ADAPTATION TO UNTIMELY FLOODS

By

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Based on the worldwide experiences, the most important Challenges of flood Engineers are:

- Managing substantial increase of flood risks with limited resources;
- Avoiding adverse environmental consequences of flood projects;
- Coping with uncertainty in all relevant aspects.

Now in early years of 21st century, it has become obvious, that the approach to flood management is increasingly adaptive and non-structural. In the last two decades, Adaptive management has been extensively utilized in environmental and restoration projects. In this context, adopting the strategies of Adaptive management in Water engineering and flood management appears to offer great advantages. Adaptive management (AM) is a structured, iterative process of optimal decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring. The strategies of Adaptive Flood Management (AFM) are as follows:

- Adaptability (Changing Threat to Opportunity)
- Flexible Decision Making (to cope with uncertainties)
- Monitoring and vigilance
- Learning while doing
- Application of New knowledge and technologies
- Avoiding costly irreversible mistakes
- Updating the Objectives
- Extensive risk recognition
- Focus on long-term management rather than construction
- Resilience
- Harmony with Environment (step by step)
- Passive and Active AM
- Stakeholders Participation
- Enhanced Real time reactions

This paper presents the history and framework of adaptive management, and its merits in flood management. Four case studies of application of AFM undertaken in Iranian large projects in the past 2 decades are also presented.

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Introduction

Adaptive management (AM) is a structured, iterative process of optimal decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring. In this way, decision making simultaneously maximizes one or more resource objectives and, either passively or actively, accrues information needed to improve future management. Adaptive management 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 adaptive management 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 (Stan key & Allan, 2009).

Adaptive management can proceed as either passive adaptive management or active adaptive management, depending on how learning takes place. Passive adaptive management values learning only in so far as it improves decision outcomes (i.e. passively), as measured by the specified utility function. In contrast, active adaptive management explicitly incorporates learning as part of the objective function, and hence, decisions which improve learning are valued over those which do not (Holling, 1978; Walters, 1986). In both cases, as new knowledge is gained, the models are updated and optimal management strategies are derived accordingly. Thus, while learning occurs in both cases, it is treated differently. Often, deriving actively adaptive policies is technically very difficult, which prevents it being more commonly applied. Key features of both passive and active adaptive management are:

- Iterative decision-making (evaluating results and adjusting actions on the basis of what has been learned)
- Feedback between monitoring and decisions (learning)
- Explicit characterization of system uncertainty through multi-model inference
- Bayesian inference
- Embracing risk and uncertainty as a way of building understanding

Adaptive management is particularly applicable for systems in which learning via experimentation is impractical.

Historical Background of Adaptive management

The use of adaptive management techniques can be traced back to ancient civilizations. For example, the Yap people of Micronesia have been using adaptive management techniques to sustain high population densities in the face of resource scarcity for centuries (Falanruw, 1989). In using these techniques, the Yap people have altered their environment creating, for example, coastal mangrove depressions and sea grass meadows to support fishing and termite resistant wood (Stan key and Shinder, 1997).

The origin of the adaptive management concept can be traced back to ideas of scientific management pioneered by Frederick Taylor in the early 1900s (Haber, 1964). While the term ‘adaptive management’ evolved in natural resource management workshops through decision makers, managers and scientists focusing on building simulation models to uncover key assumptions and uncertainties (Bormann et al., 1999).

Two ecologists at The University of British Columbia, C. S. Holling (1978) and C.J Walters (1986) further developed the adaptive management approach as they distinguished between passive and adaptive management practice. Kai Lee, notable Princeton physicist, expanded upon the approach in the late 1970s and early 1980s while pursuing a post-doctorate degree at UC Berkeley. The approach was further developed at the International Institute for Applied Systems Analysis (IIASA) in Vienna, Austria, while C.S. Holling was director of the Institute. In 1992, Hilbourne described three learning models for federal land managers, around which adaptive management approaches could be developed, these are reactive, passive and active.

Adaptive management has probably been most frequently applied in Australia and North America, initially applied in fishery management, but received more broad application in the 1990s and 2000s. One of the most successful applications of adaptive management has been in the area of waterfowl harvest management in North America, most notably for the mallard (Johnson et al., 1993; Nichols et al., 2007).

