines a sediment delivery ratio close to unity so that very little accumulation of debris occurs in the watershed and the impact of conservation programs is visible over a shorter period. Over 3 years, Chinese planners from the Ministry of Water Resources and international planners from the World Bank worked together with experts in hydrology, soil dynamics, forestry, agriculture and economics, to design a workable project plan. Early in the rehabilitation process, it was critical to engage the local people to understand and participate in the rehabilitation efforts, and to convince them of the value of rehabilitation work. Among other, measures included training activities of local communities to abandon cultivation on steep slopes, shifting them to flat areas. The latter were progressively developed in the silted area behind debris retention dams; fruit tree and cash crop cultivations provided higher income to the farmers, which was the incentive to abandon erosion prone land use practices. Reduced soil erosion, in turn, prolonged the life of the Xiaolangdi reservoir (see case study 18).

### *Communication*

A reflection is in order on the influence of fast global communication and information channels on decision-making and time to reach decision. Such tools are extremely helpful to inform the wider audience on the planning process and avoid the old "*decide-hide-defend*" approach. Informing more stakeholders, including those that oppose a project for valid reasons, adds value to the final decision. Not least because it is a two-way exercise whereby developers and governments not only inform, but are also being informed by, these dialogues.

Increasing involvement of civil society groups in decision-making processes on important infrastructure projects, including dams, can be regarded as a sign of discomfort with the way in which civil society's needs have traditionally been represented.

### *International NGOs and community based organisations*

This discomfort regarding representation has brought international NGOs to play a representation role together with, but most often in opposition to, government institutions. At the same time, it is not always the most vocal of those international NGOs that have shown themselves to be ‘close enough’ to the real needs of people. In too many cases the priorities of some international NGOs, especially single-issue ones, do not necessarily coincide with those needs. Increasing evidence indicates that what is usually presented as ‘the civil society voice’ is in reality only a segment of that voice, a segment that legitimately delivers a message about negative impacts of water infrastructures but remains silent about positive impacts. It is becoming increasingly clear that a better job needs to be done in engaging ‘civil society’ in options assessment. That job is a difficult one; it requires reaching out to stakeholders who are not vocal but have a lot to contribute to the quality of projects. In most cases, those stakeholders are not organised to speak with a common voice.

Community-based organisations (CBOs), for example consumer associations, religious/ cultural groups, emergency aid organizations, etc. are promising civil society initiatives for getting the dialogue focused on real needs and for achieving effective self-representation.

*Politics and the need for good representation*

Ultimately, good decision making is a political issue which, by definition, is rooted in good representation. Increased national and international support for CBOs would allow the latter to play a more effective role, including free and informed selection of development-oriented NGOs with which CBOs can confidently share common interests.

The International Hydropower Association (IHA) collected several cases of stakeholder consultation processes in its (“2003 White Paper”). Numerous drafts of the report were refined through a consultation process involving a wide range of organizations, covering 27 countries. IHA describes five case histories in detail.

| **Country** | **Project** | **Description** |
|---|---|---|
| Australia | King River Power Development | Development and sustainable operation of a hydroelectric scheme |
| Brazil | Salto Caxias Resettlement Project | Public participation, sharing the responsibilities with the affected communities and stakeholders since the beginning of the project. |
| Canada | EM-1 Hydropower Dam and EM-1-A and Rupert Diversion Project | Benefit sharing between the hydropower industry and indigenous communities, involved in every step of the project, from preliminary studies to project development. |
| China | Shuikou Hydroelectric Project | A development approach to dam-related resettlement, benefit sharing through the establishment of post resettlement and rehabilitation funds, follow up studies |

| | | |
|---|---|---|
| USA | Hood River Farmers Consortium | Developing small-scale hydropower facilities in an irrigation district |

*Participatory decision-making*

A relevant case of participatory decision making process, with effective stakeholder engagement is the Berg River Dam Project, in South Africa, which the following box summarises.

**Berg River Dam Project (South Africa)**

By the late 1990s, technical investigations had demonstrated that the Western Cape Water Supply System that largely serves the City of Cape Town urgently needed augmentation if water shortages in the city were to be avoided. Investment capital for projects of this magnitude is huge, often requiring blessings of the national government. In 1994, a new democratic government regime had assumed power in South Africa, which wanted to ensure that democratic values and inclusive participation were upheld in decision-making processes of its major undertakings. The Berg River Dam was such a project that had to follow that requirement, resulting in a prolonged participatory process, with approval to start construction of the project only realized in 2002. However, through this protracted process, the government demonstrated its resolve and tenacity in embedding equity principles into water use and management in the country. Dividends were reaped from this process as in the end there was public buy-in and support for the project, which helped in the signing of take-off agreement to purchase water from the project. This in turn facilitated the securing of investment capital of the project that enabled construction to run according to the program.

*Ensuring local benefits*

When planning new projects, stakeholder engagement should focus on creating new and meaningful livelihood opportunities for local populations. Local populations, and first among them project-affected communities, should be entitled to share the benefits of water infrastructure programs. While the primary beneficiaries of dams often live far away from the dam sites, other groups of people in the project-affected areas may sustain most of the negative impacts. In view of this, there is a need for project developers, operators, and regulators to commit to support measures for development and welfare opportunities for project-affected communities. Several ways for sharing benefits exist (Egré D' et al., 2002), the following box lists a few of them.

**Types of Benefit Sharing Mechanisms**

- Revenue sharing
- Development Funds
- Equity Sharing or Full Ownership
- Taxes paid to regional and local authorities
- Preferential electricity rates
- Preferential water access
- Paying for environmental services

Experience has shown that it is important to design a project so that there is a credible flow of benefits before, during, and after project construction. One way is to include local development interventions in preliminary contracts, which often precede the main construction contracts. Another approach is to invest in vocational training to enable local people finding employment during construction in better jobs than unskilled labor. A recent example of the latter comes from the San Antonio Project in Brazil. In January 2006, when the *Acreditar* (Azevedo, 2010) capacity-building program was conceived, the project employment expectation was 30% local and 70% external staff. In January 2010, thanks to *Acreditar* local employment reached 82%. The skills acquired by local workers also allow those people to seek other job opportunities after project completion.

By receiving benefits before project implementation, communities do not have to “wait and bear” until the project starts to deliver, but can share those benefits in a progressive manner. It should be appreciated that satisfactory benefit sharing requires consultation, participatory planning, and upfront investments. The financial size of large development projects can normally cover such investments, thus allowing the achievement of both national and local development goals.  (Refer also Tilmant, Goor, and Pinte, 2009).

## 3.7 Strategic Environmental Assessment

*Multipurpose as part of regional development*

Multipurpose water storage projects are generally part of major schemes for the development of a region; often they represent key features in the development of cascade projects along a river. Many case histories testimony such features. Particularly relevant is the example of Durance-Verdon River System (France).

### Durance-Verdon River System (France)

***Multipurpose fosters regional development***

The Serre-Ponçon Dam, commissioned in 1966, is the main structure of the multipurpose Durance and Verdon River system. With 32 hydropower plants, the Durance-Verdon system enables the production of 6.5 TWh of renewable electricity and an output of 2000 MW within 10 minutes, supplies drinking water and water for industrial purposes to the entire region and irrigates over 150,000-ha of farmland with guaranteed summer storage of 200 million m3.

During the last 50 years at Serre-Ponçon, EDF has reconciled electricity production with the expectations of all stakeholders and water users including that of tourism, a particularly active industry with high-growth potential for the regional economy. The shared management approach to 2002 and 2003's droughts highlighted that with high performance forecasting and a thorough and regular dialogue between stakeholders, notably Lower Durance agricultural community, it was possible to enjoy the nearly limitless recreational activities offered by the 2nd Europe's largest man-made lake.

*Planning tools*

Environmental impact identification and management should not be considered the end of the exercise, but rather an instrument to devise project rules and means to a sustainable project design and operation.

Traditionally, river basin development used to be the subject of master plans, which included option identification, assessment, analysis, and proposal of the preferred least cost development option. In the view of many people, master plans have acquired a reputation of top-down exercises; consequently, they have progressively been replaced by other planning tools such as: cumulative impact assessment, sector environmental assessment, strategic environmental assessment (SEA), or strategic social and environmental assessment (SSEA). Some prefer to use the latter denomination to explicitly recognize both environmental and social aspects; other deem the term "environmental" to cover also social aspects. The concepts of Sectorial, Regional, or Strategic Assessments have been around for at least a decade, but there is often confusion around the meaning and use of the various terms (World Bank, 2012).

- “Sectorial” Assessment generally focuses on alternative investment strategies in a particular sector, such as the power sector, as part of the process of identifying potential impacts and priorities among various, potentially competing projects that are ostensibly designed to serve a common objective, e.g., filling a gap between energy supply and demand.
- “Regional” Assessments generally are more focused on the broader spatial and geographic context of an investment, beyond the immediate physical footprint of a project, and often include a strong emphasis on cumulative, associated and induced effects of various activities in a geographic area. A Regional Assessment is a particularly valuable tool for projects with potential trans- boundary impacts. Because it is not a project-specific assessment, it often is easier for key agencies and stakeholders on both sides of the border to collaborate in preparation of a Regional Assessment to address trans-boundary issues.
- “Strategic” Assessment is most commonly referred to as the tool of choice in evaluating the likely impacts of alternative policies or programs that are under consideration. It also has a more long-term and multi-sectorial nature, looking at tradeoffs and extended time horizons.
- “Cumulative” impacts are those that result from the incremental impact of the project when added to other existing, planned, and reasonably predictable future projects and activities, including induced impacts.

While the substance of a master plan and an SEA do not differ, the SEA processes emphasizes greater participation in the decision making process. In essence, Strategic Environmental Assessments (SEAs) are rooted in stakeholder involvement and are therefore generally regarded as bottom-up processes. In addition to that, SEA takes explicitly into account the benefits of design flexibility by means of robust economic decision-making tools such as real options analysis (Jeuland and Whittington, 2013).

In any case, it is essential that the SEA process, and the associated cumulative impact assessment, duly balances economic, engineering, environmental, and social (in alphabetic order) aspects. A properly done SEA represents a valid opportunity to inform project development with a river basin perspective, a feature that is of key importance for multipurpose water storage.

*Biodiversity and fish species*

Biodiversity and fish species in particular, often represent the most significant environmental element in a river basin. From a biodiversity management point of view, it must be kept in mind that not all river segments, and associated sub-basins, have the same relevance. In fact, if river segments were identical, there would be no need to preserve all of them in a pristine state. On the other hand, if the variation of biodiversity between different segments is large, care must be taken not to severely damage habitats, because otherwise there is a risk that species will become extinct. In other words, it is increasingly acknowledged that different parts of a river basin require the establishment of different objectives, priorities and levels of protection. This recognizes the different characteristics or uses across the basin – with higher levels of protection required in some parts of the basin (e.g. key ecological zones, or sources of drinking water supply), while other areas are more heavily developed (G Pegram et al, 2013).

*Religious and cultural beliefs and practices*

In addition to biodiversity, religious/ cultural beliefs and practices around water represent a value that has to be considered in several parts of the world. Similar concepts, in terms of river segment classification, as those for biodiversity can be applied also for cultural values.

*“Managed river flows” or “environmental flows”*

*Increased attention is paid to in stream releases to manage modifications to river regimes* introduced by storage projects. Such releases are often referred to as “managed river flows” or “environmental flows”. The objective is to manage discharges from the dam in such a way that the river ecosystem can adapt to the modified flow conditions, without unacceptable environmental degradation. This subject is treated in Chapter 7 (MPWS Problem Solving).

## 3.8 Taking stock: essential elements and emerging trends

At the risk of cutting short a very complex body of knowledge, in continuous evolvement, and in the interest of focusing on key elements pertaining to multipurpose water storage projects, the following table offers a synthetic summary of essential elements and emerging trends for project sustainability.

| | **Essential elements** | **Emerging trends** |
|---|---|---|
| Planning | Needs assessment and timely implementation | Increase project's flexibility and adaptability to long-term changes. |
| Economics | Least cost option, at the same level of service as alternatives; i.e. the alternative that maximizes the discounted value of net benefits. | Improves operation of intermittent renewables (wind, solar) allowing their expansion in the system. |
| Engineering | Safe design, reliable operation. | Periodic safety review during operation; structure adaptation to changing demands; prolonging reservoir life by strategic sedimentation management. |
| Environment | Impact on biodiversity and cultural values is not worse than alternatives. | Biodiversity /cultural offsets and/or conservation areas are developed within, or outside the project area. Managed river flows. |
| Social | Affected population is no worst off after project completion. | Benefits from the project are shared with affected population. |

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# 4.0 Economic and Financial Assessment of MPWS Projects

## 4.1 Economic and Financial Perspectives

Economic assessment of multipurpose projects typically connects to some form of multi-criteria analysis to provide the holistic perspective of the economic benefits of the project, and clarity of financial basis for the monetary investments. Multi-criteria analysis (Multi Criteria Analysis – A Manual, 2009) can be used to describe any structured approach to determine overall preferences among alternative options particularly where the options accomplish several objectives. MCA is often used to describe those methods, which do not rely predominantly on monetary evaluations with the level of analysis being project specific.

The economic analysis of single purpose and multipurpose projects typically use the same economic tools. However, analyses of a single purpose and multipurpose project will generally provide very different results. As an example, a standalone irrigation project could have very different returns from one associated with a large hydro component that provides cheap power and brings in high quality roads etc. The subject will be expanded in the following sections when dealing with economic multipliers, whereby returns of an investment are influenced by context (costs, related facilities and growing income/demand of the community).

Traditional economic and financial indicators such as Net Present Value, Internal Rate of Return, Benefit Cost Ratio, etc. are utilized in economic analysis of multipurpose projects, and one aspect represents a recurrent trend and development challenge, being:

- while economic performance of MPWS projects can be good, their financial performance can be less than satisfactory.

The boundaries of analysis differ depending on whether the perspective is economic or financial. Financial analysis concentrates on costs and benefits that accrue to the project entity and is of particular concern to the developer and investors. Differently, economic analysis seeks monetization of welfare gains and losses. That way economic analysis takes a wider view to determine the impact on society; it includes externalities and is of concern to the other stakeholders, particularly government.

Whether government is investing in the project or not, the project will involve the use of the country's resources and the government must ensure that those resources are used effectively for the country's development. Economic viability should be the basis on which strategically important projects are selected and optimized, although financial viability will ultimately determine how they might be financed. Water infrastructure projects often fall in the gap between economic and financial viability (Head C., 2005). A project can be economically attractive and the preferred option when seen from the long-term national perspective, but when considered as a commercial investment it may be unable to generate adequate financial returns.

## 4.2 Cost Allocation In Multipurpose Projects

Allocating investment costs at the planning stage of a MPWS project is based on two main principles:

- Separating costs that can be clearly attributed to each purpose, and
- Allocating remaining costs in proportion to expected benefits from each purpose.

In some cases, water demands are used in lieu of benefits. This is obviously the case of consumptive water uses, such as potable, industrial, and agricultural water supplies.

The Separable Cost Remaining Benefits (SCRB) and Egalitarian Non-Separable Cost (ENSC) are well established economic methods used for cost allocation of multipurpose reservoir projects (Young, 1985).

In some cases it may be possible to restructure the project in a geographical sense, so that physical infrastructures devoted to different purposes can be financed and built separately. That was the case of San Roque Multipurpose Project in the Philippines (see box below) where private sector financed the power plant, and the public sector the dam and ancillary

**San Roque Multipurpose Project, Philippine**

**A Public-Private partnership based on Split Ownership**

This project involves a large dam that supplies around 87,000 ha of irrigation and a 345 MW power complex. In addition to proving power and water for irrigation, the scheme has flood mitigation and water quality benefits.

The project has been successfully developed as a public-private partnership under split ownership. The power complex was developed by a private company on a BOOT arrangement, and financed on a commercial basis. The dam and ancillary structures were treated as public projects and financed publicly, although their implementation was managed by the private sector.

Although there was a strong economic case for the project, it was not financially viable in its entirety due to the weak financial returns from irrigation and secondary benefits, and the risks associated with building the dam. By moving the dam into the public sector these problems were overcome, and approximately half of the project was still funded from private sector.

structures, with this arrangement it left the financially weak or particularly risky elements that are not viable for private sector financing to be developed in the public sector.

Allocation of operation and maintenance costs during project operation is typically based on the agreements reached at the planning stage among the parties involved. Some public institutions have regulations in place for cost allocation during project construction and operation.

Reference can be made, for example to United States Bureau of Reclamation (USBR) Rate Setting Process/ Cost allocation for plant-in-service costs (construction) and of annual Operation & Maintenance costs; see box below.

### USBR Ratesetting Process – Cost Allocation (www.usbr.gov)

**Definition**. "Cost allocation" is the process of identifying and allocating the costs of a multi-purpose project among the various authorized project purposes. Cost allocations are performed on an annual basis for plant-in-service (construction) costs and of annual operation and maintenance (O&M) costs. The cost allocation phase updates (1) the respective repayment obligations of the reimbursable project functions (which include irrigation and M&I water supply and power) and (2) the costs allocated to non reimbursable project functions including flood control, navigation, recreation, fish and wildlife and water quality improvement.

The method used to allocate plant-in-service costs is based upon the factors derived in the separable cost-remaining benefits (SCRB) allocation method. This is the standard economic method that Reclamation uses to allocate costs of multipurpose projects to authorized project purposes.

**Purpose**. The purpose of the annual cost allocations is to identify responsibilities for payment by project beneficiaries of reimbursable costs.

The method used to allocate O&M costs closely follows the plant-in-service allocation, although when O&M costs are not specifically related to particular CVP plant in service features, alternative factors are used for identifying costs to project purposes.

As a further example, the following table presents the shares of operation and maintenance costs allocated among all water users of the Chira- Piura Multipurpose Project developed in Peru (case study #.45). For the Chira-Piura Project the total amount paid by the water users to the concessionaire was determined on the basis of a reasonable return on financial investment, with the annual payment percentage amounts based on expected profits of water users due to the availability of regulated flows.

| ***Water user*** | ***Participation in O&M costs*** |
|---|---|
| Existing agricultural users | 58 |
| New agricultural users | 38 |
| Hydropower | 1 |
| Drinking water | 1 |
| Fish farming | 1 |
| Industry | 1 |
| Total | 100% |

In practice, cost allocation for project development will inevitably be the result of negotiated agreements among the parties involved and be influenced by the relevant financial market. In other words, financial viability largely controls cost allocation for multipurpose storage projects. Such control was less important in the early development of large multipurpose projects, when public entities were the main developers; e.g. the above-mentioned SCRB method was initially proposed by the Tennessee Valley Authority in 1938. The increasing trend and involvement of private entities, on their own, or within public-private-partnerships, makes financially viability the controlling factor for cost allocation of multipurpose projects.

### *Economic Discount Rate*

Selecting the appropriate discount rate is a much-debated subject in development economics and one that is not yet fully solved. To put the reader in context, reference can be made, among others, to (Poulos and Whittington, 2000) or to (Moore, M, et al. 2013) on discussion of social discount rates.

Regarding MPWS projects, it is important to realise that quality dam sites are scarce resources, and how non-sustainable use of these resources impacts society has been often underappreciated in the past. Past dam design and economic analysis paradigms considered benefits and costs over a period of time that often ranged from 20 to 30 years, commonly known as the “design life”.  Nowadays, organisations like the World Bank (Karki P., 2016) recommend that the time period used in economic analysis of projects should reflect reasonable estimates of the full duration of costs and benefits associated with the project, rather than be capped at 20 years or some arbitrary cut-off date. Besides, using 3%, as an approximate estimate for expected long-term growth rate in developing countries, the World Bank is considering using a discount rate of 6%. Where there is reason to expect a higher (lower) growth rate, a higher (lower) discount rate should be chosen. Consideration is also being given to the use of a declining discount rate to account for the uncertainty associated with future economic growth.

*Economic costs and benefits of the project*

One of the key planning difficulties is to fully appraise the economic costs and benefits of the project. Many projects tend to limit the analysis to focus on the energy component, which is most easily valued. If this energy component provides a positive economic rate of return then the remaining benefits may be listed as ‘unquantifiable’. To do this is to under-represent the true costs and benefits of the project and may lead to sub-optimal decision making; particularly when optimizing the size and performance of the project. Such limited analysis is of little benefit to Government’s when trying to make decisions between projects competing for scarce resources or in changing circumstances.

For example, a very important purpose of storage projects is flood mitigation. (Doocy et al. 2013) carried out a comprehensive review of the impacts of floods in the 1980-2009 period. They reported 540,000 casualties (range 511,000 to 569,000), 362,000 injuries and 2.8 billion people affected by floods in that period. Inconsistent reporting suggested this is an underestimate, particularly in terms of the injured and affected populations. The economic value of flood control to a country often justifies the allocation of funds from the public sector.

## 4.3 Indirect economic benefits and costs

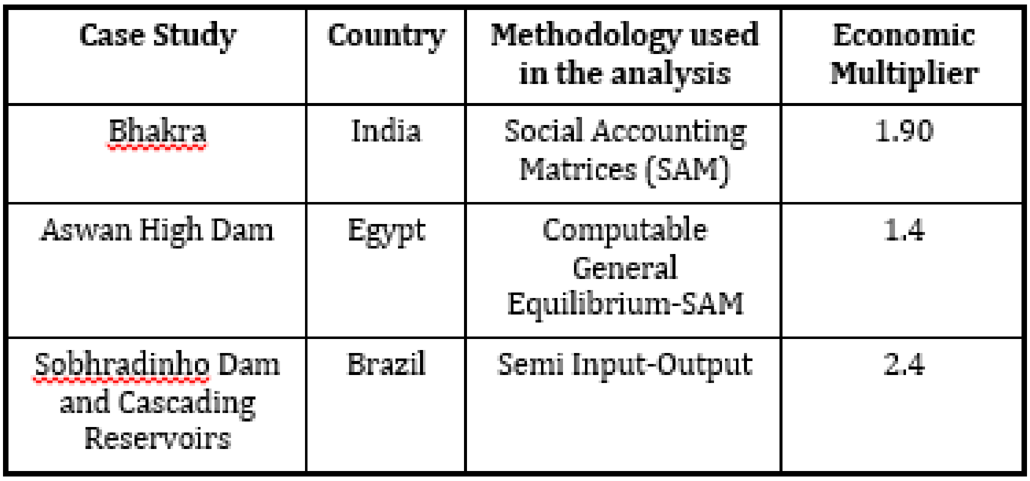
Direct economic impacts are those descending from the construction of the MPWS project, other services provided by the structure, and changes in flow regimes - regardless of whether these impacts were initially planned. Indirect and induced impacts are those that stem from the linkages between the direct consequences of a project and the rest of the economy. Among them are impacts due to changes in output and input use in sectors other than those affected directly by the project, or changes in relative prices, employment and factor wages.