Adaptive Management in Environmental Practices

Applying adaptive management in a conservation project or program involves the integration of project/program design, management, and monitoring to systematically test assumptions in order to adapt and learn. The three components of adaptive management in environmental practice are:

- Testing Assumptions is about systematically trying different actions to achieve a desired outcome. It is not, however, a random trial-and-error process. Rather, it involves using knowledge about the specific site to pick the best known strategy, laying out the assumptions behind how that strategy will work, and then collecting monitoring data to determine if the assumptions hold true.

- Adaptation involves changing assumptions and interventions to respond to new or different information obtained through monitoring and project experience.

- Learning is about explicitly documenting a team’s planning and implementation processes and its successes and failures for internal learning as well as learning across the conservation community. This learning enables conservation practitioners to design and manage projects better and avoid some of the perils others have encountered (Stan key et al., 2005).Learning about a managed system is only useful in cases where management decisions are repeated (Rout et al., 2009).

- Open Standards for the Practice of Conservation lay out 5 main steps to an adaptive management project cycle (see Figure 1). The Open Standards represent a compilation and adaptation of best practices and guidelines across several fields and across several organizations within the conservation community. Since the release of the initial Open Standards (updated in 2007), thousands of project teams from conservation organizations (e.g., TNC, Rare, and WWF), local conservation groups, and donors alike have begun applying these Open Standards to their work.

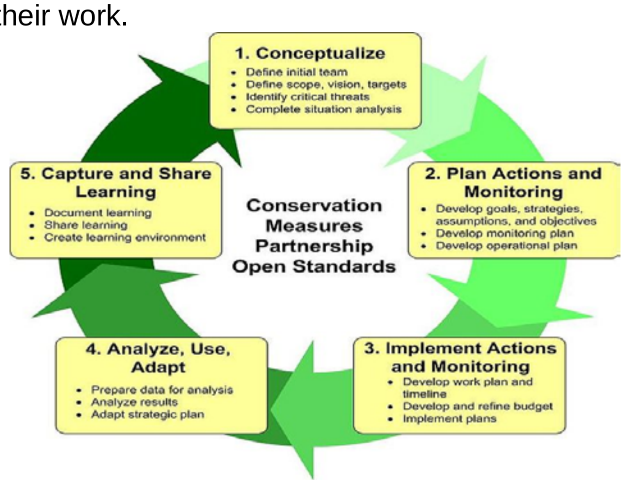

Figure 1. Adaptive Management Cycle

Some recent write-ups of adaptive management in conservation include: wildlife protection (SWAP, 2008), forests ecosystem protection (CMER, 2010), coastal protection and restoration (LACPR, 2009), natural resource management (water, land and soil), species conservation especially, fish conservation from over fishing (FOS, 2007) and climate change (DFG, 2010).

Adaptive Management in other Practices as a Tool for Sustainability

Adaptive management as a systematic process for improving environmental management policies and practices is the traditional application however, the adaptive management framework can also be applied to other sectors seeking sustainability solutions such as business and community development. Adaptive management as a strategy emphasizes the need to change with the environment and to learn from doing. Adaptive management applied to ecosystems makes overt sense when considering ever changing environmental conditions. The flexibility and constant learning of an adaptive management approach is also a logical application for organizations seeking sustainability methodologies. Businesses pursuing sustainability strategies would employ an adaptive management framework to ensure that the organization is prepared for the unexpected and geared for change. By applying an adaptive management approach the business begins to function as an integrated system adjusting and learning from a multi-faceted network of influences not just environmental but also, economic and social (Dunphy, Griffths, & Benn, 2007). The goal of any sustainable organization guided by adaptive management principals must be to engage in active learning to direct change towards sustainability (Verine, 2008). This “learning to manage by managing to learn” (Bormann BT, 1993) will be at the core of a sustainable business strategy.