The indirect and induced impacts of a project are estimated in terms of a multiplier value. Multipliers are summary measures expressed as a ratio of the total effects (direct and indirect) of a project to its direct effects.

A MPWS project featuring hydropower and irrigation may have performed less than satisfactorily on the irrigation component; however, consideration of direct and indirect linkages to regional/ national economies will capture the real standing of the irrigation-related economic performance. Non-financially strong components of a MPWS project are often in need of equity and/ or concessionary financing to become financially viable and to capture the total (direct and indirect) economic benefits.

*Economic multipliers*

Bhatia et al (2008) calculated ex-post economic multipliers of three multipurpose projects obtaining the following values.



| Case Study | Country | Methodology used in the analysis | Economic Multiplier |
|---|---|---|---|
| Bhakra | India | Social Accounting Matrices (SAM) | 1.90 |
| Aswan High Dam | Egypt | Computable General Equilibrium-SAM | 1.4 |
| Sobhradinho Dam and Cascading Reservoirs | Brazil | Semi Input-Output | 2.4 |

**Figure 11**

The interested reader should consult the reference for computational procedures and assumptions.

Academic controversy exists on the use of multipliers in the context of traditional partial economic analysis. If the analysis is done correctly, and shadow prices are properly used, then some of the indirect benefits are captured. The best way to capture overall benefits is through CGE (Computable General Equilibrium) modeling work. John Briscoe (in Bhatia et al.) has given an authoritative opinion on the use of multipliers for project appraisal. Since water investments are not “marginal” or small in comparison with the rest of the economy, it is important to capture the total benefits of the project in the context of the regional development. Such considerations of creating employment and regional incomes were the motivation behind large-scale water and other infrastructure projects in the United States, Europe and other countries. Regional benefits were the reasons that major projects such as the Hoover dam, Grand Coulee dam and Columbia Basin Project were undertaken with federal funds in the United States. As pointed out by John Briscoe, (2003), regional multipliers were precisely the point of such projects and it was expected that water investments would “change the trajectory of regional economies”.  Multipliers were the explicit and overt reason for these projects.

## 4.4 Economic multipliers and transformational projects

Assessing multipliers ex- ante is difficult and can be questionable, but neglecting multipliers (and thus failing to identify economic costs and benefits in full) in ex-post assessment of economic performance of projects may lead to meaningless results. Indirect economic benefits, or economic multipliers, assume particular relevance in the case of “transformational projects”, i.e. projects conceived to cause major changes in regional/ national economies.

Case studies presented in annex have evidenced several such projects; the Ataturk Dam, in Turkey, represents an outstanding case.

## Atatürk Dam and the Southeastern Anatolia Project

The Southeastern Anatolia Project (referred to as GAP in Tukish) is one of the largest water resources development projects in the world involving the construction of 22 dams, 19 hydroelectric power plants with an installed capacity of 7526 MW, and the irrigation of 1.7 million ha in the Euphrates and Tigris river basin. The Atatürk dam is the master piece of the GAP. Completed in 1995, it features a 169m high rockfill with central core dam. The crest has a length of 1,664m and a width of 15m. The lake behind the dam has an area of 817 km$^2$ at full supply level and its storage capacity (48.7 km$^3$) can control almost two years of the average Euphrates discharge at the dam location.

The storage of the Atatürk scheme has been designed to serve four purposes:

1) The primary objective is seasonal regulation to irrigate around 1 million hectares.
2) Hydropower, with 2,400MW installed capacity and a generation of 5,300GWh annually when the irrigation schemes will be fully developed.
3) Birecik and Karkamis Hydropower run-of-river plants benefit from the flow regulation operated by the Atatürk reservoir.
4) Fish production.
5) Tourism and recreation purposes.

For transformational projects, indirect economic benefits should be:

- Considered Ex-ante: in the analysis of externalities and as guidance for policies aimed at equitable benefit sharing.

Calculated Ex-post: to monitor the overall economic performance of a project and to learn lessons for future investments.

## 4.5 Economic cost of the no-project option

The economic assessment of MPWS projects often underestimates or ignores the economic cost of the no-project option. For some projects the consequences of taking no action at all - the project not proceeding - may be wider than has traditionally been considered during the economic evaluation.  This is particularly the case in the water sector, where lack of suitable infrastructure can lead to increased water stress over a large area.  In this situation, a true economic appraisal should include the wider costs of the “no action” option, which might imply lost food production through lack of irrigation, diminished employment, flood damage and a general lowering in the level of economic activity. Similarly, there may be an economic cost to delaying action, which is urgently needed to support development. Much of the world’s unexploited hydropower potential is in developing countries, many of whom are desperate for electricity and for water storage to support development. Similar considerations apply to flood protection and irrigation potential in developing countries. Yet these much-needed projects are typically subject to extensive delays both before and during construction, which add to their cost and impacts and threaten their sustainability.

Engineers have focused on the question of construction delay and made improvements in project management, but the implications of pre-construction delays are rarely documented or analyzed.  A recent research (Plummer and Guthrie, 2015) considers the impacts of pre-construction delay in hydropower projects and identifies how the adverse impacts of delay can be highlighted to decision makers to improve project sustainability. The impacts include obvious economic impacts on the countries concerned, but also less obvious environmental, social and even secondary economic impacts from project delays such as the stress on communities of waiting years to be resettled; deforestation of project areas; lack of local investment and services and a disincentive for foreign investment caused by a lack of reliable power supply.  This also highlights the economic impacts of construction delay, which are rarely recognized by the developer unless liquidated damages are specified, but which can cause significant loss to the country concerned in terms of lack of electricity or the necessity to rely on more expensive forms of energy.

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# 5.0 The Need for Long Term Planning

## 5.1 The Water Infrastructure Cycle

As in many other themes, water infrastructure planning and development follows a cycle and one has to realize that, given the much longer life-time of water infrastructure, compared to other sectors, such a cycle is naturally longer. This has to be kept in mind when making decisions at strategic planning level and when considering risks and tradeoffs in particular.

When population density, and associated water demand is low, natural storage in lakes, groundwater, snowpack, etc. is sufficient to guarantee the needed supply of water (m3/capita). As population increases to a certain level, additional water resources regulation can be provided by small artificial storage which enhances natural regulation (examples: rain water harvesting, irrigation "tanks" of South Asian Continent, hilly ponds, shallow aquifers, etc.). With further growth of population and standard of living, $m^3$/ capita requirement goes up to levels requiring higher regulation of natural flows. Water demand from large urban agglomerates, industrial areas, extended agriculture/ irrigation, etc. requires progressively larger scale and more sophisticated water infrastructure, and capable institutions for its governance. Large-scale water infrastructure includes surface water storage, inter-basin water transfers, groundwater well fields, conjunctive use of surface and ground water, etc. Such structural measures have to proceed in parallel with non-structural ones such as improved irrigation efficiency, water re-use, leakage reduction, institutional strengthening, etc. The path followed by all developed nations demonstrates close relationship between population and economic growth, on one side, and the stock of water infrastructure on the other. The subject has been already illustrated in Chapter 2 “The Role of Water Storage”. The recent history of Japan is a case in point (Matsumoto, 2006).

*Population, economic growth and water infrastructure – A Japanese case study*

Population in Japan started to increase from the 17th century. The following graph shows a very clear relationship between demographic growth and development of irrigated areas. A large number of dams throughout the country secured water supply for both irrigation and domestic needs.

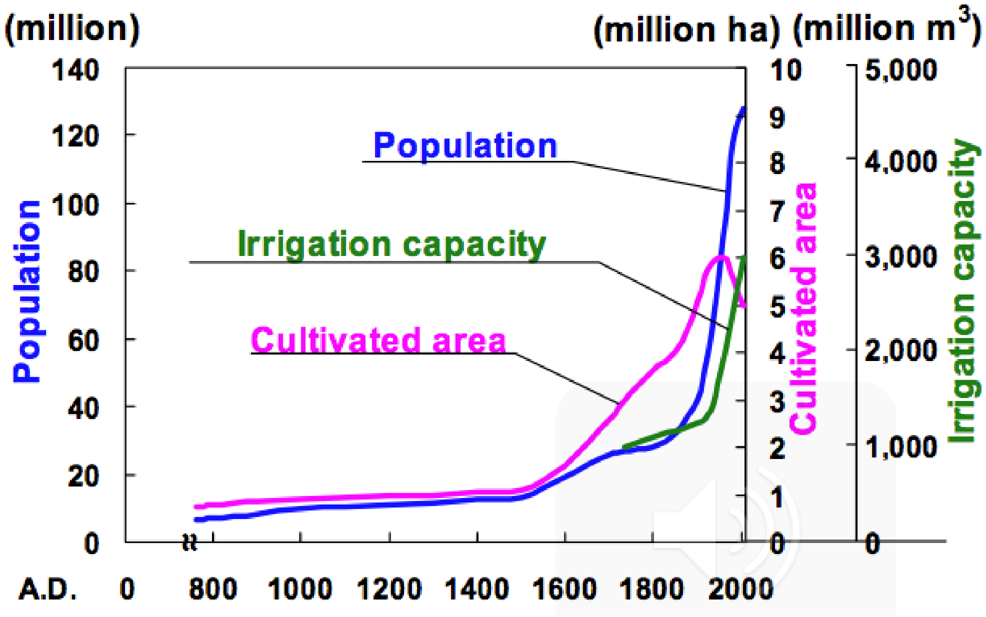


**Figure 12:** ***Ref. Matsumoto N. (2006)***

Japan opened its door to overseas countries in the late 1800's when several ports were prepared for trades. The first dams in Japan were built to supply water to port cities and to ships. At that time, outbreaks of epidemic frequently struck the country. Chlorinated public water dramatically reduced infant mortality rate and the transmission of water-related diseases. The following graph tells the story very clearly.

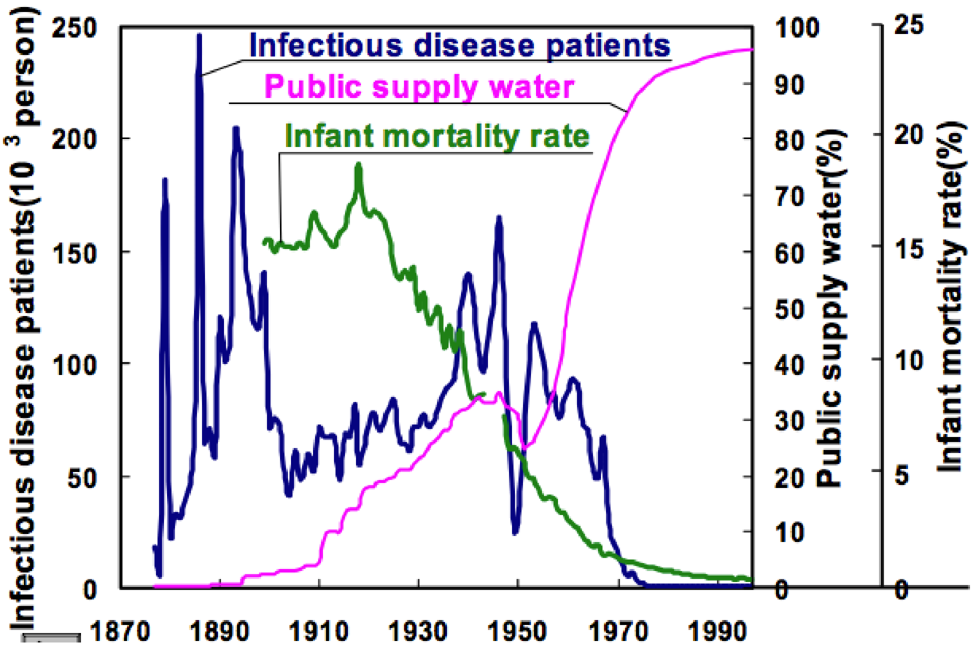


**Figure 13:** ***Ref. Matsumoto (2006)***

Until the 1950's, Tokyo's water came from underground aquifers. To meet demands of an extremely rapid population increase, over-abstraction took place, which caused ground subsidence. That determined progressive development of surface water storage and dams were built in several river basins. The following picture shows the contribution of Tone River dams to meet Tokyo's water demand.

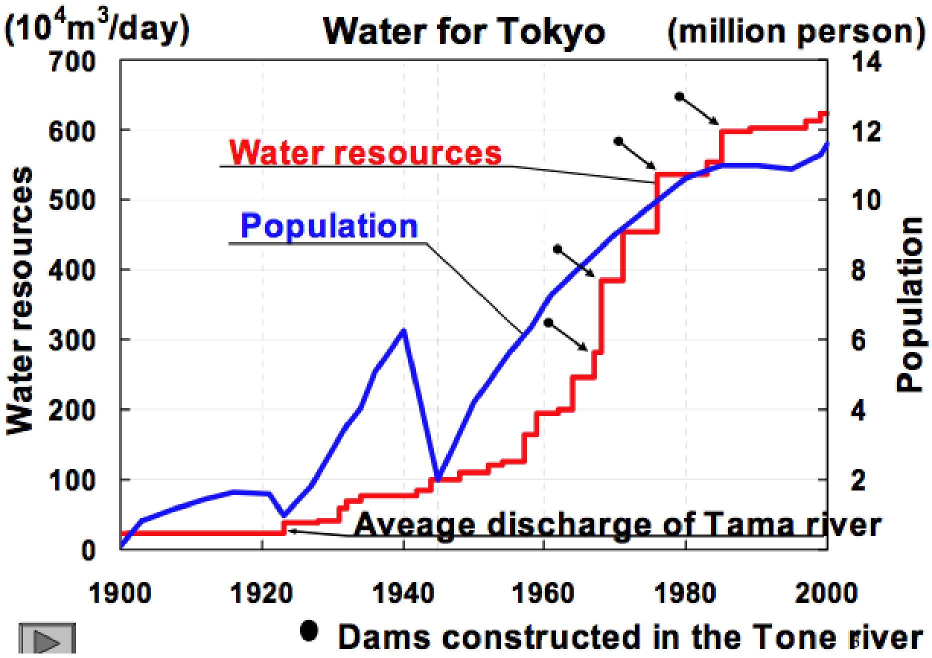


**Figure 14:** ***Ref. Matsumoto N. (2006)***

*Rehabilitation vs re-engineering*

There will be a time, in a country's development pattern, when structural measures will be mainly of rehabilitation and conservation nature, and construction of new water infrastructure will naturally diminish. This is what we have observed so far, for example, in Europe, North America, and Australia.

What we have started to observe, but that has not yet attained general attention, are cases in which supply- side options, having been neglected for too much time, require urgent investment in new water infrastructure. In addition to that, even well maintained infrastructure may become outdated or in need of re-engineering because of changing demographics and concerns associated with global warming.

A few examples of this emerging trend are listed below:

| Dam | Completion | Location | Purposes |
|---|---|---|---|
| Olivenhain Dam and San Vincente Dam raise | 2012 | San Diego (CA, US) | Water Supply |
| Berg River Dam | 2009 | Cape Town, South Africa | Water Supply |
| New Yesa Dam | 2008 | Ebro River, Spain | Flood control, water supply, managed river flows |

This is like returning to square one and starting over again, in a different social and economic context than that when the process started, but with the experience of failures and successes of the past.

## 5.2 Reservoir Conservation

*Sediment management*

Among the many sessions of the Third World Water Forum, held in Kyoto, Japan in March 2003, there was one titled “Sedimentation Management Challenges for Reservoir Sustainability”. Two main messages emerged from that session:

i) Whereas the last century was concerned with reservoir development, the 21st century will need to focus on sediment management; the objective will be to convert today’s inventory of non-sustainable reservoirs into sustainable infrastructures for future generations.
ii) The scientific community at large should work to create solutions for conserving existing water storage facilities in order to enable their functions to be delivered for as long as possible, possibly in perpetuity.

Reservoir sedimentation leads to storage loss when river-carried sediment deposits in reservoirs and takes up space originally intended for storage of water. The following figure (Schleiss et al, 2008) is a projection of the impact of sedimentation on storage capacity in Switzerland and at global level.

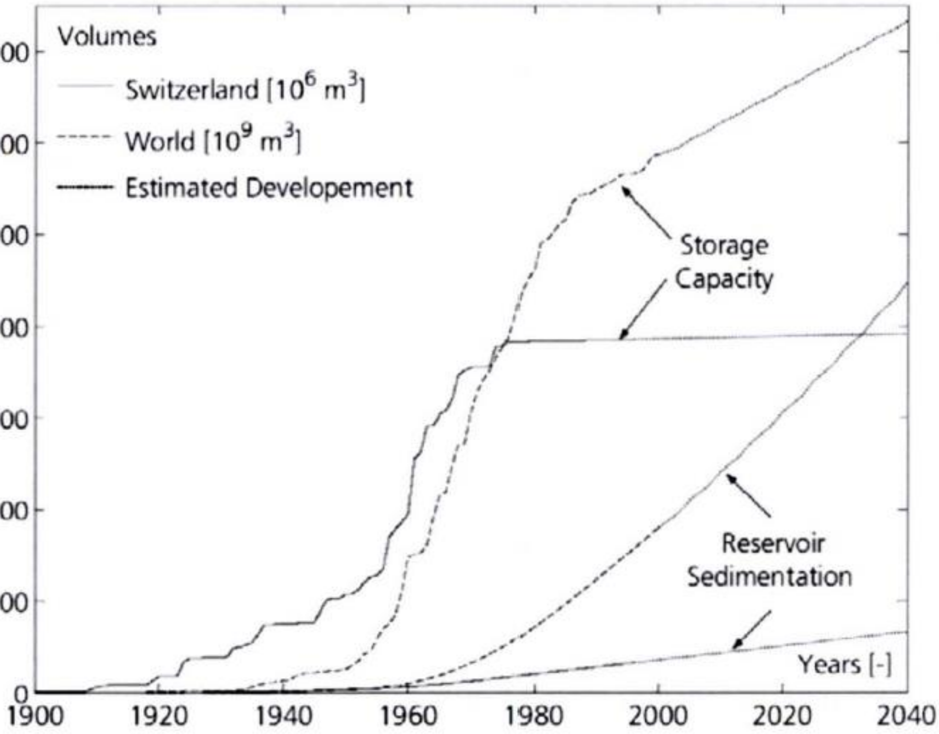


**Figure 15**

The reduction of reservoir storage space due to reservoir sedimentation has a significant adverse impact on water supply reliability. Sedimentation may also clog dam outlets and greatly accelerate abrasion of hydraulic machinery and waterways (e.g., spillways), thereby decreasing efficiency, increasing maintenance costs and reducing safety. Increased loads on a dam by sediment build up may also lead to reductions in safety factors against sliding and overturning for some types of dam.

Sediment management should be a key element in planning of new reservoirs and in addressing existing ones.

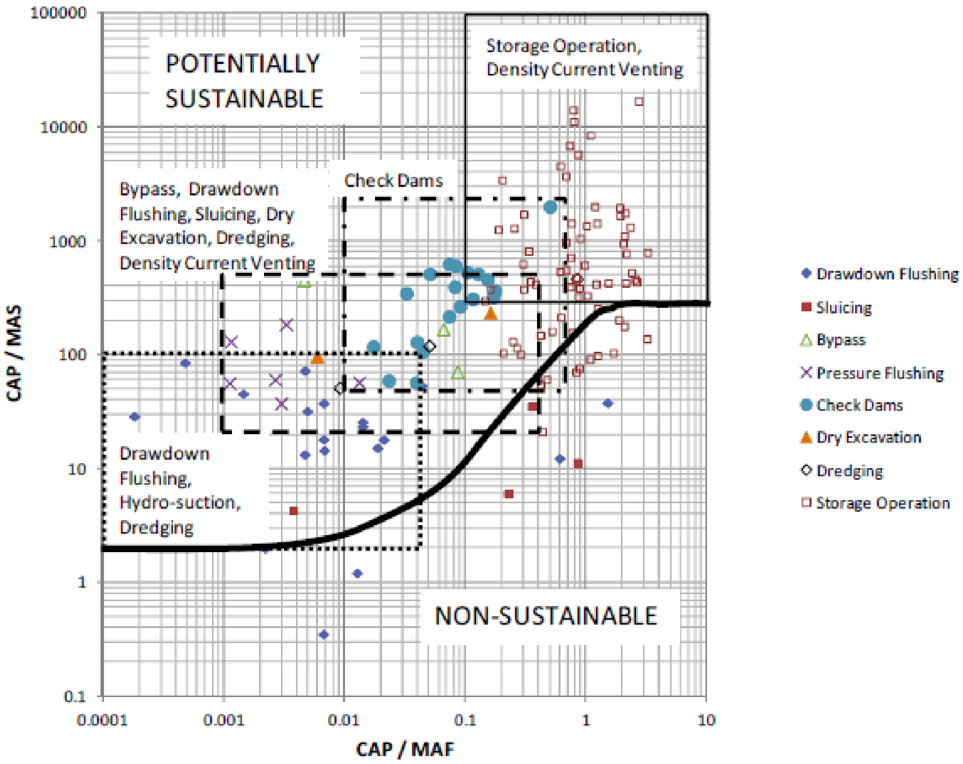
Three ICOLD Bulletins deal with reservoir sedimentation:

- B147 (2009) “Sedimentation and Sustainable use of Reservoirs and River Systems”
- B140 (2007) “Sediment Transport and Deposition in Reservoirs”;
- B115 (1999) “Dealing with Reservoir Sedimentation”.

A key reference on engineering measures for mitigating sedimentation impact is Morris and Fan (1997).

In his recent book, Annandale (2013) puts sedimentation in the broader perspective of water security. The following diagram, from that reference, contains data on engineering measures, which have been used for managing sedimentation in a number of reservoirs worldwide.