Sustainable community development requires recognition of the relationship between environment, economics and social instruments within the community. An adaptive management approach to creating sustainable community policy and practice also emphasizes the connection and confluence of those elements. Looking into the cultural mechanisms which contribute to a community value system often highlights the parallel to adaptive management practices, “with [an] emphasis on feedback learning, and its treatment of uncertainty and unpredictability”(Berkes, Colding & Folke, 2000).Often this is the result of indigenous knowledge and historical decisions of societies deeply rooted in ecological practices. (Berkes, Colding, & Folke, 2000). By applying an adaptive management approach to community development the resulting systems can develop built in sustainable practice as explained by the Environmental Advisory Council (2002), “active adaptive management views policy as a set of experiments designed to reveal processes that build or sustain resilience. It requires, and facilitates, a social context with flexible and open institutions and multi-level governance systems that allow for learning and increase adaptive capacity without foreclosing future development options”.

Adaptive Management in Flood Management and Water Engineering

Till 1927, the main flood policy of U.S. Army Corps of Engineers was "levees only". After the great flood of 1927, flood management by the reservoirs was also included. The concept of non-structural measures was some 50 years ago first used in the context of flood control, as a means to reduce the ever increasing damages, without unduly expanding the costly infrastructure. In that sense, NSM were perceived rather as complementary additions to the essentially structural solutions to flood control, in order to reduce costs and enhance efficiency. This concept has been changed in the last few decades by introduction of new approaches:

- Development of the new Swiss Safety concept for dams in 1985.
- Publication of “Manual on non-structural approaches to flood management” by ICID in 1999.
- Publication of ICOLD Bulletin on ICOLD, "Non-structural risk reduction measures; Benefits and costs for Dams in 2001.
- UNESCO (IHP-V) Workshop on "Non-structural measures for water management problems" in 2001.

- Publication of U. S. Army Corps of Engineers manual on "Adaptive Management for Water Resources Project Planning" in 2004.

- Publication of the proceeding of Q53 of ICID congress on Harmonic coexistence with floods in Beijing in 2005.

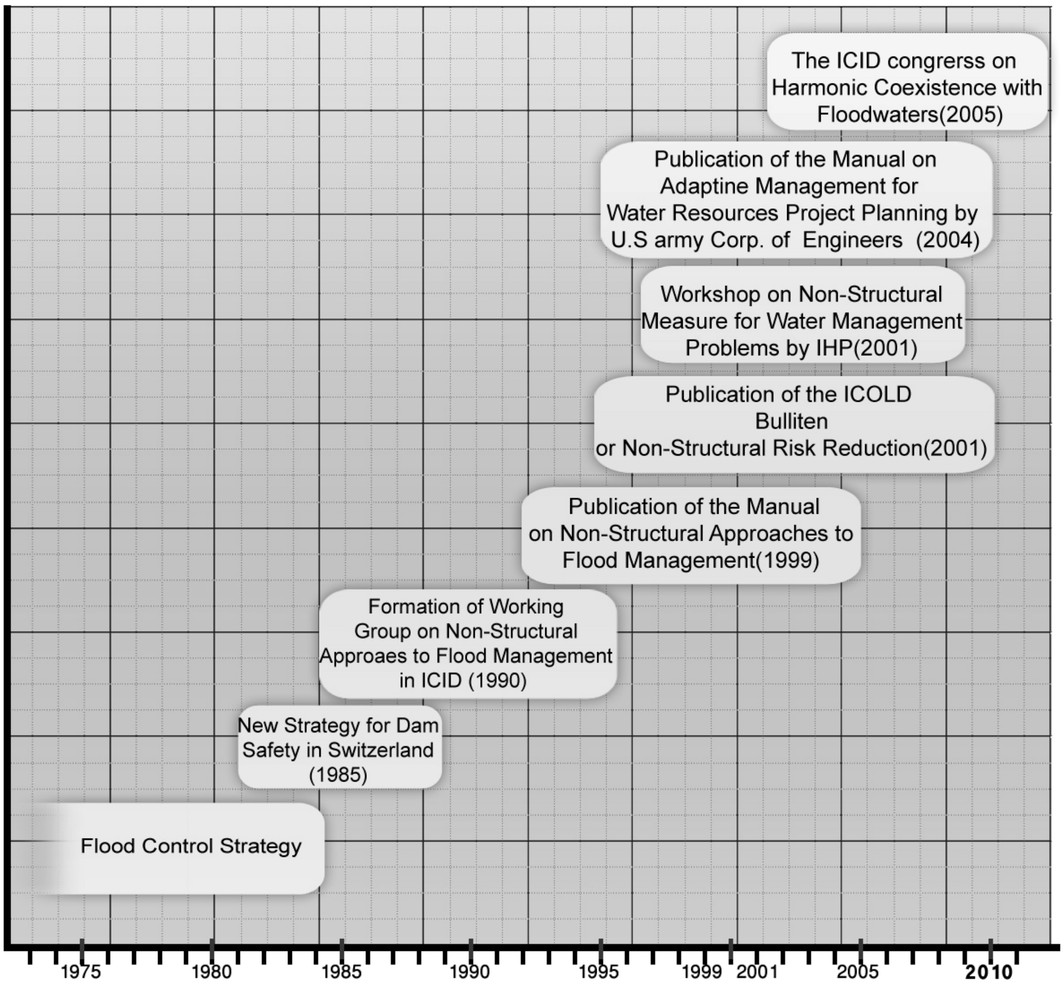

Figure 2. Evolution of non-structural approaches and adaptive management in flood management

Now in early years of 21st century, it has become obvious, that the approach to flood management is increasingly adaptive and non-structural: structural, engineering solutions appear as indispensable complements to the essentially non-structural, integrated water resources management, of which flood damage reduction is but an integral part.

Adaptive Management for Water resources planning

In the early 1800s the U. S. Congress first asked the U. S. Army Corps of Engineers (which was created in 1775) to improve navigation on the waterways of U. S. A. From that beginning, the Corps began a program of public works that has reshaped virtually all of the nation's river basins and coastal areas.

Now, at the beginning of the twenty-first century, the Corps' program is under intense scrutiny. Some of these same groups are pressing the administration, Congress, and the agency it self towards a new Corps mission, broadly described as environmental restoration.

It is just such conditions that led to the development of adaptive management as a concept and approach to allow managers to take action in the face of uncertainties, to enhance scientific knowledge and thereby reduce uncertainties, and to craft management regimes that respond to, and even take advantage of, unanticipated events. The Corps of Engineers has been incorporating adaptive management into some of its activities, particularly large-scale ecosystem restoration activities.

There have always been criticisms of Corps analytical methods and decision making, but the agency's engineering and planning expertise was long held in high regard by many observers. But the setting of U.S. water resources management changed in the latter part of the twentieth century. There were environmental consequences of previous economic development projects, laws were passed to protect the environment and endangered species, new concepts of ecosystem science and water management were developed, and there was increased recognition of long-term risks and uncertainties within water resources management.

The concept of "adaptive management" has gained attention as having the potential to help address these types of changes and challenges. Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a "trial and error" process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.

There are multiple views and definitions regarding adaptive management, but elements that have been identified in theory and in practice are: management objectives that are regularly revisited and accordingly revised, a model(s) of the system being managed, a range of management options, monitoring and evaluating outcomes of management actions, mechanisms for incorporating learning into future decisions, and a collaborative structure for stakeholder participation and learning. These elements have been traditionally viewed and promoted, to varying degrees, as essential to sound water resources management; adaptive management offers a framework for their integration. Implementation of adaptive management also provides the potential to respond in a timely manner to changing conditions, social objectives, and new knowledge. It can, therefore, help avoid costly or irreparable mistakes and unintended consequences.

U. S. Congress has expressly required the use of adaptive management in the Florida Everglades ecosystem restoration program. It is a core concept of plans to restore Louisiana's coastal ecosystems. Adaptive management promotes learning by experience; but learning from mistakes is difficult for both individuals and organizations, and it may be tempting to subvert adaptive management approaches when inevitable mistakes and setbacks occur.

In an effort to better understand the adaptive management concept and how it might be implemented to good effect within the Corps and its project operations, the Corps requested the National Research Council to convene a panel to provide advice on the subject. The Corps of Engineers began employing adaptive management approaches in the early 1990s.