**Figure 16**



The X-axis shows the ratio between storage capacity (CAP) and mean annual flow (MAF) of the river; this ratio represents the “hydrological size” of the reservoir. The Y-axis has the ratio between CAP and the mean annual sediment yield (MAS) reaching the reservoir; the higher this ratio, the longer the useful life of the reservoir. The solid curved line separates an upper area, where sedimentation management is considered possible, from a lower area where sediments are expected to irreversibly fill reservoir space. The graph is useful to obtain a preliminary idea of which technique could be suitable; however, actual feasibility of the engineering solutions will always require case specific studies.

## *Current knowledge*

Limiting to key elements, current knowledge can be summarized as follows:

- Sedimentation rates are extremely variable geographically.
- Several silted reservoirs, but not all can be remediated and reservoir life prolonged, by means of an array of management techniques.

- Sediment size is an important factor for assessing the applicability of sediment management techniques; sediment load is classified in three size categories: wash load (d< 0.075 mm), sand (0.075<d<2 mm), and gravel (d>2mm).
- Fine sediments (fine sands and below) permit implementation of most available techniques; coarse sediments (sand and gravel size) are almost impossible to handle in the long term; fortunately, coarse sediments generally represent a minor part of the solid load, although there are exceptions.
- Watershed management measures have proven effective in small catchments (less than 100 km$^2$); for large catchments (more than 1,000km$^2$) experience shows no appreciable effects, unless soils are very fine (Palmieri et al, 2003).
- In many cases, especially for large reservoirs, some form of passing sediments downstream of the reservoir by flushing is found to be the most effective management technique.

Whereas it would be wonderful if large-scale catchment policies could serve to limit reservoir sedimentation and to practice conservation at the same time, success in this regard has been very limited (ICOLD Bulletin 147, 2009). Some of the decreases in sediment loads which have been observed are due to depletion of erodible top soils rather than success with soil conservation measures. A few examples show that it is possible to reduce sediment yield in large catchments, but at sizable cost and over long periods (decades), (Wark, 2012), (Quininero-Rubio et al, 2014).

### *Sediment and environmental management plans*

Managing sediment, as with any other task dealing with natural phenomena, presents environmental opportunities and challenges. Engineering measures dealing with sedimentation have to be associated with an environmental management plan, and the plan ought to be conceived at feasibility level.

Opportunities associated with sediment release downstream of the reservoir can be associated with river morphology and coastal erosion mitigation by sediment replenishment. Uncertainty around sea level rise makes this planning of the sediment balance increasingly important.

On the negative side, sediment flushing has impacts on river water quality. Effects on two key parameters and ways to mitigate such effects are shown in the following table (Sumi, 2005).

| **Parameter to monitor** | **Influencing factors** | **Mitigation measures** |
|---|---|---|
| SS: Suspended Solids (mg/l) | Precise threshold for harmless SS concentrations do not exist, however fauna and flora normally tolerate 5-10 mg/l.<br>Values of SS and DO should be recorded during flushing to optimize future operations. | • Flushing sediments during high natural flow periods.<br>• Start gradually using clear water.<br>• Operators should be able to suspend and restart flushing.<br>• Flushing more frequently.<br>• Post-flushing rinsing with clear water. |
| DO: dissolved Oxygen | DO is little affected by “fresh” sediments. Old sediments reduce DO (organic matter, metallic ions, etc.). | Avoid rapid drawdown because it puts old sediments in suspension. |

### *The challenge of future planning*

The effects of sedimentation, and associated loss of storage, develop in the long term, and planners often do not like to take action on uncertain events that are going to occur in the far future. Politically, investing now for something uncertain in the future is not a rewarding exercise. Both for such attitude, and for poor awareness of sedimentation effects, the issue has been largely underestimated in the early dam planning period of the 20th century. What was the far future 50 or more years ago is now the present and, unfortunately, society and the environment has been left with the consequences. The problem is also an economic one:

- The lost storage capacity entails replacement costs for construction of new storage if the present level of supply is to be maintained.
- As sedimentation occurs in the future, there will be reduced economic benefits in the form of less hydropower production available for sale, less irrigated land to produce food, reduced flood routing capacity, etc.

*The Rescon approach: economic feasibility of sediment management strategies*

Having found that there was little, if any, published information on the economics of reservoir sedimentation and its implication for sustainable development, (Palmieri et al. 2003) studied the problem from an economic angle.

Their work, known as “the Rescon approach”, produced a framework to assess the economic feasibility of sediment management strategies that allow the life of dams to be prolonged as much as possible. Such a framework aims at answering two related, but distinct questions:

- Is the extra cost incurred in undertaking sediment management activities worthwhile in terms of extending the productive life of a dam?
- Is it economical to extend the life of a dam indefinitely?

Rescon advocates a “life cycle management” approach, which aims at designing and managing water resource infrastructure for sustainable use, i.e. reaching a long-term storage capacity, which is a fraction of the initial one, but still is able to deliver economically valid functions. This requires the incorporation and use of sediment management facilities and/ or the implementation of a long-term action plan to prolong asset life. Such a plan should be conceived at the feasibility stage and will require periodic reviews and adjustments to ensure its adequacy during the life of the reservoir.

The long-term arrangements being considered for the proposed Rogun HPP, in Tajikistan, represent a pertinent example.

**Proposed Rogun HPP - Long Term Sediment Management Strategy**

(www.worldbank.org/content/dam/Worldbank/Event/ECA/centralasia/TEAS%20Rogun_Summary_eng.pdf)

Due to the high level of carried sediment, any storage reservoir on the Vakhsh River is bound to have a limited lifetime of the order of 100 to 200 years. This requires the development of specific long-term strategies to ensure a safe long term configuration of the site.

At the end of useful life, the surface spillway could also discharge the solid inflows and manage the sediment balance, long after the plant and the other spillway facilities will be put out of operation.  An ultimate long-term management option could be to remove the surface spillway’s gates allowing sediments to erode an incised water way through the spillway and underlying rock over a period of several decades.

To put in place a de-commissioning fund as early as possible, fed with part of the projects benefits, would permit to finance long term de-commissioning costs.

In the case of existing dams, which were built along the concept of “dead storage”, the potential for converting them into sustainable projects should be investigated. Pertinent actions can comprise substantial plant modification (e.g. protecting the intakes and converting to a run-of-river scheme), change of purpose (e.g. recreation, farming, environment creation) and in extreme cases dam retirement with partial or complete removal of the dam.

## 5.3 The challenge of envisioning long-term changes

Planning periods of large multipurpose projects last rarely less than a decade; normally they last a few decades. During those long periods, the needs to be fulfilled by the planned project evolve and change. The following case from China is a pertinent example.

**Dalong Water Control Project**

Evolution of multipurpose function during the planning period (43 years):

- 1958 to 1966: hydropower oriented.
- 1969 to 1985: irrigation oriented, urban water supply, flood control and hydropower; storage capacity increased to 373 million m3.
- 1988 to 1995: urban water supply-oriented, irrigation, hydro, flood control.
- 1998 to 2001: flood control oriented, flood control capacity increased to 148 million m3, irrigation, urban water supply, irrigation, hydro.
- 2013: included in “Green Island “water park (water conservancy area) in Hainan Province.

It is reasonable to expect, as several case studies demonstrate, that such changes will also occur during the life cycle of the project. The boxes below illustrate other three such cases.

**Danjiangkou Reservoir, China**

Built in 1968 for flood control, hydropower (900MW), water supply, irrigation, navigation. The strategic value of the multipurpose asset lays in its adaptation, by structural measures (dam rising), to serve an additional function, after 37 years of operation. Allowing the middle route of the South to North Water Transfer Project, Danjiangkou produced major indirect economic benefits.

**Xhafzotaj Reservoir, Albania**

Initially built for irrigation, Xhafzotaj is a small off-stream reservoir, which used to be filled by a feeder canal and by pumping. Neither the feeder canal, nor pumping have been in operation since about 1999. The lake is practically empty and settlements are present on most of the lakeshores well below minimum operating level. Areas around the reservoir are almost totally urbanized and there is hardly any significant irrigation demand any longer. At the same time, a nearby town is in need of additional water supply and modernization of Xhafzotaj Dam can meet that demand.

**Waipori Dam, New Zealand**

Built in 1907 for hydropower (83 MW). The dam allowed reclamation of land downstream, which promoted agricultural development. The investment downstream therefore was deemed to need a higher level of flood protection, so reservoir operation had to include flood management.  Recreation and ecological functions were added about a century after construction.

Hydraulic infrastructure is characterized by its longevity and by its broad impact on the environment and society. Scale, site selection and operational characteristics need to be assessed from a long-term planning perspective, incorporating anticipated trends and emphasizing adaptability. This will ensure that future generations inherit institutions and infrastructure that can adapt to their evolving values. There is no doubt that this sustainability principle is valid; how to implement it in practice is not a trivial exercise.

### *Post-project monitoring and evaluation*

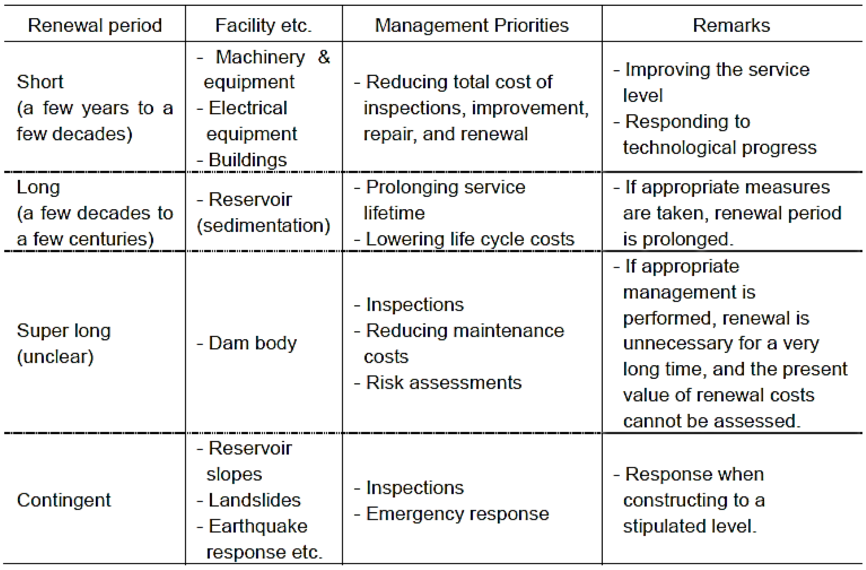
A reasonable approach is to establish a post-project monitoring and evaluation process to periodically review performance, benefits and impacts. Comparing findings with planned outcomes would suggest measures to optimize/ rectify/ improve those outcomes. Where dams are part of a larger river basin and regional development scheme, the process should take into account basin-level effects of all project and program components linked to the project in consideration. In such cases, Cross Impact Assessment (see section 8.2) could be a useful tool.

### *Scenario building*

Scenario Building is also useful in managing issues associated with long-term planning. It is in fact impossible to anticipate what will happen in one century or so, however, a scenario pertaining to long-term performance of the multipurpose project can be postulated at feasibility stage. A key factor in scenario building is generally sedimentation, but other factors could have a role such as reliability and safety, cumulative effects of future projects, effects of climate change, emerging demands, etc.

*Asset management concept*

Sumi et al. (2009) argued that, in order to sustain reservoir functions and to avoid transferring the full burden of their maintenance to the next generation, it is essential to apply asset management concept to dams. In the near future, strategic asset management including preventive countermeasures for river sedimentation will be an important challenge. They noted that asset management concepts normally apply to machinery and equipment with relatively short service lifetimes, to diagnose deterioration of hydropower equipment and to survey maintenance costs. However, overall asset management of dam and reservoir systems, including dam bodies, is generally not pursued. This is presumably a result of the fact that a dam body has such a long service lifetime, which is difficult to specify, and that the need to discuss the optimum repair plan is generally low at a relatively new dam. The following table (Sumi et al., 2009) categorizes dam-related facilities and management priorities by renewal period.



| Renewal period | Facility etc. | Management Priorities | Remarks |
|---|---|---|---|
| Short<br>(a few years to a few decades) | - Machinery & equipment<br>- Electrical equipment<br>- Buildings | - Reducing total cost of inspections, improvement, repair, and renewal | - Improving the service level<br>- Responding to technological progress |
| Long<br>(a few decades to a few centuries) | - Reservoir (sedimentation) | - Prolonging service lifetime<br>- Lowering life cycle costs | - If appropriate measures are taken, renewal period is prolonged. |
| Super long<br>(unclear) | - Dam body | - Inspections<br>- Reducing maintenance costs<br>- Risk assessments | - If appropriate management is performed, renewal is unnecessary for a very long time, and the present value of renewal costs cannot be assessed. |
| Contingent | - Reservoir slopes<br>- Landslides<br>- Earthquake response etc. | - Inspections<br>- Emergency response | - Response when constructing to a stipulated level. |

Sumi et al. (2009) extended the concept of asset management to reservoir sedimentation and concluded that it should preferably be implemented on a system of reservoirs. Optimizing sediment management measures in a dam system context implies periodic application of sedimentation countermeasures at one reservoir, while the others continue to deliver services. In practice, this requires N+1 reservoirs in the system, whereby the “N+1 dam” provides service backup when countermeasures, involving reservoir drawdown, are implemented at another reservoir. In brief, sedimentation management should be recognized as “another water user”.

*Financial aspects of asset retirement planning*

A recurrent issue, in this context, is the discount rate that should be used in the presence of a very long discount period, which is discussed in section 4.1 herewith. The circumstance that costs and benefits happening far in the future have limited impact on present decisions, may be attenuated by a suitable financial plan for funding asset retirement/ replacement when the asset gets close to the end of its economic life.

At the time of feasibility, the retirement plan should be addressed at a conceptual level. The corresponding design and financing plan should be progressively developed during the operation period. The plan should ensure, not only resources for project retirement and site restoration, but also for the continued supply of the dam/ reservoir purposes. A financial replacement policy should address:

a) establishment of a replacement fund and its initial balance;

b) annual withdrawals from the replacement fund;

c) required outside sources of fund replenishment (e.g., user fee surcharges, operational transfers, bond issues, etc.).

Monitoring of dam/ reservoir aging (notably, but not limited to, sedimentation) should determine how the residual life of the asset compares with the anticipated one. Annual deposits to the fund should be increased if the current estimate of the residual life falls short of the anticipated one. Deposits could be reduced in the opposite case (longer residual life). This mechanism, of the adaptive management type, encourages allocation of suitable funds for recurrent operation and management of the assets, and results in more sustainable projects.

## 5.4 Dam decommissioning put in context

Decommissioning of dams is a relatively recent happening, which should be regarded as a normal process in countries where dam construction started about a century ago. The 'normality' of the process is because societal demands and priorities change over time, therefore it should not be surprising that they may become radically different after a century or so. Notably, many dams that have been decommissioned in the United States, and incidentally the highest ones, are old mining dams, which were built during the Gold Rush. At the same time, many dams built to provide water and power for mining are still in service; most have been modified and strengthened to meet current dam safety standards.

ICOLD established a Committee in 2005 to develop information that can be used to respond to inquiries on dam decommissioning and to provide a forum for exchange of information on the subject. In 2012, the committee issued Bulletin 160 "Dam Decommissioning Guidelines" to provide guidance on the decision-making process, consultation and regulatory approvals, design and construction issues, sedimentation management and performance monitoring.

*Decommissioning vs re-engineering*

The United States is the principal place where decommissioning of old dams is being carried out. Dams are removed principally for environmental, safety, and economic reasons. Other countries where that process can, to some extent, be traced are Australia, Canada, and a few European countries (France, Italy, Switzerland, Sweden, and UK); in all cases, the extent is much lower than in the USA. Needless to say, the subject is far from being contemplated in those developing countries which have not yet built their stock of hydraulic infrastructure.

In the United States (Charlwood, 2004), dam removal (or decommissioning) has become an accepted alternative for dealing with ageing dams with about 500 documented cases as shown in the following table; note that this is a small number compared to the 87,000 dams in the National Inventory of Dams (NID).

**Total dams decommissioned in United States** (1946 to 2004): 467

| **State** | **Number** | **Highest (m)** | **Average Height (m)** |
|---|---|---|---|
| California | 48 | 17.1 | 4.6 |
| Wisconson | 73 | 17.7 | 3.0 |
| Connecticut | 16 | 7.9 | 3.4 |
| Ohio | 38 | 12.2 | 5.8 |
| Pennsylvania | 38 | 9.1 | 2.7 |
| Tennessee | 26 | 48.8* | 14.3* |
| Illinois | 17 | 29.3 | 7.9 |

*Owned and removed by mining companies

It can be seen that most of these decommissioned dams are of very modest size.

When dealing with large, multipurpose projects with a very long service life, it is very unlikely that decommissioning or total dam removal becomes the preferred course of action. Re-engineering the project, with major rehabilitation and upgrading investments, is the obvious alternative. Intermediate options, with full or partial replacement of services, should also be considered. The following two boxes provide examples of a dam decommissioning project in USA, and a dam re-engineering project in China.

### Elwha River Restoration Project (United States, WA)

Built for electricity supply to the mining sector, the two dams (Elwha and Glines Canyon) delivered, during their life, additional functions such as flood management of domestic/ industrial water supply. In 1992, after 70 years of operation, the Elwha River Ecosystem and Fishery Restoration Act suspended FERC re-licensing. The 1992 Act provided for project acquisition by U.S. Government at a fixed price ($29.5 million) from the private owner. Electricity production discontinued. Continuation of non-electricity services to affected parties would be ensured: quantity and quality for water supply, flood protection, protection of cultural resources. Overall cost sustained by the public sector: 325 million USD; implementation time 7 years. Major technical issue: sediment management.

### Fengman Reservoir Re-engineering (China)

Fengman Reservoir has been in operation for nearly 70 year. It is the first dam in China reaching the expiry of service life and the first large dam in China to be rebuilt. Several Chinese institutes carried out in-depth comparison among different options and full reconstruction emerged as the preferred course of action. In October 2012, the state Development and Reform Commission approved the reconstruction project. Re-engineering includes partial demolition of the original dam and building a new dam 120m downstream of the original one. The new dam will have a length of 1068m, and maximum height of 94.5m. After completion of the reconstruction program, "a site of two dams" spectacle will appear at the mouth of the canyon. Six new turbine generator sets, 200MW each, will be installed at the new site, and 2*140MW at the original dam. The total installed capacity will go from 1022 to 1480MW, with an annual generation capacity of 1709 GWh. Re-engineering and uprating of Fengman Reservoir Project will cost 9.1 billion RMB (year 2010 estimate).

*Dam decommissioning and environmental assessment*

In many cases, real benefits to society and to the environment occur following the removal of an old dam. However, removing a dam from a river is not always an appropriate solution.

Indeed, there have been significant unanticipated problems that have resulted from inadequately planned and executed removal projects. Sediment removal from the reservoir and/or sediment transport after dam removal must be carefully planned and executed to prevent unwanted downstream effects. As well, there is insufficient data available in the literature to definitively support (or refute) the notion that dam removal actually enhances the health of a river system.

River restoration and natural channel design has become an objective in itself in many cases during the last few decades. Millions of dollars have been, or will be, spent on river restoration projects all over North America. The objectives of these projects are often intended to restore a river to its pre-disturbance status or simply to return a river to a natural condition.

However, in many cases these objectives cannot be achieved because:

1) Knowing and restoring all of the complex and dynamic variables making up a river system to their natural status is almost impossible.

2) In some cases, it is not possible to define a river's pre-disturbance status.

3) Even when the pre-disturbance status of a river system can be established, restoring the river to that status may not be sustainable or desirable under new demographic and climate futures, and taking account of environmental adaptations that have taken place during the life of the infrastructure.

Often, what is needed is a plan to establish a new, naturally behaved river system that maintains as many of the desirable components of the system as possible. However, in some cases these desirable components may be at odds with the pre-disturbance characteristics of the river. Therefore, the term restoration should be defined to include broader meanings including rehabilitation, enhancement and stabilization through sustainable management. Clearly then, defining achievable objectives for a river restoration project is extremely important for successful implementation of a river restoration plan.

The need for an adequate environmental impact assessment of dam decommissioning projects should not be underestimated. Contrary to general belief, the exercise can be as complex, if not more, than the assessment of new dam projects. The need for an adequate environmental impact assessment of dam decommissioning cannot be underestimated. Besides, there can also be significant public opposition to dam decommissioning. The USSD has published guidelines (Randle et al., 2013) for dam decommissioning projects, including on environmental assessment.

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# 6.0 Institutional and Procurement Aspects

## 6.1 Water Governance

Water governance is defined (UNDP Water Governance Facility (WGF) and SIWI) by the political, social, economic and administrative systems that are in place, and which directly or indirectly affect the use, development and management of water resources and the delivery of water services at different levels of society. Importantly, the water sector is a part of broader social, political and economic developments and, as such, it is affected by decisions outside of the water sector. Increasingly Corporate Governance is becoming a key factor of Water Governance, with the growth of privatization or semi-privatization of water infrastructure, particularly for MPWS schemes. The aspect of corporate influences, compliance and risk management, board responsibility and actions, and shareholder demands needs to be integrated into the decision making process.

Governance of multipurpose water projects was discussed in a session of the 7th World Water Forum (Branche, 2015) where the SHARE concept was proposed. The following plate summarizes the SHARE concept.

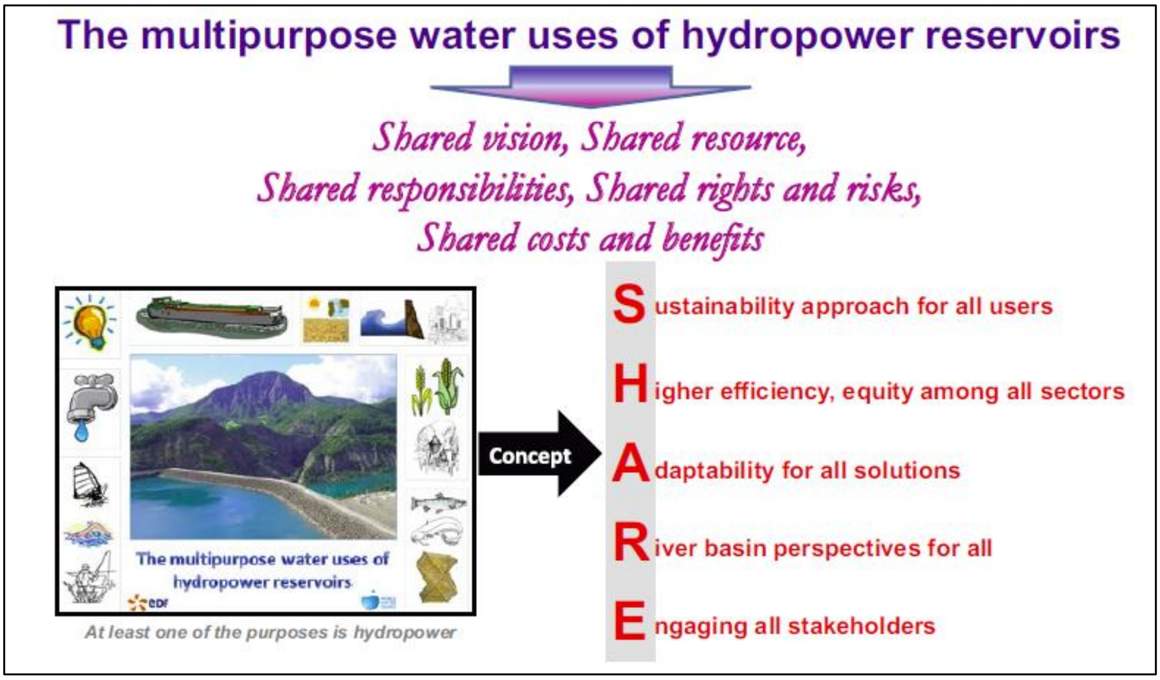

**Figure 17**

The ICOLD-MPWS Committee coordinated with the EDF-WWC Team in the early stages of the process[9] with the objective of minimizing duplication and maximizing synergies between the two initiatives. It was agreed to:

- Share case studies of mutual interest, and
- Exploring to some detail, in the ICOLD MPWS Bulletin, a few topics about Water Governance where ICOLD's knowledge can be of comparative value.

Based on the above, the present chapter discusses two additional subjects, which are relevant to governance: institutional arrangements, and procurement aspects. Because of its importance in MPWS projects, the present bulletin addresses some important topics of water governance, "stakeholder engagement" in particular (Chapter 3.6).

We advise to make reference to the SHARE concept for a broader treatment of the Water Governance subject.

## 6.2 Institutions and institutional arrangements

*Investment in infrastructure: Institutions*

The key to successful and sustainable development of water resources lays in balancing and sequencing investments in both water institutions and infrastructure (Grey and Sadoff, 2006).

While developed countries with ample infrastructure stocks appropriately focus on the implementation of water management and infrastructure operation, there are developing countries in which it is more appropriate to place a relatively greater emphasis on infrastructure investments. The social and economic cost of not developing water, or simply maintaining the status quo, may also be much higher in developing economies where many people are physically vulnerable and live in life-threatening poverty.

When stocks of hydraulic infrastructure are low, investment in (man-made and natural) infrastructure may provide relatively higher returns. Investment in management capacity, and infrastructure operation and institutions may become increasingly important as larger and more sophisticated infrastructure stocks are built. The following graph visualizes the concept.

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[9] Kick-off meeting and workshop- Paris 6 December 2013

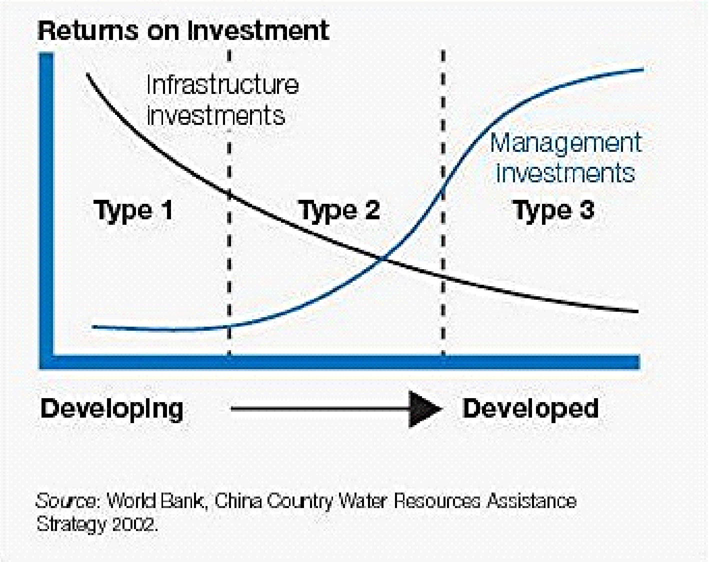

**Figure 18**

As infrastructure investments grow, it is imperative to balance investments in institutions and capacity building, recognizing that institutional development and reform can be slow and difficult; particularly difficult is translating policies into practice.

### *“3Is Concept”*

Hall et al. (2014) go further on the subject, introducing the “3Is” concept: Institutions, Infrastructure, and Information. Institutions and governance (including river basin organization, legal systems, national governments, and non-governmental organizations) support proactive planning and development of legal and economic instruments to manage and share risks (water allocation, and property rights, land zoning, watershed protection, water pricing and trading, insurance, and food trade liberalization. Investment in infrastructure buffers variability and minimizes risk (storage, transfers, groundwater wells, levees, wastewater treatment, and desalination). Information collection, analysis, and transfer (monitoring, forecast and warning systems, expert know-how, simulation models, and decision support systems) are essential for operating institutions and infrastructure.

### *Regulatory frameworks*

Regulatory frameworks for multi-purpose dams are more complex than those of single-purpose projects. Water rights and allocation quotas have to be distributed among different users, with potentially competing demands and impacts usually spread over a large portion of the river basin. Consequently, inter- and cross-sectorial coordination demands are much higher, requiring relatively strong institutional capacities.

### *Water institutions*

Saleth and Dinar (2008) carried out one of the most comprehensive analyses of water institutions. Their study presents an analytical framework for specifying alternative models of institution-performance interaction within the water sector under different assumptions concerning institutional linkages and their structural properties. Based on the model results, the study offers quantitative evidence for institutional linkages and their performance implications, and concludes by indicating policy roles, especially in developing some reform design and implementation principles useful to overcome the technical and political economy constraints for institutional reforms.

Having said that, the greatest challenge in institutional reform, is making progress, not achieving perfection. The World Bank's Water Sector Strategy (World Bank 2004) found out that:

- Selectivity and sequencing (of institutional reforms) are important,
- Progress takes place more through "unbalanced" development than comprehensive planning approaches;
- Triggers for reforms usually come from outside the water sector, often from the power sector.

The goal should be to define practical, implementable and therefore sequenced and prioritized actions that can lead to effective institutions. Institutions with transparent consultative processes promote the development of water information systems that include water resources and socio-economic data bases.

A major project can become the cornerstone of important policy and institutional reforms as has happened in Laos.

**Lao PDR, Nam Theun 2 HPP**

Nam Theun 2, with support from 27 financing parties from around the world, has helped usher in changes to government budgeting and spending, to consultation, resettlement, environmental protection, and national hydropower development policy. Nam Theun 2, a build-own-operate-transfer project, trans-basin diversion hydro-power plant, enables Lao PDR to generate 75 MW for domestic use and export 995 MW to Thailand.  NT2 consists of several complementary projects, which include the Lao Environment and Social Project, the proposed Khammouane Rural Livelihoods Project, and the Rural Electrification Project.

*Water user organizations*

Institutional aspects are generally perceived as associated with medium to large size public sector organizations. In addition to such organizations, there are other institutional entities that play very important roles. Water user organizations, in the context of river basin management, represent an important form of private institution. In that context, water users associations are usually broader than “irrigation water users associations”. When irrigation is one of the purposes of a water storage project, involvement of beneficiaries through an instituted water user association is now considered an indispensable component of project planning. A typical subject for shared planning is time sequencing of infrastructure and on-farm works. Very often those beneficiaries are also stakeholders for possible flood protection purposes.

There are quite a few examples of river basin/ water resources planning, mostly at watershed level. (Delli Priscoli, 2004) gives a comprehensive overview of arrangements for river basin management in different countries.

## 6.3 Procurement aspects

*Cost estimates for large civil works*

Procurement methods are addressed for sake of completeness only; clearly, their discussion goes far beyond the scope of the present bulletin. Methods differ from country to country however, at international level, the most frequently used, or at least referred to, procurement methods are those codified by FIDIC (International Federation on Consulting Engineers) and by the World Bank.

Before touching on procurement methods, it is necessary to clarify some basic concepts associated with cost estimate of large civil works. One mistake often made, sometimes accidentally and sometimes deliberately, is to compare initial construction cost estimates (the Engineer’s Estimate) with eventual Project Costs. The Engineer’s Estimate may only be for construction and engineering costs based on the year the estimate is made. The eventual project costs will include Employer’s costs, environmental and compensation costs, interest during construction (i.e. funding costs) and escalation over a period of years to completion. Even when costs are compared properly on a like-by like basis, an apparent overrun of 30% on the tendered or bid price is quite common. In addition to that, when dealing with a group of pre-qualified bidders, it is challenging NOT to give the job to the lowest bid, unless the difference in risk is fully appreciated, which, of course, further widens the difference between initial estimate and awarded contract.

*<u>Procurement methods</u>*

Procurement methods depend on:

- The type of financing,
- Financing sources, and
- The form of construction contract.

The most authoritative institution on the latter subject is FIDIC (International Federation on Consulting Engineers), and most professionals working on large civil engineering projects are familiar with their guidelines and "books". Figure 19, from FIDIC's web-site, provides a useful overview of the key elements that affect the selection of the preferred form of contract.

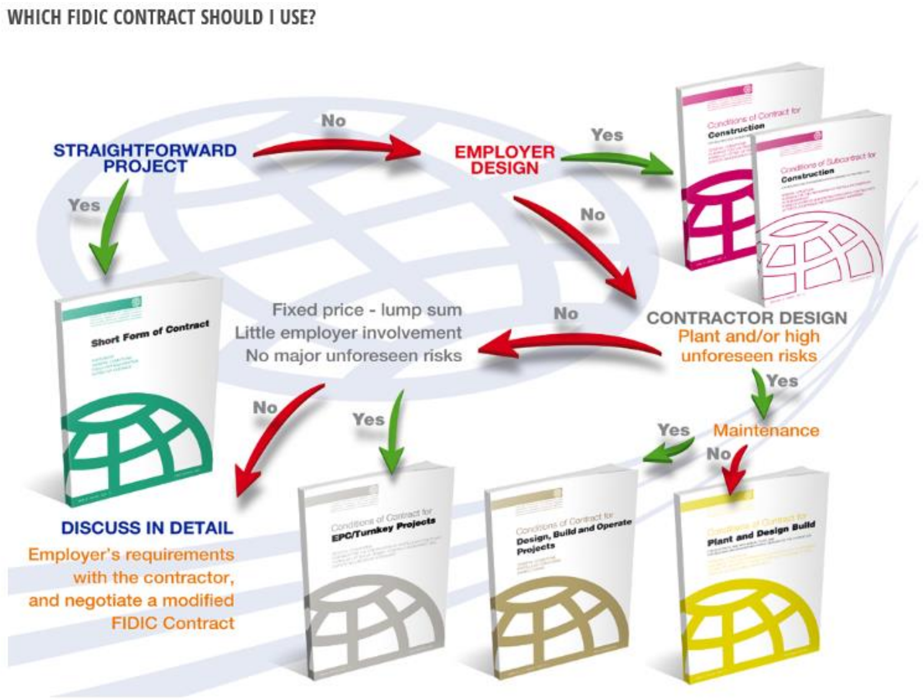

**Figure 19: From: www.fidic.org/**

| **FIDIC Guidelines** | **Application** |
|---|---|
| Green Book | straight forward, quick or cheap project |
| Red Book | employer design (traditional project) |
| Pink Book | employer design (Multilateral Development Banks providing finance) |

| | |
|---|---|
| Yellow Book | contractor design (traditional project) |
| Silver Book | EPC/Turnkey project |
| Gold Book | design, build, operate project |

The reader is advised to consult FIDIC for detailed information.

Good procurement management and implementation is also a cornerstone of good Governance, which is of key relevance to large infrastructure projects. According to many, the World Bank Group has the most comprehensive set of procurement guidelines (www.worldbank.org\procurement). The institution believes that increasing the efficiency, fairness, and transparency of the expenditure of public resources is critical to sustainable development and the reduction of poverty.

In terms of procurement, multipurpose water storage projects are not necessarily different from single purpose ones. However, one element that characterizes the former is the “financing gap”, which has been discussed in Section 4 (Economic and Financial Assessment of MPWS Projects).

*Financing instruments*

Several financial instruments, from private equity to concessionary finance, have been used for financing infrastructure projects; their choice is strongly dependent upon project structure and ownership (Head, 2005). There is a wide spectrum of financing instruments, ranging from publicly sourced grants and soft loans to financing on strictly commercial terms. With some generalization, it is possible to group these disparate sources of finance into six broad categories of financing instruments.

| Instrument | Source |
|---|---|
| Concessionary finance | Grants or soft loans (low interest or long tenor), usually from bilateral or multilateral aid agencies |
| Public equity | Public investment with the support of the government, often indirectly funded from bilateral and Multilateral Development Bank (MDB) sources. |
| Public debt | Project-specific loans from the government or from bilateral and multilateral development banks. |
| ECAs and Guarantees | Finance direct from the Export Credit Agencies (ECAs), or from private commercial banks using Guarantees from public MDBs. |

| | |
|---|---|
| Private “commercial” debt | Loans from private banks, and from the commercial arms of the public MDBs. Also occasionally bond issues. |
| Private equity | Direct investments made by private Sponsors and other private investors, and by the public MDBs. |

In general, the wider the gap between economic and financial viability in a project, the more that project will require concessionary and/ or public finance. A financially strong project can be fully sustained by private financing and in addition provide positive economic externalities.

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# 7.0 MPWS Problem Solving

## 7.1 The challenge of good solutions

Multipurpose water storage projects pose additional engineering challenges when compared to single purpose projects, and the typical task of planning professionals is to develop and implement solutions to these challenges. Given the longevity of the infrastructure of large storage projects, such solutions can prove either correct or incorrect if they are, or were not, conceived with adequate flexibility to adapt to changes or to the diverse needs of multipurpose schemes. At the time of decision to implement a scheme from concept to constructed reality, the solution developed needs to be good for the infrastructure, the environment and the society. The present chapter discusses elements to improve the chance of good solutions to these challenges.

Although sometimes they are of a mixed nature, engineering solutions are herewith presented separately as "structural" and "non-structural". The two types are often portrayed as competitive, with the former supported by engineers, and the latter by others. In the context of this bulletin this is considered an incorrect interpretation for two reasons:

a) good solutions inevitably involve an intelligent combination of both, and
b) several non-structural solutions require an important engineering input, for example flood forecast, early warning, emergency preparedness plans, etc.

## 7.2 Structural solutions

*Responding to changes over the life cycle*

Many see dams for water storage as immovable structures with a kind of "eternal" presence in the landscape. Others argue that all dams should be decommissioned at the end of their lifetime. As usual, the truth sits somewhere between these two extreme views. It is a fact that large dams have a life cycle, which exceeds that of most other civil engineering structures. As discussed in Chapter 5, during that life, which can be in the order of a century or more, many circumstances change and the asset, and its operational use, is called upon to meet such changes. Introducing structural modifications to adapt the project accordingly poses non-trivial problems, but such problems cannot be dodged and will be increasingly recurrent in the years to come.

Many case studies have provided examples of such necessity and shown engineering solutions adopted to meet changing demands. The following box summarizes relevant examples.

| **Case Study #** | **Country** | **Project** | **Structural solutions** |
|---|---|---|---|
| 3 | China | Danjiangkou Water Control Project | As the headwater of phase 1 – middle line- of the South to North water transfer project, Danjiangkou Reservoir was raised from 157 to 170m, with an increase in storage capacity of 11.6 billion cubic meters. Through optimized scheduling, the flood control capacity has been improved, annual water supply reached 12 billion m3, making it possible to mitigate water shortage of North China until year 2030. |
| 13 | China | Miyun Reservoir | Completed in 1960, Miyun has undergone several expansions and upgrading works to enhance its flood protection function. As such, it has become one of the key projects to ensure flood protection to Bei Jing. |
| 16 | China | Sanmenxia Dam | Construction of sediment flushing orifices through the concrete dam to extend the reservoir's service life. |
| 30 | Greece | N. Plastira | Inter catchment diversions to provide an additional 25 million cubic meters of water to mitigate droughts and shortages during summer months. The added inflows also allow meeting ecological requirements, recreation, and fish farming. |
| 44 | Pakistan | Mangla Dam | Dam raise to enhance electricity generation, flood and drought protection of Jhelum flood plain, extension of irrigated areas, increase of property value near the reservoir. |
| 47 | Russian Federation | Cheboksarskaya Dam and Hydro | Infrastructure upgrades to cope with increased navigation needs as well as environmental and social demands. |

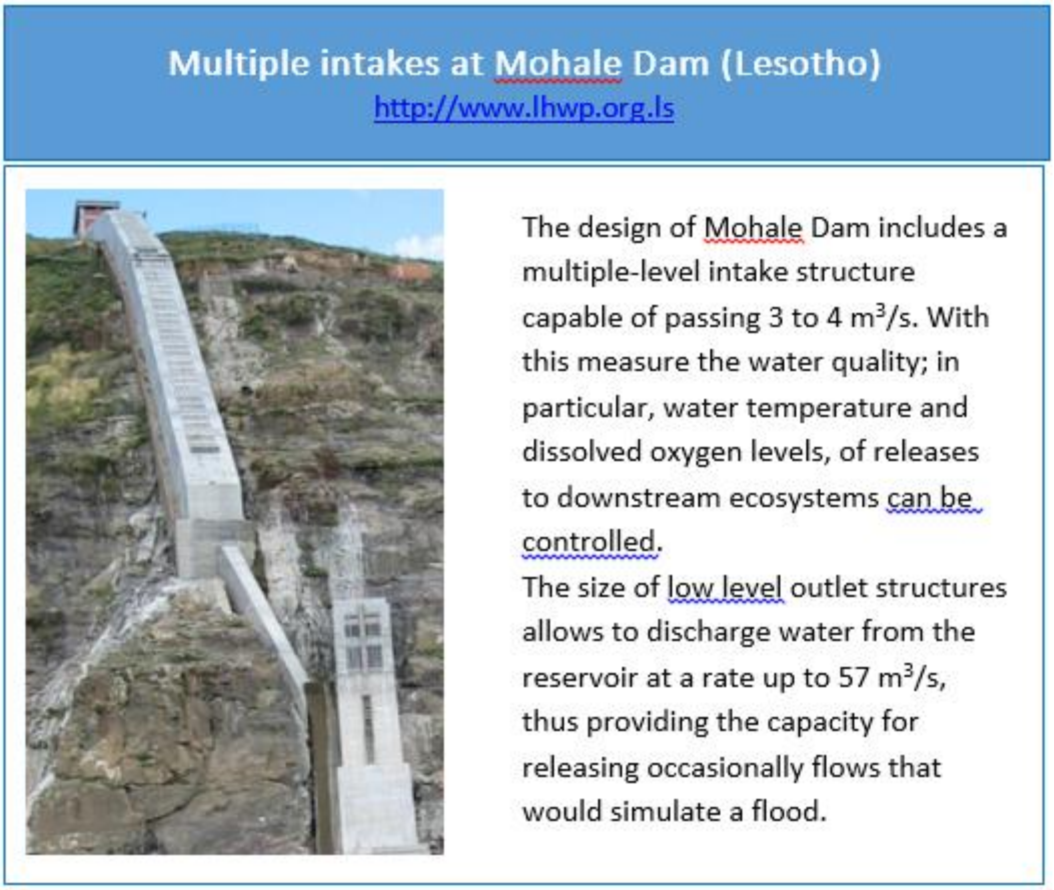
Two emerging trends, representing structural solutions, can be highlighted:

1. multiple intakes and draw-off facilities, and
2. managed river flows.

*Multiple Intakes and Draw-off Facilities*

Intakes at different reservoir elevations allow selective water withdrawal. That has obvious benefits in terms of water quality, and in terms of temperature and dissolved oxygen. It also introduces flexibility of use for water supply, irrigation, recreation etc., and provides opportunities for future reconsideration of uses. It also permits to prolong reservoir functions in the context of sedimentation management.

The following box illustrates multiple intakes for selective water withdrawals at Mohale Dam (Lesotho).



**Multiple intakes at Mohale Dam (Lesotho)**
http://www.lhwp.org.ls

The design of Mohale Dam includes a multiple-level intake structure capable of passing 3 to 4 m$^3$/s. With this measure the water quality; in particular, water temperature and dissolved oxygen levels, of releases to downstream ecosystems can be controlled.
The size of low level outlet structures allows to discharge water from the reservoir at a rate up to 57 m$^3$/s, thus providing the capacity for releasing occasionally flows that would simulate a flood.

*Managed River Flows*

In the last few decades, the subject of environmental flows released from dams to maintain river and ecological health has also received significant attention. Testimony to that is the large number of publications and congresses on the subject or the topic' subsets. Several professional organizations and interest groups have also formed on the theme. In the context of multipurpose reservoirs, which are created to modify natural water resource availability, it is misleading to use the term "environmental flows" as it can be interpreted as a practice intended to guarantee river flow regimes practically equal to natural ones. In the context of multipurpose reservoirs it is considered more appropriate to use the term "in stream releases "or better "managed river flows", i.e. "managing discharges from a multipurpose reservoir in such a way that the river ecosystem can adapt to the modified flow conditions, without unacceptable environmental degradations”. That should be regarded as an essential element for design and operation of a multipurpose project.

As an example, the Gibe III dam (Ethiopia) regulates the floods of the Omo River, with consequences for the downstream areas. In particular, on the Lake Turkana habitat and recession agriculture around its shores, which depend on flood pulses during the rainy season.

Adaptive management is a key component of a successful managed river flow program. The following box recommends the key steps for defining and implementing a managed river flow program. Not necessarily all steps may receive the same level of attention, but it is necessary to consider all of them at planning stage. (Refer also Tilmant et al, 2010).