Adaptive management's core principles emphasize concepts such as uncertainty, surprise, and resilience. These concepts run counter to traditional engineering planning concepts of deterministic systems, precision, and model predictions. Adaptive management stresses the value of variability and extremes in sustaining healthy ecosystems. Adaptive management will thus entail changes in operational styles and in organizational accountability.

Adaptive management may be particularly suited to large, complex ecosystem restoration projects, which entail large degrees of risk and uncertainty, multiple, and changing objectives, and phased components. Adaptive management can be especially important in multi-phase activities, as it can promote adaptation of ends and means based on lessons learned that lead to model improvements to support future decisions.

Adaptive management entails a spectrum of approaches. These range from "passive" programs, which focus on monitoring and evaluating outcomes from a particular policy choice, to more formal and rigorous "active" adaptive management, which designs management actions to test competing models of system behavior so that models can be improved for future decision making. Components of Adaptive Management by the Corps of Engineers are as follows:

1. Post-construction evaluations should be a standard for adaptive management of Corps projects and systems.

2. Stakeholder collaboration should be an integral component in the adaptive management of Corps projects and systems.

3. Independent experts should be periodically enlisted to provide advice on the organization adaptive management initiatives.

Adaptive Management Concepts and Rationale

During the twentieth century, scientists like Bohr and Heisenberg challenged traditional paradigms with discoveries and theorems that emphasized uncertainties, complexities, and the limits of scientific knowledge (Peat, 2002). These contrasting paradigms are today reflected in distinctly different scientific schools of thought. On one hand, a Newtonian vision of the world is based on stability and predictability of natural systems. On the other, the vision promoted by Bohr and Heisenberg recognizes that change and surprises are the essence of natural systems. Newtonian principles are appropriate when working in stable systems and for designing civil engineering structures, for example, but are not fully adequate when applied to complex, dynamic ecosystems.

Adaptive Management Applications

As the world changes, or as unanticipated consequences are revealed, organizations should adjust plans and operations to deal with the new conditions and to incorporate improved understanding.

Adaptive management is a commonsense strategy for addressing the reality of a changing and uncertain environment. Recognition of the need to adjust management strategies can derive from at least three broad sources. First, *scientific advances* can provide better understanding of the complex linkages between human activities and environmental impacts. The U. S. Army Corps has experienced such paradigm shifts, one of the most famous being the abandonment of its "levees only" strategy in the early twentieth century (Barry, 1997). Through much of the nineteenth century and the early twentieth century, the Corps of Engineers based its flood control program on the notion that levees were, by themselves, adequate for controlling all floods and that other measures (e.g., upstream reservoirs) were not necessary. Devastating floods along the lower Mississippi River in 1927 proved the inadequacy of this policy and ultimately resulted in the Corps moving toward a broader approach to manage flood risks. Second, *environmental changes and variability* affect the operations and impacts of Corps projects. For example, climatic variability may affect precipitation patterns, which in turn may affect the parameters of dam and reservoir operations (Rhodes et al., 1984).Thirdly, *shifts in social objectives and preferences* may challenge conventional operations schemes. In the United States, for example, the 1960s and 1970s marked a period of increasing concern over environmental issues.

Adaptive Management Theories, Frameworks, and Practices

Adaptive management seeks insights into the behavior of ecosystems that are utilized by humans, and it draws upon theories from ecosystem sciences, economics and social sciences, engineering, and other disciplines. Adaptive management incorporates and integrates concepts such as social learning, operations research, economic values, and political differences with ecosystem monitoring, models, and science.

Adaptive management aims to create policies that can help organizations, managers, and other stakeholders respond to, and even take advantage of, unanticipated events (Holling, 1978; Walters, 1986). Instead of seeking precise predictions of future conditions, adaptive management recognizes the uncertainties associated with forecasting future outcomes, and calls for consideration of a range of possible future outcomes (Walters, 1986). Management policies are designed to be flexible and are subject to adjustment in an iterative, social learning process (Lee, 1999).

Adaptive management is intended to increase the ability to fashion timely responses in the face of new information and in a setting of varied stakeholder objectives and preferences. It encourages stakeholders to bound disputes and discusses them in an orderly fashion while environmental uncertainties are being investigated and better understood.