## Managed River Flows – Key Steps

a) **Scoping**: Assess dry season flows on the tributaries and on the main stem of the river. This can be done by means of flow measurements, hydrological analysis, and anecdotal information; results are presented in the form of duration curves (discharge versus probability of occurrence) in correspondence with the section immediately downstream of the confluences of the tributaries in the main stem. This allows assessing the length of the river that will be significantly affected by the flow regime modifications associated with the project.

b) **Baseline surveys**: Ecological baseline surveys are carried out along the affected river stretch; surveys will look, among other aspects, into the following:
   i) human uses of river water;
   ii) key chemical and biological parameters;
   iii) micro and macro flora and fauna including fish and macroinvertebrates in water column, sediment and benthic deposits and associated wetlands, key foodwebs;
   iv) assessment of “reference reaches” to establish relatively pristine sites for comparison purposes.

c) **Critical areas**: Ecological surveys of critical areas permit assessing the minimum flow requirements to maintain an “ecological corridor” during the period of lowest flow conditions.

d) **Modifications to riverbed**: Surveys are also aimed at proposing methods for modification of the riverbed and shores in order to enhance the resilience of critical ecosystems; such modifications can take the form of sills, partial or full width weirs, plunge pools, dykes, etc.

e) **Stakeholder consultations**: consultation can be necessary on landscape aspects related to religious/ traditional values; information gathered could suggest special measures for limiting degradation of particularly important viewpoints.

f) **Monitoring plan**: a monitoring plan of key ecological indicators should be developed and linked to an adaptive management plan of in-stream releases from the project.

g) **Electricity generation**: Consideration should be given to the installation of a water turbine on the in-stream flow conduit so that managed river flows can also provide an energy output.

*Structural measures allowing adaptive management*

Dam design includes engineering solutions that allow management of different ecological functions, in an adaptive manner, both in the short and in the long term. Temporary and permanent discharge devices allow the release of:

- minimum vital flow in the driest periods, and
- flood pulses during the rainy season.

Regarding the latter function, the spillway can release artificial floods, up to 1600 m3/s peak value, which mimic natural floods during the wettest month of the year. Being the impounding expected to last some years, the middle level outlets are also sized to release the same discharge, so providing the same ecological function also during the reservoir-filling period.

Effective implementation of managed river flows requires structural measures. First of all discharge facilities must be designed and built to ensure adequate releases during river construction, reservoir filling, and operation. In addition to that, effective impact mitigation may suggest building of river bed structures (weirs, sills, dykes, etc.).

Based on experience and case study findings, the following table lists several structural measures to enhance sustainability of MPWS projects.

| **Project stage** | **Structural measures** |
|---|---|
| Planning process | • Dam type: easy to raise/ resistance to overtopping.<br>• Emergency off-stream diversion/ storage.<br>• Feeder canals from adjacent watersheds. |
| Design | • Spillway design: “Two-tier flood" concept: design flood, and safety check flood.<br>• Low-level outlets to permit in-stream releases during construction, reservoir filling, and operation of the project.<br>• Emergency spillway and/or fuse gates to face extremely high floods.<br>• Multi-level intakes for selective withdrawals<br>• Design structures to allow future reservoir rising, if and when necessary. |
| Construction | • Build river diversion waterways to allow future use in sedimentation management. |

| **Project stage** | **Structural measures** |
|---|---|
| Operation and maintenance | • Test gate operation regularly to ensure responsiveness in emergency conditions.<br>• Add controllable gates to free spillways.<br>• Increase reservoir freeboard during flood seasons.<br>• Change number or type of turbines to increase installed capacity. |
| Re-engineering | • Retrofit dams to provide more resistance to overtopping; particularly in case of small dams in typhoon/ monsoon areas.<br>• Increase spillway capacity. |

## 7.3 Non-structural solutions

### 7.3.1 Virtual Water

Virtual water is a term that links water, food, and trade (Allan, 2003). Virtual water is the water needed to produce agricultural commodities[10]. For example it requires about 1,000 cubic meters of water to produce a ton of grain. If the ton of grain is conveyed to a political economy short of freshwater and/or soil water, then that economy is spared the economic, and more importantly, the political stress of mobilizing about 1,000 cubic meters of water. Hoekstra and Hung (2002) suggest that in 1999 Israel exported 0.7 cubic kilometers of virtual water and imported 6.9 cubic kilometers. For Egypt, they calculated the net virtual water import to be 15.3 cubic kilometers. Trading virtual water, among politically willing partners, can ease the pressure of developing some water storage, or at least delay such action. At the same time, the most appropriate course of actions generally consists in using both non-structural and structural measures, with a political and economically sensible planning sequence.

### 7.3.2 Water Markets

Water markets provide the enabling environment for the process of buying and selling water access entitlements, also often called water rights. The terms of the trade can be either permanent or temporary, depending on the legal status of the water rights. In the long run the creation of water markets may permit more flexibility in water allocations, allowing limited

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[10] The concept can be expanded to include the water needed to produce non-agricultural commodities.

water supplies to move to the highest value uses. For example, high water intensive-low revenue irrigation may trade its water allocations with water demanding-high revenue industrial entities.

Not only are semi-arid and arid areas subject to physical scarcity, but also financial scarcity is introduced when construction and maintenance of more water infrastructures is pursued.

It has been argued for a long time that water markets provide a possible instrument to contribute to more efficient water resources allocation and use. The principal argument is that markets provide economic incentives for water users, inducing the use and allocation of water according to its real value and its conservation. A further argument is made that markets are more flexible than administrative allocation mechanisms, which have been the rule in most countries in the past. Also, when users themselves can decide if they want to buy or sell, those who sell their water do so voluntarily and get a financial compensation. This is often not the case when water is reallocated or expropriated by a central authority. Thus market mechanism can be used to reduce conflict (Marino and Kemper, 1999).

Several developed and developing countries have been promoting water markets, among them as examples are: Australia, Brazil, Chile, Mexico, Peru, Spain, and the USA.

### 7.3.3 Flood management

ICOLD Bulletin 156-2014 “Integrated Flood Risk Management” lists a number of non-structural approaches to flood management of which the most important are:

- Control of floodplain development,
- Flood proofing,
- Land use management,
- Flood insurance,
- Flood forecasting and warning,
- Flood emergency response planning,
- Evacuation and emergency assistance and relief.

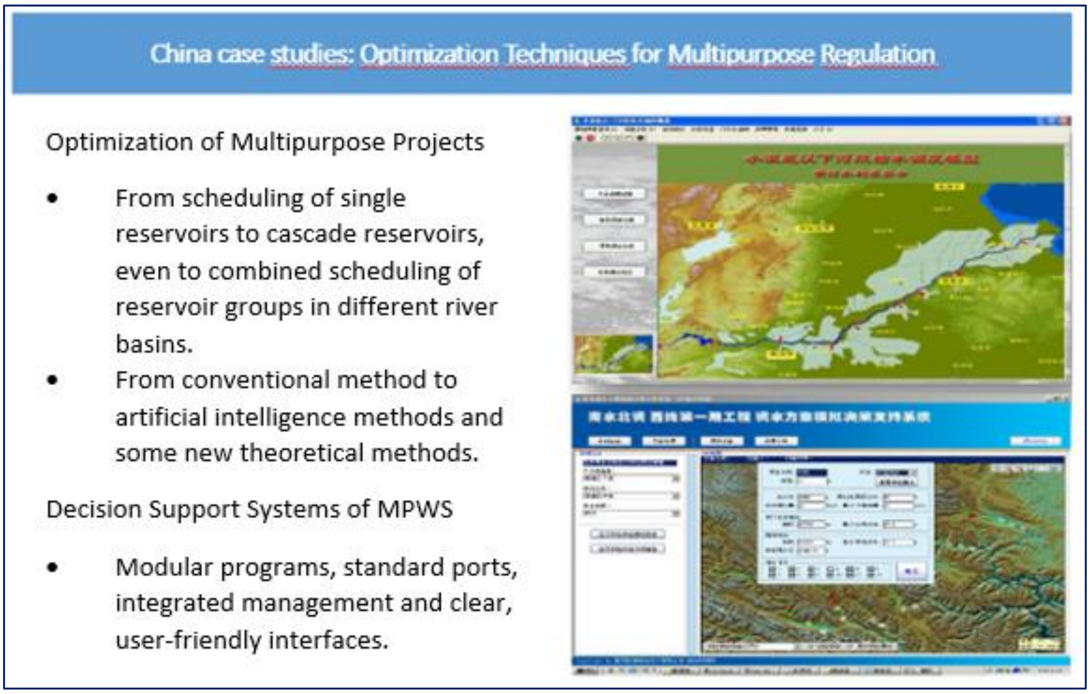
Experience indicates that the best results are obtained by integrating structural and non-structural measures, with a design that takes the specifics of the case under consideration.

### 7.3.4 Predictive Uncertainty in Decision Support Systems

*Decision support systems*

Optimal reservoir operation has been extensively reported in the literature since the early 1980’s and techniques have evolved over the years making it possible to apply implicit stochastic optimization techniques to multipurpose multi-reservoir systems (mostly based on extensions of the well-known stochastic dynamic programming technique).

Progress in software and remote sensing technology have allowed development of sophisticated Decision Support Systems (DSS) to optimize water resource management for multiple purposes. DSS represent a key non-structural solution for planning and management of multipurpose water storage projects. Case studies from China revealed remarkable advance in DSS development, as highlighted in the following box.



China case studies: Optimization Techniques for Multipurpose Regulation

Optimization of Multipurpose Projects

- From scheduling of single reservoirs to cascade reservoirs, even to combined scheduling of reservoir groups in different river basins.
- From conventional method to artificial intelligence methods and some new theoretical methods.

Decision Support Systems of MPWS

- Modular programs, standard ports, integrated management and clear, user-friendly interfaces.

It is wrong to assume that operating rules should be defined at the end of the planning process or even by the end of construction, as observed in some development cases. Conversely, consideration of operational planning during the early planning of the project is very useful for optimizing the size as well as for setting certain design features of the infrastructure.

Detailed examination of and guidance on DSS is the scope of a separate ICOLD Committee (Technical Committee on “Integrated Operation of Hydropower Stations & Reservoirs). This bulletin deems it appropriate to reflect on the role of Predictive Uncertainty (PU) in assisting good decision-making and, in particular, in solving conflicts among different storage purposes (Todini, 2008).

### *Conflicting operational demands and uncertainty*

Flood control typically conflicts with other reservoir purposes (electricity, irrigation, water supply, etc.), in that flood management requires preventive reduction of water levels and reservoir storage to accommodate forecast (uncertain) incoming flood volumes. The appropriate quantity to release is a function of the decision maker's risk aversion. It has to be decided upon by trading off the expected flood damage cost, with the loss due to the released volume, which will not be available to meet planned objectives (irrigation, electricity, domestic supply, etc.). Flood damage cost decreases with increasing storage made available to accommodating flood volumes, while the latter cost (forgone production) increases with the released volume. There is obviously a considerable level of uncertainty in the decision making process; such uncertainty cannot be eliminated, therefore it must be managed.

### *Predictive Uncertainty*

Although well known in statistics and decision theory, it is only in the last two decades that the concept of Predictive Uncertainty (PU) has emerged in hydrology and water resource management, together with the appropriate techniques allowing assessing and incorporating the uncertainty information into the decision making process.

PU can be defined as the uncertainty that remains on the future realization of a physical parameter, or status of a system, after using all available information, which is usually, but not necessarily, embedded in one or more mathematical models. Realizing the role of uncertainty in the decision making process is of fundamental importance because the quantity needed for appropriately taking decisions is the expected damage cost, not the cost computed in the expected "most likely scenario".

Traditionally, planning decisions are taken on the basis of scenarios assumed for the future as subjective hypotheses or as the result of some modelling exercise. For instance, climate change effects have been estimated using a series of General Circulation Models and, although their reliability is known to be quite low, adaptation measures are planned today taking one or the other of the anticipated scenarios. A model forecast cannot be considered "reality", but rather "virtual reality" and, as such, should never be directly compared to real quantities such as thresholds, which are set on the basis of measured (real) parameters.

The following box provides an example of PU use for establishing a Decision Support System (DSS) for Lake Como water management.

### DSS for Lake Como (Italy)

Todini, E. (1999) “Using phase-space modelling for inferring forecasting uncertainty in non-linear stochastic decision schemes” Journal of Hydroinformatics. 01.2.75-82.

Lake Como is a natural water body with a multi-gate weir controlling its outlet. Lake outflows are mainly used for irrigation and hydro-electricity generation; protection against floods has become an increasingly important additional purpose. The effective control volume of the reservoir, 246 million m3, is only 1/20 of the mean annual inflow volume; combined with the small discharge capacity of the control gates, that makes management  a challenging exercise. Operating rules to meet long term objectives (irrigation and hydro) were established on a 10-day basis using a Stochastic Dynamic Programming algorithm. The shorter term rule, i.e. flood crest subsidence, was derived conditionally to daily inflow forecasts with the objective of minimizing total expected losses. DSS simulation over a 15-year period, compared to recorded data showed the following improvements on all albeit conflicting management objectives:

- 30% frequency reduction of Como city floodings,
- 12% average reduction of irrigation deficit,
- 3% increase of electricity generation.

The DSS was installed in 1997. An evaluation of Lake Como management during the drought years 2000-2006 provided a very satisfactory outcome by fully matching the DSS anticipated results.

*Steps for making decisions under uncertainty*

In making decisions under uncertainty, a basic need of all decision support systems, one has to bear in mind the following steps.

| **Step** | **Action** |
|---|---|
| Describe the uncertainty | By assessing PU in terms of a probability density function conditional upon all the available information. |
| Define a utility function | Utility functions may range from a simple description of decision maker’s propensity towards risk, to complex loss/ benefit functions involving actual costs. |
| Marginalize the effect of uncertainty | Compute the expected value of the utility function by integrating the product of probability (of occurrence) times the utility function. |

| | |
|---|---|
| Use results | Use the expected value of cost/ benefit to inform decision making by means of trade-off analysis or by optimization. |
| Risk allocation | Decide on the party best able to bear/mitigate/manage the risk |

From a developer or a Government's point of view, in the early structuring of a project, a decision on the allocation of risk to different agents within the process should only be taken after the actions listed in the table.

It is fundamental to understand that removing uncertainty by directly using a forecast, or our own expectation, does not solve the problem. In fact, by doing so, one inevitably assumes, implicitly or otherwise, to deterministically know what will happen. Since this is not true most of the times, the final decision is bound to be poor and very often wrong.

### 7.3.5 Water conservation

*Site selection to reduce evaporation from reservoirs*

Evaporation from the reservoir surface is the most important element that reduces water storage efficiency. That is not a problem for narrow and deep reservoirs located in cold climates, but is very much a problem for large and shallow reservoirs located in hot, arid areas.

Large river basins (Nile, Niger, Amu Darya, Syr Darya, Benoue, to name a few) feature several reservoir sites, existing or potential, which can be optimized in terms of evaporation management. That represents a large potential for conserving water, however the feasibility of such optimization often faces trans- boundary issues, which are very complex and lengthy to solve. Harmonization of policies and regulations, joint planning and operation of reservoirs are typical measures that technical staff have to agree upon. Such measures have then to be vetted at political level.

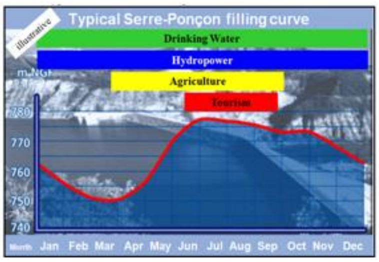
*Non-structural solutions contributing to water conservation*

Technical solutions of a non-structural nature, which can play an important role in optimizing the use of existing storage and planning new one, are also being used in irrigation.

Food production and associated irrigated agriculture is the largest consumer of water. Storage space for that purpose has therefore to be assessed carefully in a MPWS scheme and all possible savings introduced to optimize the use of scarce natural and financial resources. After calculating monthly water stress indices for over 11,000 watersheds with global coverage, Pfister and Baumann (2012) showed that the crop growing period has a considerable influence and shifting crop planting dates (or crops with different calendars) can help to relieve water stress. Furthermore, in some regions the temporal dimension is crucial, especially in cases with high variability of water use and availability.

Water saving programs are also adopted by Electricitè de France (EDF) in one multipurpose asset under their management.

### FRANCE: DURANCE-VERDON RIVER MULTIPURPOSE SYSTEM



The Serre-Ponçon reservoir, commissioned in 1966, is the main infrastructure of the multipurpose Durance and Verdon River system. With 32 hydropower plants, the system enables generation of 6.5 TWh of renewable electricity and an output of 2000 MW within 10 minutes, it supplies drinking water and water for industrial purposes to an entire region, as well as irrigation of over 150,000 ha of farmland with a guaranteed storage of 200 million m3 in summer.

EDF is required to deliver 200 million m3 for irrigation between 1st July and 31st September, and an information bulletin is sent each week to farmers about irrigation flows. EDF encourages farmers to save water by financing modern systems for water use reduction. Through a specific agreement (Water Saving Convention signed in 2000), which causes EDF to payback part of the savings if the targeted objectives are reached, the agricultural consumption for one partner decreased from 310 million m3 in 1997 to 201 million m3 in 2005. EDF, in association with the Water Agency, also co-financed a number of environmental initiatives e.g. reforestation of catchment area.

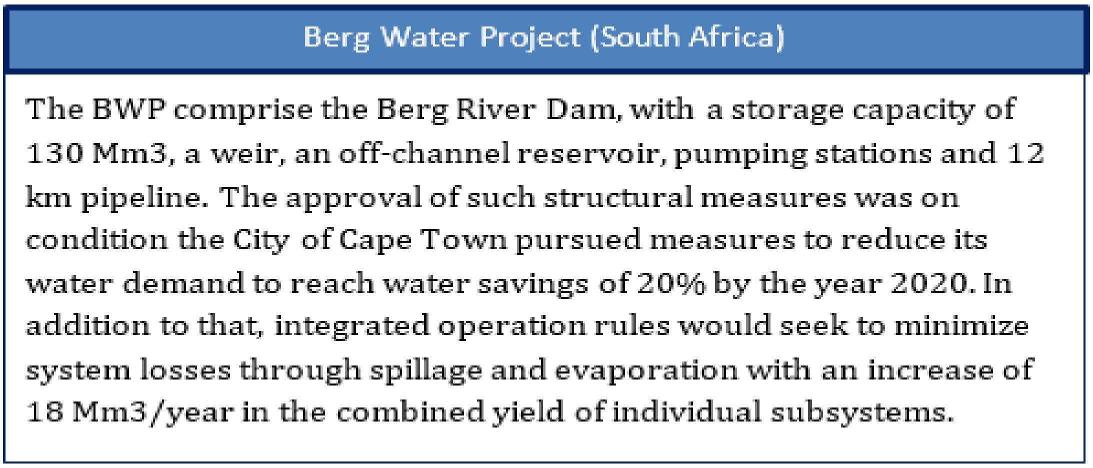
Based on experience and case study findings, the following table lists several non-structural measures to enhance sustainability of MPWS projects.

| **Project stage** | **Non-Structural measures** |
|---|---|
| Planning process | • Catchment gauging, water inflow and sediment yield, involving communities as appropriate.<br>• Restrictions on use of area at risk of flooding; flood insurance. |

| Project stage | Non-Structural measures |
|---|---|
| | - Modification to the price of energy and/or water to affect the extraction of water for irrigation, industrial, and other consumptive activities. |
| Design | - Risk assessment: identify risk, quantify consequences, ranking. |
| Construction | - Potential Failure Mode Analysis: conduct PFMA to assess impact of findings/ design adaptations on long-term safety. |
| Operation | - Hydrological monitoring of rainfall, temperature, snow pack.<br>- Update reservoir operation rules.<br>- Promote synergy with alternative sources of electricity.<br>- Emergency preparedness: emergency identification, classification, warning, response.<br>- Training dam operators/ population at risk.<br>- Decision support systems linked to flood forecast.<br>- Early warning. |
| Re-engineering | - Adaptation fund: initial estimate at commissioning, annual replenishments, periodic re-evaluation. |

*Blending of structural and non-structural measures*

The Berg Water Project, in South Africa, is an example of efficient blending of structural measures with non-structural ones to face urgent water shortages in the City of Cape Town.



**Berg Water Project (South Africa)**

The BWP comprise the Berg River Dam, with a storage capacity of 130 Mm3, a weir, an off-channel reservoir, pumping stations and 12 km pipeline. The approval of such structural measures was on condition the City of Cape Town pursued measures to reduce its water demand to reach water savings of 20% by the year 2020. In addition to that, integrated operation rules would seek to minimize system losses through spillage and evaporation with an increase of 18 Mm3/year in the combined yield of individual subsystems.

## 7.4 Adaptive Management

*Definition*

Adaptive Management (AM) is a structured, iterative process of robust decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring. In this way, decision making simultaneously meets one or more management objectives and, either passively or actively, accrues information needed to improve future management.

### *System learning through adaptive management*

AM is a tool, which should be used not only to change a system, but also to learn about the system (Holling, 1978). Because adaptive management is based on a learning process, it improves long-run management outcomes. The challenge in using the AM approach lies in finding the correct balance between gaining knowledge to improve management in the future and achieving the best short-term outcome based on current knowledge (Allan and Stankey, 2009).

### *Planning and management change utilizing active adaptive management*

Active adaptive management appears as the method of choice in the presence of:

a) uncertainty,
b) complexity,
c) changing conditions,
d) early action requirement,
e) diverse stakeholder interests,
f) public participation.

All the above points firmly pertain to planning and management of water resources and to multipurpose storage projects in particular. AM therefore closely relates to, and is informed by, the concepts discussed in the previous sections on "Hydrological Resilience" and "Predictive Uncertainty". Planning and management of water resources with certain pre-determined assurance of supply criteria, using the draft-yield reliability curves that characterize a particular water resource system, provides for easy adjustment of uses and user requirements "as economies develop, as circumstances change and as societal values evolve". Reference levels of supply reliability allow for risk assessment in anticipation of major changes in demands. On the supply side, revision of the water resource system characteristics are going to be required when system configuration is changed and/ or effects of global warming may manifest.

Use of probabilistic approaches to planning and management of water resources have been successfully applied in South Africa (Basson and Van Rooyen, 2001), a water scarce country, since the 1980's. Acceptance today is not only due to the sound theory underpinning the methodology and the success achieved with respect to improved resource utility, but also because of efforts to communicate findings to decision makers and interested and affected parties.

*USBR Guidance on AM – a form of structured decision making*

The U.S. Department of the Interior has developed practical guidance on AM (Williams and Brown, 2012). The guide uses case studies to show how adaptive management can be used for both management and learning. Adaptive management is presented as a form of structured decision making, with an emphasis on the value of reducing uncertainty over time in order to improve management.

At the heart of adaptive decision making is the recognition of alternative hypotheses about resource dynamics, and the assessment of these hypotheses with monitoring data. Recognizing such framework, the guide identifies the following elements in the set-up phase of AM:

- stakeholder involvement,
- statement of objectives,
- management alternatives,
- predictive models, and
- monitoring protocols.

The iterative phase of AM consists of the following recurrent steps:

- decision making (at each point in time that reflect the current level of understanding and anticipate the future consequences of decisions),
- follow-up monitoring,
- assessment,
- learning and feedback, and
- institutional learning.

## 7.5 References

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# 8.0 Essential Elements and Emerging Trends

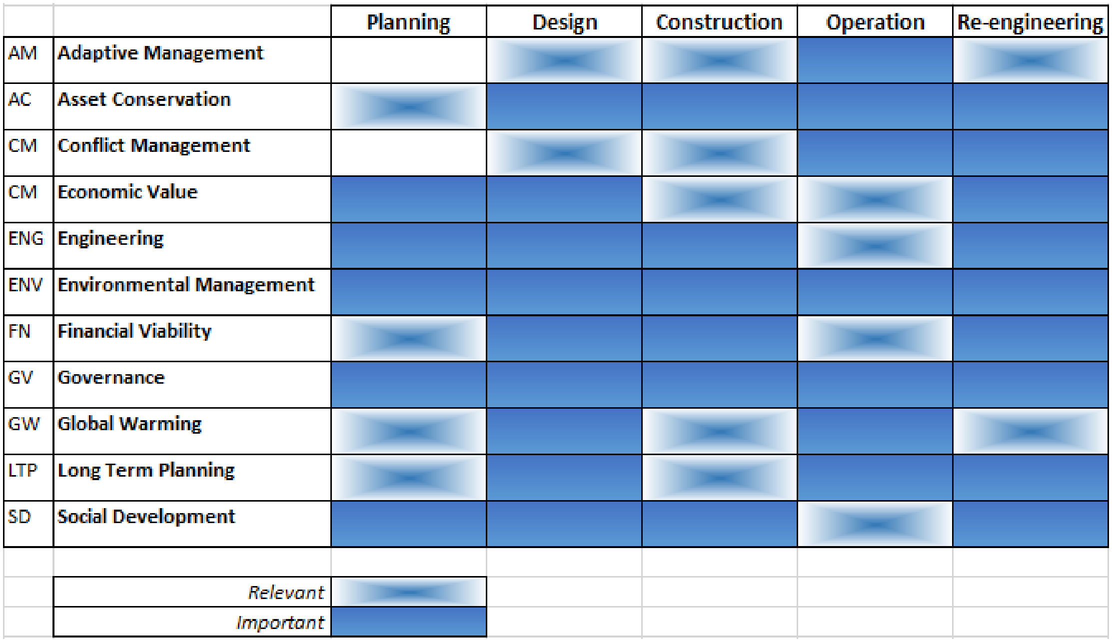
## 8.1 Essential Elements

Case study analysis, review of relevant literature, and experience of the professionals who contributed to the Bulletin have identified 11 essential elements pertaining to planning and management of multipurpose water storage projects. The elements are listed in the following table, along with a brief description of the respective scope/ latitude.

| **Essential Element** | **Scope/ Latitude** |
|---|---|
| Adaptive Management (AM) | Changes in reservoir operation and/ or implementation of structural modifications based on system monitoring. |
| Asset Conservation (AC) | Reservoir conservation by sediment management. Asset management approach. |
| Conflict Management (CM) | Operationalize and update Decision Support Systems to optimize reservoir operation in the face of multiple uses (e.g. flood management and water yield). |
| Economic Value (EC) | Project's impact on society, including externalities. Effective use of country's resources for the country's development. Usual indicators are net present value, benefit-cost ratio, internal rate of return, etc. |
| Engineering (ENG) | Safe and reliable design of project structures, plant and equipment. Rapid response to unanticipated conditions requiring structural modifications. |
| Environment Management (ENV) | Management of externalities. Equator Principles. Stakeholder Engagement in option assessment. Strategic Environmental Assessment. Environment management plan. |
| Financial Viability (FN) | Costs and benefits that accrue to the project entity, developer and investors. Risk perception. |
| Governance (GV) | Stakeholder engagement, institutional aspects, procurement. |
| Global Warming (GW) | Adaptation to potential effects on water resources availability, and extreme hydrological events. |
| Long Term Planning (LTP) | Assess scale, site selection and operational characteristics in view the long life-time of MPWS projects. Scenario Building. Financial plan for funding asset re-engineering/ replacement/ retirement. |

| **Essential Element** | **Scope/ Latitude** |
|---|---|
| Social Development (SD) | Promote local development giving priority to directly affected stakeholders (e.g. resettlement). Benefit sharing. |

The following table suggests the level of criticality of the essential elements in the context of the development and operational cycle of MPWS projects. The classification is generic and should always be revised and adapted to the specific case at hand.



| | | Planning | Design | Construction | Operation | Re-engineering |
|---|---|---|---|---|---|---|
| AM | Adaptive Management | | ▨ | ▨ | ■ | ▨ |
| AC | Asset Conservation | ▨ | ■ | ■ | ■ | ■ |
| CM | Conflict Management | | ▨ | ▨ | ■ | ■ |
| CM | Economic Value | ■ | ■ | ▨ | ▨ | ■ |
| ENG | Engineering | ■ | ■ | ■ | ▨ | ■ |
| ENV | Environmental Management | ■ | ■ | ■ | ■ | ■ |
| FN | Financial Viability | ▨ | ■ | ■ | ▨ | ■ |
| GV | Governance | ■ | ■ | ■ | ■ | ■ |
| GW | Global Warming | ▨ | ■ | ▨ | ■ | ▨ |
| LTP | Long Term Planning | ▨ | ■ | ▨ | ■ | ■ |
| SD | Social Development | ■ | ■ | ■ | ▨ | ■ |

| | |
|---|---|
| *Relevant* | ▨ |
| *Important* | ■ |

**Figure 20**

The essential elements are presented here in alphabetical order as it would be improper to recommend any kind of hierarchy among them, in addition to the generic level of criticality shown in the above plate. Project analysts and decision makers need to have a project-specific approach, which looks into the interrelationships among the essential elements in their specific case. A useful tool for that task is Cross Impact Analysis.

## 8.2 Cross Impact Analysis

*Definition*

Cross-impact analysis (CIA) is a methodology developed in 1966 to help determine how relationships between events would affect resulting events and reduce uncertainty in the future. It is used to forecast developments in different sectors, with more or less sophisticated techniques.

*Application to understand relationship between "Essential elements"*

Application of CIA to study mutual influence of the “essential elements” identified in the previous section may have a value for the present study. Such expectation is based on the observation that the importance of a variable in a system cannot be determined from the variable itself, but only through its relationship with the other variables. Cross impact analysis is a tool that uses a matrix, which provides a simple means to estimate this relationship among variables on a step-by-step basis. Using this tool to analyze the influence of “essential elements” is considered important.

### *Estimating Intensity of Impact and Classifying Variables*

The effect of each variable on all the others is estimated by allocating to each relationship an intensity of the impact with a value between 0 and 3. The range is from 0 (no impact) to 3 (for strong impact). The question is: *if variable A is changed, to what degree is variable B affected (regardless of whether the change is positive or negative)?*

By building the sum of rows (“active sum”) and the sum of columns (“reactive sum”), the variable can be classified as critical/ inert (for their degree of participation in the vents) and active/ reactive (degree of dominance). Results can be plotted in a graph for visual presentation. Based on their position in the graph, the representative points allow classifying the variables as follow:

- Active variables, which affect all the others strongly, but are not changed by them; active variables provide good leverage for change in a system.
- Reactive variables, which leave low impact on others, but are themselves highly affected by changes of the other variables.
- Critical variables, which have strong impact on other and are themselves strongly affected.
- Inert or buffering variables, which neither have an impact on others nor are they themselves strongly affected; these are stabilizing forces in the system.

Of greatest interest to the decision makers are those variables which are active; programs of action focused on these active variables have the greatest chance of success.

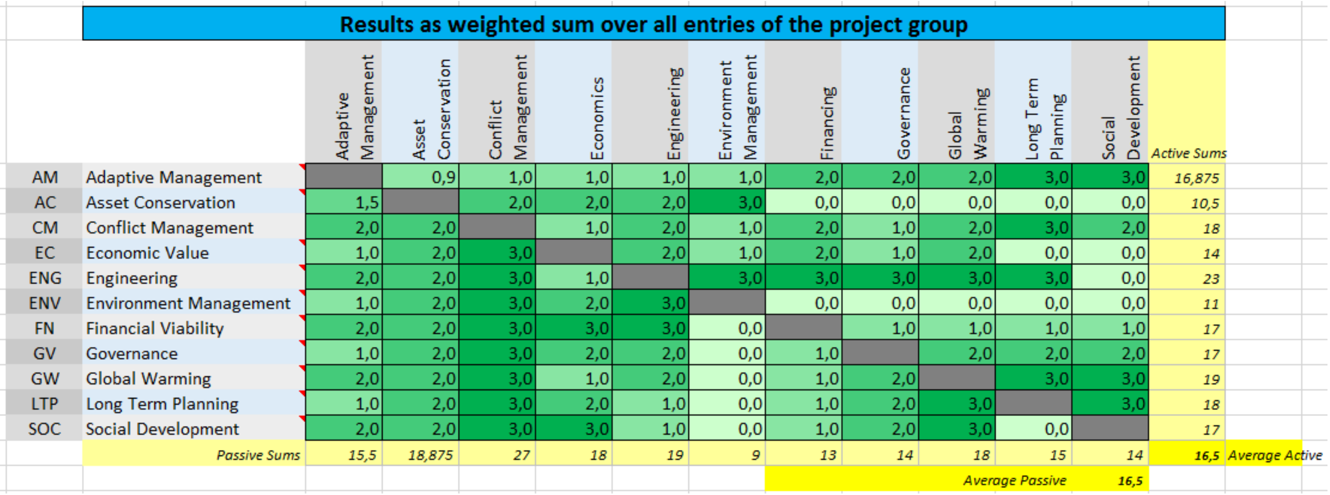
### *Workshop Example and Conclusions*

A CIA workshop was held in Stavanger, during ICOLD’s Congress on June 14, 2015, to:

- Make use of the audience experiences and views to prepare a guide on CIA to be included in this Bulletin;

- Prepare recommendations on how to apply CIA in the context of specific projects.

During the workshop, participants reviewed each essential element with the intent of clarifying its scope/ latitude. An elicitation process, with the participation of all attendees, analyzed several CIA cases. The following plate shows the output of one CIA case.



**Results as weighted sum over all entries of the project group**

| | | Adaptive Management | Asset Conservation | Conflict Management | Economics | Engineering | Environment Management | Financing | Governance | Global Warming | Long Term Planning | Social Development | *Active Sums* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AM | Adaptive Management | | 0,9 | 1,0 | 1,0 | 1,0 | 1,0 | 2,0 | 2,0 | 2,0 | 3,0 | 3,0 | *16,875* | |
| AC | Asset Conservation | 1,5 | | 2,0 | 2,0 | 2,0 | 3,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | *10,5* | |
| CM | Conflict Management | 2,0 | 2,0 | | 1,0 | 2,0 | 1,0 | 2,0 | 1,0 | 2,0 | 3,0 | 2,0 | *18* | |
| EC | Economic Value | 1,0 | 2,0 | 3,0 | | 2,0 | 1,0 | 2,0 | 1,0 | 2,0 | 0,0 | 0,0 | *14* | |
| ENG | Engineering | 2,0 | 2,0 | 3,0 | 1,0 | | 3,0 | 3,0 | 3,0 | 3,0 | 3,0 | 0,0 | *23* | |
| ENV | Environment Management | 1,0 | 2,0 | 3,0 | 2,0 | 3,0 | | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | *11* | |
| FN | Financial Viability | 2,0 | 2,0 | 3,0 | 3,0 | 3,0 | 0,0 | | 1,0 | 1,0 | 1,0 | 1,0 | *17* | |
| GV | Governance | 1,0 | 2,0 | 3,0 | 2,0 | 2,0 | 0,0 | 1,0 | | 2,0 | 2,0 | 2,0 | *17* | |
| GW | Global Warming | 2,0 | 2,0 | 3,0 | 1,0 | 2,0 | 0,0 | 1,0 | 2,0 | | 3,0 | 3,0 | *19* | |
| LTP | Long Term Planning | 1,0 | 2,0 | 3,0 | 2,0 | 1,0 | 0,0 | 1,0 | 2,0 | 3,0 | | 3,0 | *18* | |
| SOC | Social Development | 2,0 | 2,0 | 3,0 | 3,0 | 1,0 | 0,0 | 1,0 | 2,0 | 3,0 | 0,0 | | *17* | |
| | *Passive Sums* | *15,5* | *18,875* | *27* | *18* | *19* | *9* | *13* | *14* | *18* | *15* | *14* | ***16,5*** | *Average Active* |
| | | | | | | | | | | | *Average Passive* | ***16,5*** | | |

**Figure 21**

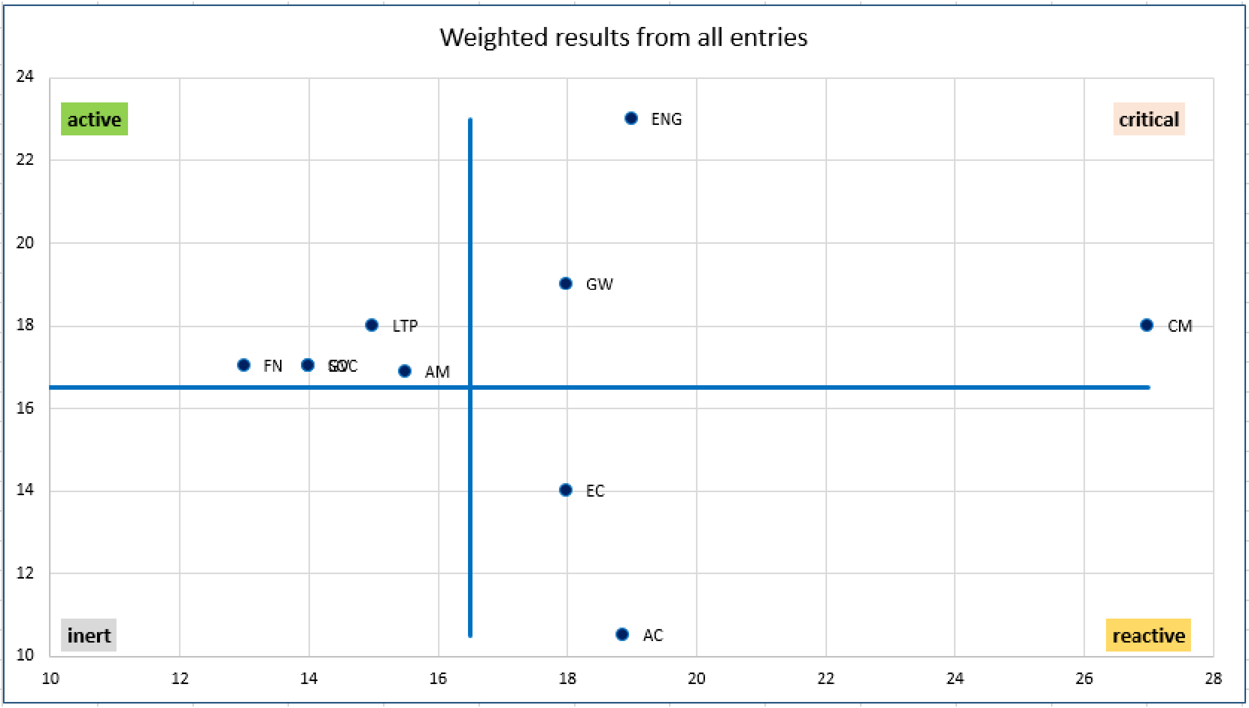


**Figure 22**

The example above identified:

- Critical Variables: Engineering, Global Warming, and Conflict Management;
- Reactive Variables: Economic Value and Asset Conservation;
- Active Variables: Adaptive Management, Environmental Management, Financial Viability, Governance, Long Term Planning, Social Development.

It would be tempting, but misleading to suggest generalization of the results. In fact, discussion of the results permitted to draw the following conclusions:

i. Outcome varies significantly by context of project, i.e. CIA application is case specific and no general conclusions on the mutual influence of the essential elements can be drawn.
ii. Outcomes are also time-specific, i.e. they change over life of project.
iii. It is desirable to get examples of application from different countries and projects.
iv. CIA tool could add a further stage of analysis to the IHA Sustainability Protocol (see section 3.5 “Project Sustainability”).

Participants had the following perspectives on potential use of the CIA tool.

a. Governance guidance for a project(s) through identification of critical variables.
b. Tool for analyzing differing perspectives of ‘critical element’.
c. Assist in prioritizing financial expenditure with a focus on critical variables.
d. Multiple ‘project’ or ‘options’ can be compared based on critical variable analysis.
e. Could be useful for debate between different discipline experts to foster interaction. Basic disciplines should cover essential elements = environmental, economist, engineer, hydrologist, social scientist, governance.
f. Education tool to understand perspectives of others.
g. New perspectives for engineers focused on design - broaden thinking - actions and effects.
h. Comparing alternatives, beginning of a tradeoff analysis.
i. Project delivery focus - to give direction for Project Management.
j. Multi stakeholder interacting including cross border - forum tool for engagement and perspective sharing.
k. Early planning tool - use to readjust perspectives on multipurpose.
l. Can be down scaled to focus on influence of one or two key elements.
m. Multi-disciplinary cooperation tool.

In conclusion, application of CIA is recommended during project planning and to revisit project functions during the life of the project. Given CIA’s potential in giving insights into future trends, the tool can be of assistance in MPWS management. At the same time, it is always important to balance between getting greater detail by breaking down the categories of variable vs not over-complicating the analysis.

## 8.3 Emerging Trends

Most of the essential elements identified in the previous section are well-established concepts in water infrastructure planning and management. Three of such elements qualify as emerging trends; they are:

- Long Term Planning,
- Adaptive Resource Management, and
- Asset Conservation (notably sedimentation management).

In addition to those, this Bulletin has identified practices that show a positive or progressive way of doing business. Such practices represent additional emerging trends that planners and managers should take into account in the context of MPWS projects.

The following table lists the identified MPWS emerging trends.

| **Emerging Trend** | **Descriptive** |
|---|---|
| Long Term Planning | Assess scale, site selection and operational characteristics in view the long life-time of MPWS projects. Scenario Building. Financial plan for funding asset re-engineering/ replacement/ retirement. |
| Water Supply Reliability | Securing adequate supply reliability to domestic/ industrial users, and some, strategically selected irrigation demands is expected to be the trend in the near future. Technologies such as desalination and reuse will play an important role, nonetheless matters of scale and relative multipurpose capability (e.g. flood management) will forcefully require storage. As society demands evolve, together with their welfare, water storage becomes more and more strategic for its capacity to adapt to society's needs. |
| New storage in developed countries | There will be a time, in a country's development pattern, when structural measures will be mainly of rehabilitation and conservation nature, and construction of new water infrastructure will naturally diminish. This is what we have observed so far, for example, in Europe, North America, and Australia. What we have started to observe, but that has not yet attained general attention, are cases in which supply- side options, for too much time neglected, require urgent investment in new water infrastructure. |

| Emerging Trend | Descriptive |
|---|---|
| Transformational projects in developing countries | Creating employment and regional incomes were the motivation behind large-scale infrastructure projects in the United States, Europe and other countries, with the expectation that investments would “change the trajectory of regional economies”. The new millennium is witnessing the same process taking up in developing countries, which are making huge national efforts to implement “transformational projects”, i.e. projects conceived to induce major changes in regional/ national economies. |
| Adaptive Management | Changes in reservoir operation and/ or implementation of structural modifications based on system monitoring. |
| Predictive Uncertainty | Although well known in statistics and decision theory, it is only in the last two decades that the concept of Predictive Uncertainty (PU) has emerged in hydrology and water resource management. |
| River ecology | Two emerging trends, representing structural solutions, can be highlighted:<br>• multiple intakes and draw-off facilities, and<br>• managed river flows. |
| Asset Conservation | Whereas the last century was concerned with reservoir development, the 21st century will need to focus on sediment management; the objective will be to convert today’s inventory of non-sustainable reservoirs into sustainable infrastructures for future generations.<br>The scientific community at large should work to create solutions for conserving existing water storage facilities in order to enable their functions to be delivered for as long as possible, possibly in perpetuity. |
| Synergy among renewables | The extensive development of intermittent “non programmable” renewable energy is increasing the need for back-up plants, i.e. direct hydro or pumped storage plants. It is easy to forecast a rapid spread of the tendency at international level, with energy storage assuming increasing relevance in the hydropower sector. Planning of future multipurpose reservoirs should consider such trend. |

It is recommended that the essential elements identified in section 8.2 be always taken in due account in planning and management of multipurpose water storage projects.

Consideration of the hereby-identified emerging trends should:

- Be used for benchmarking purpose with reference to evolving international practice, and
- Always be done in the context of the specific case, being that a policy, a program, or a project in which multipurpose storage features as a prominent component.

# Annex: Summary of Case Studies

This Bulletin benefited a lot from the wealth of information provided by the 52 case studies that the MPWS Team collected, analyzed, and synthetized. Those case studies are the backbone of the information and many of the messages contained in this report.

Group 1 dealt with case studies from China. Group 2 did the same for international case studies.

Volume II of the MPWS Bulletin contains detailed data sheets. The present annex to the main report presents a synthesis of the main findings from each working group.