Adaptive management can help reduce decision-making gridlock by making it clear that decisions are provisional, that there is often no “right” or “wrong” management decision, and that modifications are expected. Adaptive management should help stakeholders, managers, and elected officials and other decision makers recognize the limits of knowledge and the need to act on imperfect information.

Adaptive management is not simply a “trial and error” process, but rather represents a more systematic “learning while doing” process (Lee, 1999).

Some degree of learning is inevitable in almost any management approach; adaptive management is structured to make that learning more systematic and efficient.

A distinction is often made between adaptive management approaches that are “passive” and those that are “active.” Within “passive” adaptive management, a single, preferred course of action, based on existing information and understanding, is selected. Outcomes of management actions are monitored, and subsequent decisions are adjusted based on the outcomes. This approach contributes to learning and to more effective management, but it is limited in its ability to enhance scientific and management capabilities for conditions that go beyond the course of action selected. By contrast, an “active” adaptive management approach reviews information before management actions are taken. A range of competing, alternative system models of ecosystem and related responses (e.g. demographic changes; recreational uses), rather than a single model, is then developed. Management options are then chosen based upon evaluations of these alternative models. All modes of adaptive management require outcomes of management actions to be monitored.

Elements of adaptive management that have been identified in theories and practice are:

1. Management objectives that are regularly revisited and accordingly revised.

2. A model(s) of the system being managed.

3. A range of management choices.

4. Monitoring and evaluation of outcomes

5. A mechanism(s) for incorporating learning into future decisions.

6. A collaborative structure for stakeholder participation and learning.

Current and prospective Crops of Table 1 summarizes practices that were fairly standard as of a generation ago, as well as ways in which those practices are evolving).

Table1. Trends in the Evolution of Civil Engineering Design Practice

Nature of Change		
Broadening To	**From Traditional**	**Design Element**
System of projects	Project	**Scope**
Multiple and sometimes conflicting objectives	Single purpose	**Purpose**
Nonstructural	Structural	**Means**
Long-term Management	Construction	**Focus**
Extensive	Little	**Risk Recognition**

An important aspect of evolving concepts of engineering practice is the way uncertainty is recognized and addressed. It is today widely appreciated that many consequences of civil engineering investments cannot be precisely fore castled. Whether the objective is to take advantage of new opportunities or to insure against bad outcomes, the goal is to create the capacity to respond appropriately as new situations which may include unforeseen surprises develop. Flexibility over the life of the project is essential to effective development and functioning of civil engineering systems.

Adaptive management concepts and practices represent innovative, current thinking on resolving conflicting demands and adjusting to changing social preferences and priorities.

Many of adaptive management’s benefits come in the form of better knowledge of ecosystem response to management actions. This improved knowledge reduces uncertainties and should, therefore, improve management decisions. Benefits of better future management decisions will be realized in the future. These benefits, however, are difficult to measure and translate into dollars, the standard metric of economic analysis. The intangible nature of these benefits stands in contrast to the direct, up-front costs of adaptive management programs, such as ecosystem monitoring programs, scientific staff, and institutional support.

Holistic Design of Adaptive Hydraulic Structures

A Doctoral dissertation entitled 'holistic design of adaptive hydraulic structures' was presented in 1997 (Emami, 1997). The main strategies of the holistic design are to:

- Ensure a flexible and adaptive design in view of hydrosystems changes and the inherent uncertainties of water engineering.

- Establish the interdependence of hardware (structures) and software (management and knowledge) in design.

- Adapt to the stochastic nature of river flow by integration of seasonal characteristics and river forecasting.

- Learn while doing.

- Recognize the uncertainties of risks of project and design hydraulic structures to adapt to extreme events far larger than design parameters and remain inherently safe (structural ductility and resilience).

- Base the design on comprehensive management and flexibility.

- Enhance safety by 'designing' crisis management preceding the events and in real time for the structure an downstream population centers.
- Monitor hydro system and structures on a continuous basis.

Using FAST (Function Analysis System Technique) which is one of the main features of Value Engineering methodology, the Holistic design strategies are shown in Figure 1. FAST diagram interconnects the functions by How-Why logic.