<table>
<tr><th colspan="3">CASE STUDIES</th></tr>
<tr><td colspan="3">Case Studies from **China** prepared by Group 1</td></tr>
<tr><td>***#***</td><td>***Country***</td><td>***Project***</td></tr>
<tr><td>1</td><td>China</td><td>Banqiao</td></tr>
<tr><td>2</td><td>China</td><td>Dahuofang</td></tr>
<tr><td>3</td><td>China</td><td>Dajiangkou</td></tr>
<tr><td>4</td><td>China</td><td>Dalong</td></tr>
<tr><td>5</td><td>China</td><td>Feilaxia</td></tr>
<tr><td>6</td><td>China</td><td>Fengman</td></tr>
<tr><td>7</td><td>China</td><td>Guanting</td></tr>
<tr><td>8</td><td>China</td><td>Guxian County</td></tr>
<tr><td>9</td><td>China</td><td>Hongshan</td></tr>
<tr><td>10</td><td>China</td><td>Liujiaxia</td></tr>
<tr><td>11</td><td>China</td><td>Linhuaigang</td></tr>
<tr><td>12</td><td>China</td><td>Longyangxia</td></tr>
<tr><td>13</td><td>China</td><td>Miyun</td></tr>
<tr><td>14</td><td>China</td><td>Nierji</td></tr>
<tr><td>15</td><td>China</td><td>Panjiakou</td></tr>
<tr><td>16</td><td>China</td><td>Sanmenxia</td></tr>
<tr><td>17</td><td>China</td><td>Three Gorges</td></tr>
<tr><td>18</td><td>China</td><td>Xiaolangdi</td></tr>
<tr><td>19</td><td>China</td><td>Xiangjiaba</td></tr>
<tr><td>20</td><td>China</td><td>Xiluodu</td></tr>
<tr><td>21</td><td>China</td><td>Zipingpu</td></tr>
<tr><td colspan="3">**International** Case Studies prepared by Group 2</td></tr>
<tr><td>22</td><td>Australia</td><td>Hinze</td></tr>
<tr><td>23</td><td>Australia</td><td>Wivenhoe</td></tr>
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| CASE STUDIES | | |
|---|---|---|
| 29 | Germany | Eifel-Rur Reservoir System |
| 30 | Greece | Tavporos Multipurpose |
| 31 | Iran | Doosti Multipurpose Dam |
| 32 | Iran | Gotvand Multipurpose Dam and Hydropower Plant |
| 33 | Iran | Karun I Multipurpose Dam |
| 34 | Iran | Karun III Multipurpose Dam |
| 35 | Iran | Karun IV Multipurpose Dam |
| 36 | Italy | Ridracoli |
| 37 | Japan | Tokuyama Dam |
| 38 | New Zealand | Argyle |
| 39 | New Zealand | Coleridge |
| 40 | New Zealand | Land and Water Forum |
| 41 | New Zealand | Karori |
| 42 | New Zealand | Opuha |
| 43 | Nigeria | Kashimbila |
| 44 | Pakistan | Mangla |
| 45 | Peru | Chira- Piura |
| 46 | Peru | Olmos Project |
| 47 | Russian Federation | Cheboksarskaya HPP |
| 48 | South Africa | Berg River Dam Project |
| 49 | Turkey | Ataturk |
| 50 | United States | Elwha River |
| 51 | United States | Shasta |
| 52 | United States | Tennessee Valley Authority |

## Case Studies from China

### 1.1 General

The Yellow River Engineering Consulting Co. took the lead of Group 1 with the task of collecting case studies from China utilizing the framework agreed in Seattle, August 2013. Results were collected in two reports and a synthesis of the main findings was presented during the ICOLD Annual Meeting in Bali, 2014. Both reports may be consulted in … (ICOLD website). The present chapter offers a summary of the process of the study and of its outcomes. The latter are of high interest because they are based on a wealth of information and thorough analysis, which is coming from the world leading country in dam development and management.

### 1.2 Research process

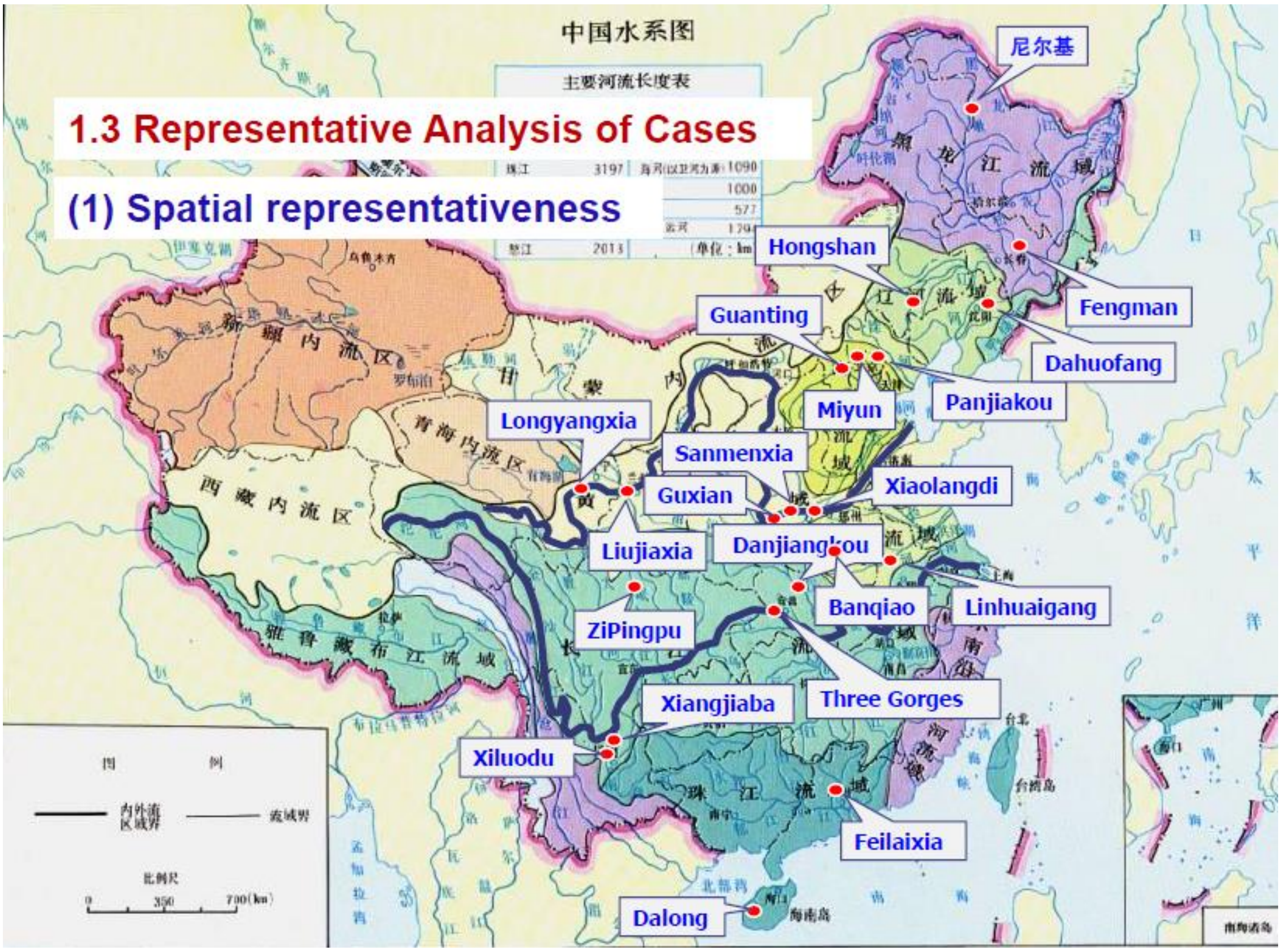
The research process started with a long list of cases, which was progressively refined to meet the objectives of the MPWS research. Information was gathered from published papers, ICOLD literature and the internet. An effective cooperation was established with the Yangtze and the Pearl River Basin Authorities. The first draft, containing 8 cases, took 5 months to prepare and was ready by February 2014. Following comments from the rest of the team, other 13 cases were prepared by the end of May 2014. The entire process took about 8 months, providing a strong start to the activities of the Committee.

## 1.3 Selection criteria

Case studies selection was based on the following criteria:

- Project should feature at least three, mainly public sector-related, purposes;
- Dams with large catchment areas and with important roles in the respective river basins;
- Cases are representative in terms of of both time and spatial scales;
- Main dam types should be represented;
- Cases should be technologically relevant;
- Availability of data.

21 reservoirs, from 6 Chinese river basins were finally selected and analysed. The following plate shows spatial distribution.



The following table summarises some data of the Group 1 case studies.

| Dam | River Basin | Year completed | Dam type | Height (m) | Reservoir (million m3) | Design flood (m3/s) |
|---|---|---|---|---|---|---|
| Banqiao | Huaihe | 1953 | Concrete+Earthfill | 51 | 675 | 9770 |
| Dahuofang | Songliao | 1959 | Zoned rockfill | 49 | 1430 | n.a. |
| Dalong | Pearl | 2007 | Zoned earthfill | 66 | 468 | 10000 |
| Danjiangkou | Yangtze | 1973 | Concrete+Rockfill | 117 | 17450 | 98400 |
| Feilaixia | Pearl | 1999 | Concrete gravity | 49 | 1870 | n.a. |
| Fengman | Songliao | 1942 | Concrete gravity | 91 | 10800 | n.a. |
| Guanting | Haihe | 1954 | Zoned earthfill | 45 | 2270 | 11450 |
| Guxian | Yellow | 1995 | Concrete gravity | 125 | 1170 | n.a. |
| Hongshan | Songliao | 1960 | Earthfill | n.a. | n.a. | n.a. |

| **Dam** | **River Basin** | **Year completed** | **Dam type** | **Height (m)** | **Reservoir (million m3)** | **Design flood (m3/s)** |
|---|---|---|---|---|---|---|
| Linhuaigang | Huaihe | 2006 | n.a. | 21 | n.a. | n.a. |
| Liujiaxia | Yellow | 1974 | Concrete gravity | 147 | 5700 | 8860 |
| Longyangxia | Yellow | 1989 | Arch-gravity | 178 | 2470 | n.a. |
| Miyun | Haihe | 1960 | Eartfill | n.a. | 4370 | n.a. |
| Nierji | Songliao | 2006 | Asphalt core rockfill | 42 | 8610 | n.a. |
| Panjiakou | Haihe | 1985 | Concrete gravity | 107 | 2930 | n.a. |
| Sanmenxia | Yellow | 1960 | Concrete gravity | 106 | 16200 | n.a. |
| Three Gorges | Yangtze | 2010 | Concrete gravity | 181 | 39300 | 98800 |
| Xiangjiaba | Yangtze | 2015 | Concrete gravity | 162 | 4970 | 41200 |
| Xiaolangdi | Yellow | 2001 | Zoned rockfill | 160 | 12650 | 40000 |
| Xiloudu | Yangtze | 2015 | Arch double curv. | 285 | 11570 | 43700 |
| Zipingpu | Yangtze | 2006 | Concrete face rockfill | 156 | 1112 | 12700 |

### 1.4 Evolving reservoir purposes

Water infrastructure development started in China in the 1950s. Initially, the principal purpose was electricity generation, and reservoirs were mainly single purpose. In 1954, the *Technical and Economic Report on Comprehensive Harnessing and Planning of the Yellow River*, listed 46 cascade reservoirs, out of which 42 were exclusively for electricity generation. With national economic growth, irrigation and domestic-industrial water supply added on. As more land became used, flood control became an additional, frequently dominating, purpose. Since the 1990s, increasing awareness of ecological protection brought to the decision to assign environment management functions to some reservoirs. In line with that, for example, Xiaolangdi Reservoir was to release in stream flows to sustain ecological functions of the Yellow River.

Flood control is, since the late 1990s, the main purpose of many large reservoirs. Miyun Reservoir, the main drinking water source of Bei Jing, is a large-scale multipurpose project integrating flood control, water supply, irrigation, electricity generation, and fish farming.

Completed in 1960, Miyun has undergone several expansions and upgrading works to enhance its flood protection function, as such it has become one of the important projects that ensure flood protection to Bei Jing.

China's history of water infrastructure development shows progressive and significant increase of multiple purpose projects. Increasingly sophisticated Decision Support Systems became necessary for regulating reservoirs to achieve multi-objective decision making subject to complex, often conflicting, constraints.

Xiaolangdi is the most multipurpose reservoir in China and, probably, in the world. Conceived mainly for managing sedimentation in the lower reaches of the Yellow River, Xiaolangdi also delivers electricity generation, irrigation, water supply, managed river flows and other purposes. The project features an automatic scheduling system, which adopts C/S (Client/ Server) architecture, including data acquisition & processing, information display and inquiry, office works of reservoir scheduling, system alarms and 3D reservoir modules.

The Danjiangkou Water Control Project was completed in 1973. For over 30 years, the project has played an important role and delivered significant economic benefits. With national economic growth, shortage of water in North China became more urgent; therefore, it was necessary to launch the South-to-North water transfer project to solve the water shortage issue in Bei Jing- Tianjijn areas. As the headwater of phase 1 – middle line- of the water transfer project, Danjiangkou Reservoir was raised from 157 to 170m, with an increase in storage capacity of 11.6 billion cubic meters. Through optimized scheduling, the flood control capacity has been improved in the middle and lower reaches, annual water supply reached 12 billion m3, making it possible to mitigate water shortage of North China until year 2030.

The decision support system of Danjiangkou consists of the following modules: reservoir information inquiry, real-time water and rainfall information management, reservoir flood forecasting, power generation and irrigation scheduling, hydrological database maintenance.

### 1.5 Project sustainability

*Environment management*

Impact of hydraulic infrastructures on riverine ecosystems has emerged at world level in the 1970s and new concepts, such as human-river relations and river health have gradually entered project planning. Three Gorges, Xiaolangdi and several other large-scale reservoirs in China incorporate principles of environmental management in addition to optimization of economic benefits.

*Sedimentation management*

The Loess Plateau occupies a vast area in the upstream reaches of the Yellow River basin and has some of the highest silt loads in the world. About 1.5 billion tons of sediment passes to the lower reaches each year. As a result, riverbed raises about 100 mm/year and, in many places, the Yellow River flows inside its own sediments, above the surrounding campaign level. E.g. in Kaifeng, the riverbed is more than 10m above the city with disastrous consequences when dykes break.

Government of China answer to the challenge has been twofold:

- Loess Plateau Watershed Rehabilitation Project, and
- Xiaolangdi Multipurpose Project.

The Loess Plateau project addresses the long-term issue of sediment yield. Its key objectives are:

- to increase agricultural production and incomes on 15,600 km2 of land, and concurrently
- to reduce sediment inflows to the Yellow River from nine tributary watersheds.

Related actions include: (a) replacing areas devoted to crops on steep slopes; (b) planting trees, shrubs and grasses on the slope lands; (c) construction of sediment retention dams.

Xiaolangdi reservoir is conceived to release clear water (flushing) in the downstream reaches to reverse the above described aggradation phenomenon. The first large scale flushing operation was carried out in July 2002:

- Flushing lasted 11 days,
- Average discharge 2,740 m3/s,
- Volume released 2.61 billion m3,
- The test interested a total length of 800 km of the Yellow River,
- Gates at Sanmenxia and Xiaolangdi were operated 294 times.

As a result, 362 million tons of sediments moved onto the estuary in the N-E China Sea (900 km downstream). Since then, annual flushing operations have continued with successful results.

## 1.6 Economic analysis

Different methods of cost allocation, to each purpose of multipurpose reservoirs, are adopted. Chinese practice is to use two or three alternative methods and using judgement to combine results. In the case of Xiaolangdi Multipurpose, two methods were considered:

- Proportional to storage capacity allocated to each purpose, and
- Separable cost remaining benefits.

The former was selected at feasibility level.

Calculation of project benefits in the case of flood control also covers ice flooding and tide control. According to economic practice, benefits are based on loss reduction and derived from the difference between flood damages with and without project. Losses are divided in five categories:

- Causalities and injuries to people;
- Damage to urban and rural assets, facilities and goods;
- Suspension of industry and mining, shutdown of commerce, cut-off of transport, power supply and telecommunications;
- Reduction of output from agriculture, forestry, livestock, fishery;
- Expenditure for flood mitigation, disaster relief and rescue.

Flood losses are calculated for events of different frequencies and duration curves drawn to link probability of occurrence to extent of losses.

According to international practice, both financial and economic analyses are carried out. The former calculates financial benefits and costs directly resulting from the project, to assess the project’s profitability, solvency, and foreign exchange balance requirements. Under the conditions of market-oriented economy, the project developer is an independent financial entity with sole responsibility for its profits and losses.

Economic analysis calculates project’s contribution to national economy, analyses environmental and social impacts, and evaluates project’s efficiency in allocating public resources in the context of national economic interests.

The difference between financial and economic performance grows with the number of purposes of the project. The following table summarizes economic and financial indicators of Xiaolangdi Multipurpose.

| **Project planning level** | | **During operation (2002-2013)** | |
|---|---|---|---|
| Economic internal rate of return (EIRR) | Financial internal rate of return (FIRR) | EIRR | FIRR |
| 20.2 % | 3.9 % | 11.08 % | 4.01 % |

Financial profitably is low (around 4% FIRR) because non-profit functions (e.g. flood control, ice flooding prevention, sedimentation management, environmental management) generate no income, income from water supply is limited, and electric energy supply constitutes the major source of income. On the other hand, economic performance indicators are quite good and environmental benefits remarkable. Since start of operation, Xiaolangdi allowed recovering fresh water and wetlands, fish stocks that had almost disappeared in the 1980s swim back, river water has become clear and limpid, and water treatment fees for urban drinking water are reduced.

The selection of discount rate for large-scale multipurpose projects in China is based on the following criteria:

- Different discount rates are assigned to construction and operation phase respectively;
- A higher value is used for the construction phase (in the order of 8%), and a lower one (some 3 to 4%) during operation;
- The latter increases the long-term value of the reservoir, reflecting its importance as a scarce resource.

## 1.7 Main findings and Lessons Learnt

- Historical evidence exists in China of a progressive trend from single purpose -mainly electricity generation - to multipurpose reservoirs.
- After electricity generation, water supply (domestic, irrigation and industrial) were added, followed by navigation and flood protection.
- Flood protection has become a dominant purpose due to very high population density in the major river basins.

- Environmental aspects have been addressed since the 1970s and have produced unprecedented results, especially in sedimentation management and soil erosion control.
- Economic analysis incorporates externalities and makes clear differentiation between financial and economic performance of the project.
- A higher discount rate is used for the construction phase (in the order of 8%), and a lower one (some 3 to 4%) during operation to reflect the long-term value of the reservoir.

## 2. Case Studies from Group 2 and 3

### 2.1 General

Groups 2-3 of the committee developed case studies from the ICOLD membership globally excluding the contributions of China which are reported separately as Group 1. Case studies were documented from the countries as detailed in table 1:

| | | | |
|---|---|---|---|
| Australia | France | Iran | Peru |
| Cameroon | Germany | Japan | South Africa |
| Canada | Greece | New Zealand | Russia |
| Egypt | Italy | Nigeria | Turkey |
| | | Pakistan | United States |

**Table 1: Groups 2-3 contributing ICOLD member countries to case studies**

In total the 18 countries contributed 31 case studies to inform the bulletin and the results were collected within individual case study reports on each scheme, with an interim summary report based on draft case study findings; and finally after review individually within detailed case studies. The first synthesis of the main findings was presented during the ICOLD Annual Meeting in Norway, 2015.

The present chapter offers a summary of the process of Groups 2-3 study and of its outcomes.

### 2.2 Research process

The research process started with a call for committee members to provide case studies, and this was then extended to ICOLD member not on the board of the committee. The process was started during the draft preparation of the Chinese case studies (Group 1), with substantial detailing after the Group 1 case studies were complete and the experience of Group 1 research incorporated into the Groups 2-3 research.

The case studies were authored by various representative with an understanding of the scheme ranging from owners through to consultants and or persons with a professional interest in a particular scheme. The case studies selected were then refined to meet the objectives of the MPWS research. Like the case studies from Group 1 the information was gathered from published papers, available information, ICOLD literature and the internet. For each analysis the following information was gathered and described in the case study;

- Salient data on the scheme and the multiple uses
- Scheme infrastructure, environmental and social setting
- Long term planning goals of the project or scheme
- Description of the institutional and governance arrangements
- Description of the project cost allocation (purposes, cost sharing) and economic description (direct, indirect, benefits, costs etc)
- Engineering modifications (structural and non-structural) to enhance present multiple use or planned for the future
- A bibliography of information sources

The first drafts took approximately 12months to prepare and these were refined over a 6 month period and were ready by April 2016.

### 2.3 Selection criteria

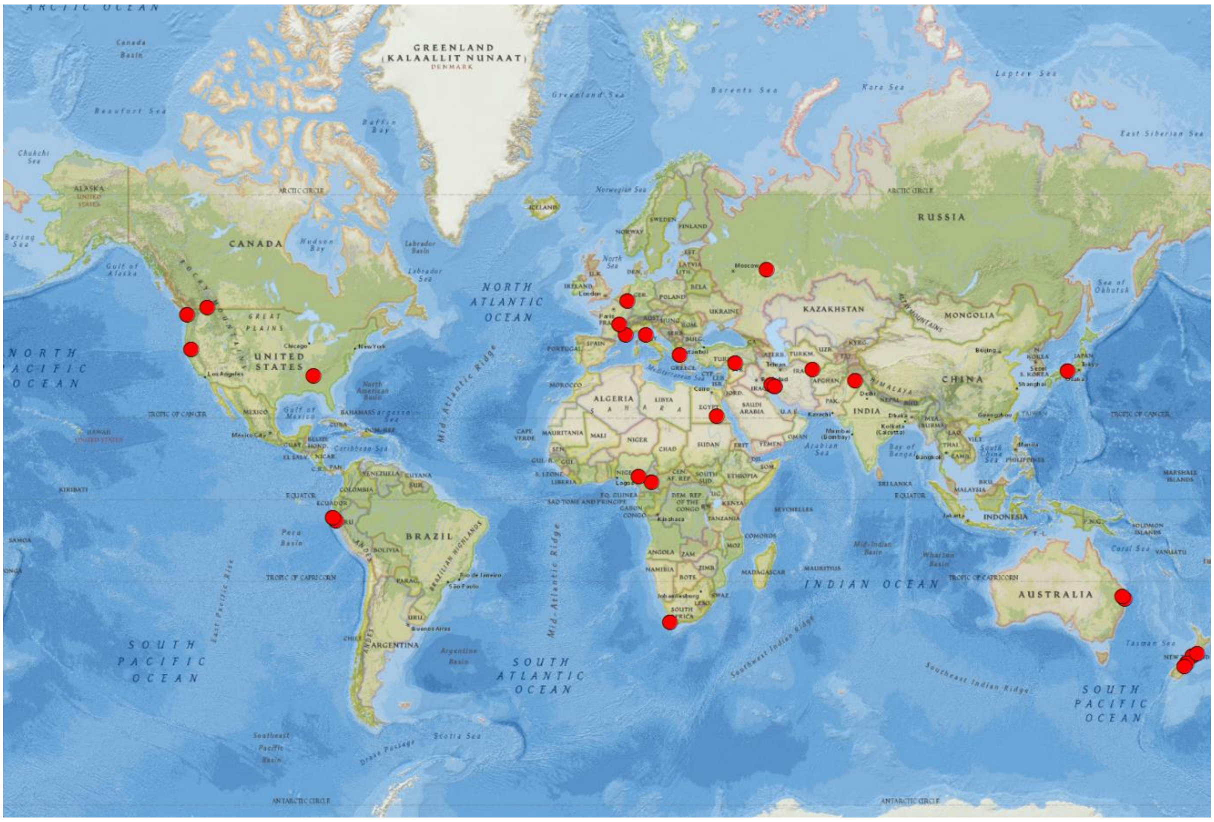
Case studies for Groups 2-3 were selected was based on the following criteria:

- Projects should present global diversity of location
- Project should ideally feature at least three purposes now or be planned for future use
- Schemes or projects should be diverse in their multipurpose use
- Scheme or projects should be diverse is size, scale, cost, impacts or benefits
- Dams with large catchment areas and with important roles in the respective river basins should be considered
- Cases are representative in terms of of both time and spatial scales
- Main dam types should be represented
- Cases should be technologically, environmental, social or economically relevant

- Availability of data should be considered.

In total the 31 schemes which were researched ranged from some of the largest water schemes in the world, the Atatkurk Dam as an example; the Kuran developments in Iran; through to modest size schemes like the Ridracoli Dam in Italy. Schemes with global recognition were selected such as the High Aswan Dam in Egypt, through to schemes with less recognition such as Tokuyama Dam located in Japan. Modern schemes were represented though examples such as the Kashimbila Multipurpose Dam, though to schemes developed many decades ago such as the assets of the Tennessee Valley Authority in the United States. Developments with a diversity of use were selected such as the Cheboksarskaya scheme in Russia, through to examples such as the Chira-Piura Hydro and Irrigation Scheme in Peru.

The following plate shows spatial distribution.



The following table summarizes various data of Groups 2-3 case studies.

| Scheme or Dam/Reservoir Name | Country | Trans-boundary Countries | River | Dam Height (m) | Multiple Uses |
|---|---|---|---|---|---|
| Durance-Verdun River System | France | None | Durance and Verdun | Various | Hydropower, agriculture, regulation, recreation |
| Tennessee Valley Authority | United States | None | Tennessee | Various | Hydropower, navigation, flood control, recreation, power cooling |
| Olmos | Peru | None | Huancabamba | 43 | Irrigation, Hydropower |
| Lom Pangar | Cameroon | None | Sanaga | | Hydropower, regulation |
| Berg River Dam | South Africa | None | Berg | 68 | Water supply, irrigation, flood control, fisheries, recreation, sanitation |
| Ataturk Dam | Turkey | None | Euphrates | 169 | Agriculture, hydropower, regulation, recreation, fisheries |
| High Aswan Dam | Egypt | Sudan, Ethiopia, Eritrea, Uganda, Kenya, Rwanda, Burundi, Tanzania | Nile | 111 | Agriculture, hydropower, flood control, water supply |
| Mangla Dam | Pakistan | None | Jhelum | 147 | Hydropower, agriculture, navigation, recreation, fisheries |
| Shasta Dam | United States | None | Sacremento | 183 | Hydropower, agriculture, regulation, recreation, sanitation |
| Tokuyama Dam | Japan | None | Ibi | 161 | Water supply, hydropower, flood control, regulation |
| Cheboksarskaya HPP | Russia | None | Volga | 30 | Hydropower, flood control, navigation, water supply, regulation, recreation, fishery |
| Chira-Piura Hydro Scheme | Peru | None | Chira and Piura | 50 | Agriculture, hydropower, flood control, water supply, recreation, fisheries |
| Doosti Multipurpose Dam | Iran | Iran, Turkmenistan | Harir Roud | 78 | Irrigation, flood control, hydropower, water supply, artificial recharge |
| Tavropos Hydroelectric Project | Greece | None | Tavropos | 83 | Water supply, hydropower, recreation, irrigation, flood control, regulation, fisheries, sanitation |

| Scheme or Dam/Reservoir Name | Country | Trans-boundary Countries | River | Dam Height (m) | Multiple Uses |
|---|---|---|---|---|---|
| Lake Argyle | New Zealand | None | Branch | 15 | Hydropower, irrigation, sediment, recreation, fisheries |
| Lake Coleridge | New Zealand | None | Rakaia | n/a | Hydropower, recreation, fisheries, irrigation, water supply, regulation |
| Hinze Dam | Australia | None | Nerang | 78.5 | Water supply, flood control, recreation |
| Wivenhoe Dam | Australia | None | Brisbane | 59 | Water supply recreation, hydropower, regulation, irrigation |
| Kashimbila Multipurpose Dam | Nigeria | Cameroon | Kashimbila | 32 | Flood, hydropower, agriculture, water supply |
| Karori Reservoir | New Zealand | None | Kaiwharawhara | 24 | Heritage, water supply, recreation, fisheries |
| Lake Opuha | New Zealand | None | Opuha | 50 | Irrigation, regulation, flood control, recreation, water supply |
| Gotvand Multipurpose Dam and Hydropower Plant | Iran | None | Karun | 182 | Irrigation, hydropower, flood control, water supply |
| Hugh Keeleyside Dam | Canada | Canada, United States | Columbia | 52 | Hydropower, flood control, navigation |
| Elwha River Restoration Project | United States | None | Elwha | | Recreation, hydropower |
| Karun I Multipurpose Dam | Iran | None | Karun | 200 | Sediment management, flood control, agriculture, navigation, hydropower, recreation |
| Karun III Multipurpose Dam | Iran | None | Karun | 205 | Sediment management, flood, agriculture, navigation, hydropower, recreation |
| Karun IV Multipurpose Dam | Iran | None | Karun | 230 | Flood control, hydropower, recreation |
| Eifel-Rur Reservoir System | Germany | Belgium, Germany, Netherlands | Rur and Maas | 12 to 59 | Flow regulation, water supply, hydropower, flood control, recreation |
| Ridracoli | Italy | None | Bidente | 103 | Hydropower, water supply, regulation, saltwater intrusion |

| Scheme or Dam/Reservoir Name | Country | Trans-boundary Countries | River | Dam Height (m) | Multiple Uses |
|---|---|---|---|---|---|
| Villerest Dam | France | None | Loire | 70 | Hydropower, recreation, power cooling |
| New Zealand Land and Water Forum | New Zealand | None | N/A | N/A | Irrigation, hydropower, water supply, environmental, social |

## 2.4 Reservoir purposes

The case studies researched present the multiple diverse uses of dams and reservoirs globally. In general, the primary uses of reservoirs for the researched schemes can be described as for hydropower, agriculture, flood and ice control, domestic and industrial water supply, navigation, flow regulation, recreation, environmental mitigation, fishery and aquaculture or sanitation. The case studies included some diverse uses such as volcanic lahar projection provided by the Kashimbila Multipurpose Dam in Nigeria.

*Hydropower*

Many of the case studies had or have hydropower as a component of the scheme infrastructure and revenue earner. Many modifications to sole use schemes have been completed or are planned to accommodate other uses of water and provide additional benefit to communities and users. The dam raise of the Mangla Dam in Pakistan provides an example to the background to enhancement of generation with improved benefits such as protection of the Jhelum flood plain from high floods and droughts that could persist for several years, development of a fish aquaculture industry, reliable supply of water encouraging farmers to extent irrigated area and invest in non-water inputs needed to maximize yields and output, replacement of thermal plant generating capacity with hydropower,  and an increase in property values near the reservoir. These benefits have come with recognized impacts which have been incorporated into the project design such as siltation and sediment issues, the spread of aquatic weeds and waterborne endemic diseases, the increased localized flood damage during extreme events, and significant social impacts to 81,000 people.

*Agriculture*

For many countries the case studies showed the expansion of irrigated agriculture as one of the primary changes to existing schemes to enhance their use or integrated into planned new schemes.  The Olmos Project in Peru commenced in 2014 is a very modern scheme that was conceived as multipurpose project since the initial planning stage, although the prospect of deriving water from the Huancabamba River in the Amazon basin to irrigate the pampas of Olmos was first proposed in 1924. The project is primarily an irrigation scheme with approximately 44,000 hectares planned, with 100MW or power generation as a secondary development, but the project has notable environmental concerns regards logging of dry forest in favor of new irrigation grounds, the deterioration of ecosystems in the donating basin, and changed river flows. Social impacts have included the loss of communal grounds and debated recognition of the communal land rights of the farmers, and relocation of 200 people in donating basin. The scheme has strived to accommodate all issues in the project design and whilst the project development cost is US$ 242 million, the direct economic benefit of the scheme is agricultural production of US$ 400 million per year, and electricity generation revenue of US$40 million per year.

### *Navigation*

Navigation is not a significant use or need identified by the wider case studies, however in regions where river transport is a prime means of good or passenger transport the need for navigation and enhanced navigation driven by changes in ship type (Panama Canal third locks project for example) or river morphological changes was identified. The Cheboksarskaya Dam and Hydro Power project presented as good case study for this modification. The dam is the fifth in the Volga-Kama river’s scheme and which located by the Novocheboksarsk city in the Chuvash Republic or the Russian federation presented an example of how the changes in river navigation requirements have required modern upgrades to infrastructure to cope with changing needs, and then as a result of the upgrade incorporating enhancements to environmental and social requirements. Of all the Group 2 case studies this project with modernization aims to provide the greatest multiple use benefits with creation of a deepwater ways network in the European part of Russia and traffic flow organization on the route from Center to Middle and North Ural bypassing Nizhniy Novgorod. The modifications will improve regulation of Volga River’s basin runoff and provide additional water quality control of Cheboksary reservoir for supplying large settlements with drinking water. The completion of levees and flood protection measures will guarantee protection against natural under flooding of urban areas in lowlands of Nizniy Novgorod. Significantly the changes will improve the ecological conditions by creation of ecologically restricted areas and by decreasing area with a water level under 2.0 m deep**;** **i**mproving the quality of life for people living near the reservoir; and increasing the capacity of power plants in the European part of Russia’s Unified Energy System by 820 MW.

### *Domestic and Industrial Water Supply*

Increasing urbanization and industrialization in many global regions, combined with hydrological change and variability is creating a greater need for stored water supply and reliability and leading many older reservoir schemes to be enhanced and upgraded for capacity storage and enhanced outflow. This trend is evident in the case studies, particularly for single purpose hydropower projects where social demand for water is necessitating infrastructure enhancements and permit condition changes to supply water at time to the detriment of energy production. The N. Plastira dam on Tavropos River is located near the Kastania village approximately 350 km north of Athens, Greece, is a modern example of changing hydrological needs necessitating enhanced inter basin water transfer to mitigate growing demand and hydrological change. The upgrade includes inter catchment diversions from the Aspros and Oxoula streams diversion to provide an additional 25 million cubic meters of water at a cost of US$35M to mitigate droughts and shortages during summer months. The project design has recognized that early clarification of the ecological flow requirements for the watersheds is to be respected during summer periods, mainly allowing diversion of the excess winter flows as a result the design only allows for 40% of the total flow of the Aspros stream to be diverted at its higher flow regime, leaving enough water resources downstream to be used for in stream ecological requirements, recreation, and fish farming.

### *Flood and Ice Control*

Flood and Ice control was a core change in use and upgrade requirement for dam and reservoirs in the Group 1 case studies presented in Chapter XXX. The Group 2 research case studies presented flood control as a core function of reservoirs in the modern era, particularly for large storage schemes with large and growing downstream populations where the awareness or flood or dam break risk has necessitated changes in reservoir operating rules and infrastructure upgrade to modernize dams to best practice and often for enhanced peak flood risk. The Wivenhoe Dam is the largest dam in South East Queensland, Australia and was developed as a dual-purpose storage facility that provides urban water supplies, as well as flood mitigation benefits to areas impacted by flood flows along the Brisbane River. It is classified as an extreme hazard dam with a Population At Risk (PAR) of 270,000. Following the 2010-2011 devastating Queensland floods, a Commission of Inquiry investigated the circumstances in which the flooding occurred and put forward recommendations subsequently endorsed by the Queensland Government. The Department of Energy and Water Supply (DEWS) in 2014 released the ‘Wivenhoe and Somerset Dams

Optimisation Study (WSDOS)' which presented options for the management of the Wivenhoe and Somerset dams during the event of a flood. The study determined that improvements to flood mitigation (without physical works to upgrade the storage capacity) can only be achieved by either decreasing the space set aside for water supply or to safeguard the dam, highlighting the tension between water supply design and flood mitigation provided by storage capacity, and the report found that lowering the water supply below its current 37 percent share would risk long term water supply security. Partial modernization to the spillways has provided a flood passing capacity of 1 in 100,000 was recently completed.

*Other uses*

The research showed that there are many other multiple uses of reservoirs such as environmental related uses as described in section XX1.5XX. Flow regulation for environmental and other enhancements uses was a common theme among case studies. Various sanitation uses related to water quality were presented. Other non-typical uses included thermal power station cooling, volcanic eruption lahar control, heritage etc.

## 2.5 Project sustainability

*Environment management and enhancement*

The case studies presented the diverse nature of the environmental impacts both negative and positive that the schemes have created. The case studies showed that globally there is diverse environmental management methods and practices, but with a common theme of enhancement occurring for long term existing scheme being upgraded through to new modern projects. The Elwha River Restoration Project in the United States is an extreme example where after many years of environmental and social impact the removal of the dams was approved and completed, with post economic analysis showing the total estimated benefits of dam removal was $355.3 million in 2001, without consideration of the estimated non-use benefits. In New Zealand the land and Water Forum are a modern method of public and community engagement for decision making that is a cutting edge process for water infrastructure development considerations.

Environmental mitigation, improvements to river flow regulation and health, establishment of fisheries for income, recreation and tourism are all aspects related now to exiting projects and new projects whether originally planned for or that have developed over time through community engagement and planned into new projects.

The development of the Eifel-Rur Reservoir System in Germany on the boarder of Belgium and Netherlands reservoir system provides an example of environmental change considerations incorporated into system design. The scheme was built over an 80 year period with the Urft Reservoir constructed from 1900 to 1905 through to the Olef Reservoir built drinking water and flood protection completed in the early 1960's and eventually the system was completed with the Wehebach Reservoir in 1983. The total storage capacity of the system is 300 Mm³, flood control and low flow augmentation are the main purposes, but this is complemented with 60 Mm³ allocated for drinking water serving more than six hundred thousand people. Power is generated in five powerhouses.

The region is now experiencing highly variable flow with long lasting dry spells and destructive flood events along with an increase of domestic and industrial water demand in the wake of industrialization which prompted the construction of the Eifel-Rur Reservoir System originally. Exploitation of lignite in the river basin has occurred for long periods and dewatering of the open pits significantly reduces groundwater levels and causes drying out of local streams and wetlands. This, in turn, increases the demand for water for irrigation and compensation. There are now clearly defined ecologically valuable river reaches and floodplains still along the river and this has gained more attention in recent years with raising environmental consciousness adding new water management considerations. To manage all these challenges the management of the river system operation is changing to reflect these new environmental considerations to achieve a balance between benefits and impacts. The order in which additional purposes were added to the system is shown below:

Low flow augmentation ► hydropower ► flood control ► water supply ► enhanced requirements low flow augmentation ► environmental flows ► (future - flooding open pit)

In the wake of the modern German energy turnaround, considerations about using the Reservoir Rur for hydro pumped storage were carried out. Notably the risks during the construction phase with regards to water quality and impacts on recreation were considered and despite positive response of communities in the vicinity of the reservoir the proposals were not progressed as the consequences were deemed too high.

### *Social Enhancement*

For the researched case studies this section is not intended to describe holistically all the social aspects related to society and dam and reservoir development. Conclusions drawn from the case studies indicate that for many redevelopments of existing schemes and creation of new schemes that are socially driven and have requirements for the local communities, or directly and indirectly impacted persons, leading many of the decision criteria for multiple use reservoirs and or mitigation of impacts created by the developments.

An example of socially driven development for community safety, the Kashimbila Multipurpose Dam in Nigeria was initially proposed to be developed in the event of Lake Nyos' natural embankment failing or in the event of the volcanic lake erupting and releasing poisonous gas and water. The last eruption was in 1986 which released poisonous gas and caused extensive flooding, resulting in the death of about 1,700 people, 4,000 herds of cattle 330 sheep and thousands of other livestock in the villages of Cham, Nyos and Subum, just downstream of the lake. In anticipation of a similar environmental disaster the Nigerian Federal Government embarked on the construction of a buffer dam (Kashimbila) that would accommodate the poisonous water.

Although initially conceptualized as a buffer dam in the event of embankment failure at Lake Nyos, it was later changed to enhance the social benefits of the project during the design process to include the supply of potable and irrigation water and the generation of hydropower. The potable water supply was identified as a major contribution to the improvement of public health in surrounding communities.

### 2.6 Economic and Financial analysis

The Group 2 case studies presented a wide variety of economic and financial detail, from very detailed pre and post construction analysis though to minimal analysis. The degree of variability was clearly defined by the time since development of the original projects, some of the scheme are over 100 years old and no detail was available, to more recent schemes where the financial and economic analysis of the impacts and benefits of the projects or enhancements were defined in detail.  There was a notable difference in available data relating to financial and economic analysis with the former being available for most projects and redevelopments, and fewer examples of the latter.

An example of modern documented pre and post construction financial and economic analysis is the Opuha reservoir and dam development, completed in 1998, located in the South Island of New Zealand. The primary purposes of the scheme is the storage of water for river regulation in order to improve the environmental conditions in the river and to provide irrigation water and subsidiary purposes are for the provision of industrial and public water supply, hydropower generation, fishing, boating. The Opuha scheme was a private development by the Opuha Dam partnership comprising Alpine Energy via Timaru Electricity

Ltd (50%), Opihi River Development Company (private investors) via Opihi River Holdings Ltd 36%, South Canterbury Farmers Society Ltd via SCFIS Holdings Ltd (8.6%), and Levels Plains Irrigation Company Ltd via Levels Plains Holdings Ltd (5.4%). In 2007, the farmer irrigators bought out the other partners to achieve 100% ownership in a co-operative model by approximately 250 irrigator shareholders. The scheme operates by regulating the river flows downstream of the dam with all abstractions occurring downstream of the dam. The operating rules were designed to maintain storage for irrigation and environmental flows in preference to other needs such as the hydro generation. However, water releases are prioritized for environmental flows (including maintaining river mouth opening), water supply, irrigation and then electricity generation.

Example financial and economic data indicated some of the following information for:

- Total revenue is approximately 2.4 times for the irrigated farms than the dryland farms
- Capital expenditure per hectare is no greater on irrigated properties than on dryland properties.
- The scheme has increased farm revenue by NZ$40m/annum with profit increases of approximately NZ$3m/annum (2006 costs)

Example scheme wide on farm Impacts:

- An increase in Total Farm Working Expenditure of approximately NZ$28 m per year
- An increase in Cash Farm Surplus of approximately NZ$12 m per year
- An increase in Net Trading Profit after Tax of approximately NZ$3 m per year
- In terms of on farm impacts the irrigated farms generate 2.0 times as many jobs, 2.3 times as much value added, and 3 times as much household income per ha as do dryland farms.
- The location of impacts indicate that approximately 55% of expenditure is in rural areas or small towns, with a further 34% to 39% in Timaru the nearby large city.

Whole Community Impacts have been modelled for the Opuha regionalized economy to investigate the flow on and downstream impacts of the changes. For the entire economy, the Timaru District and the Fairlie Basin, each thousand hectares of irrigation adds NZ$7.7 million in output, 30 full time employees, $2.5 million in value added and $1.2 million in household income. The increase in value added associated with irrigation from the whole Opuha Dam scheme has been calculated at $41 million per year, which is equivalent to 3.1 % of total value added in the region in the 2003/04 year. It generated an additional 480 jobs, which is 2.4 % of total employment. The calculated economic impacts, interviews with businesses has revealed that irrigation is associated with an increase in confidence, infrastructure, and enables better utilization of capacity in downstream businesses. Social indicators on which data has been collected indicate that younger, better educated farmers, and greater employment are associated with the irrigation. In addition a significant proportion of farm direct spending occurs in small centers and rural areas and therefore flow on economic impacts may be concentrated in these areas. These changes are likely to result in more vibrant and sustainable rural communities.

## 2.7 Governance

The research asked the case study author's questions regards the governance makeup of the project. The focus of the research was an understanding of the decision making and control of the infrastructure and how the decision regards schemes use be made. With regards large water infrastructure water management 'governance' typically refers to the institutions, legislation and decision-making processes applied to develop and manage water resources by either national, bi-national and local authorities. Whilst this aspect is vital to schemes and their licenses to operate, the case studies highlighted that governance from a 'company' perspective which inherently has a different set of drivers to 'water management governance' is an important and grown consideration as company directors often have differing duties or responsibilities to regulatory bodies that are charged with management of water.

Many of the projects case studies were government initiatives, however the preponderance of the private sector in modern water infrastructure for new and enhanced old schemes showed the governance makeup of the project organisations to be evolving to public-private governance structures where new investments are made, or in cases where government privatization of national assets is occurring. Coupled with this change was recognition within the case studies of the society and environmental setting in which the projects operate in and incorporation of local representation in either the management or the governance structure of the projects has evolved and is still evolving.

## 2.8 Main findings and Lessons Learnt

- Globally there is a strong progressive trend from single purpose mainly electricity generation to multipurpose reservoirs
- After electricity generation, water supply (domestic, irrigation and industrial) are prime water users, followed by navigation, fisheries and flood protection.

- There are diverse tertiary drivers for multiple use and such examples from the case studies included, power station cooling, recreation, historical aspects, tourism etc.
- Like Group 1 Flood protection has become a dominant purpose due to very high population density in the major river basins
- Environmental and Social aspects were all underpinning driver for enhancement to schemes to make them multipurpose, and for new developments.
- Economic and financial analysis levels of detail vary globally with a preponderance to financial analysis for decision making, and few economic analysis available.
- Infrastructure governance is changing to accommodate social and environmental concerns, and incorporate the private sector into a traditionally government infrastructure led industry.