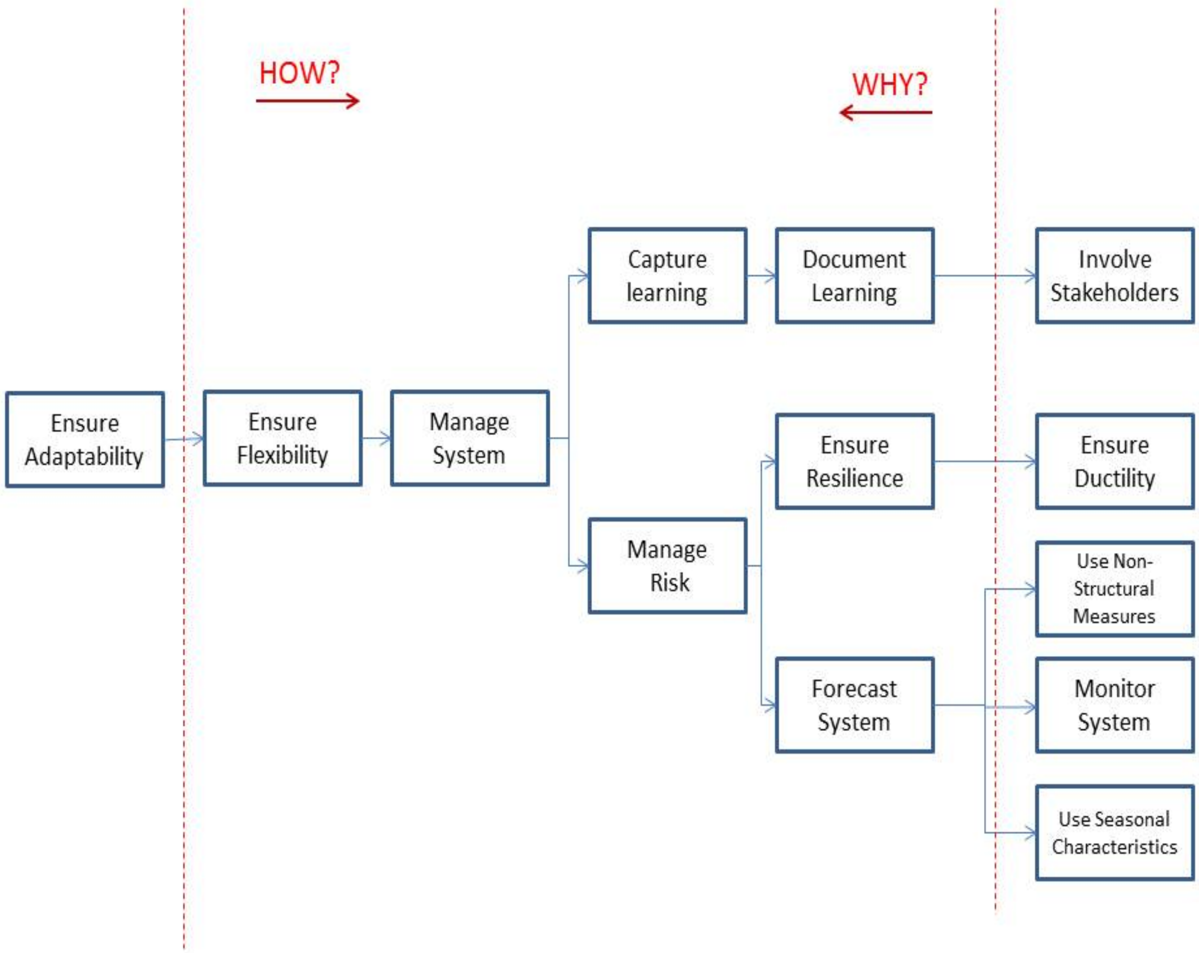

Figure 3. FAST diagram of Holistic Design of Adaptive Hydraulic Structures

In the last two decades, the strategies of Adaptive Flood Management (AFM) were successfully applied to a few large water projects in Iran. A summary of these cases studies are presented below.

Case Study #1: Adaptive flood management of Vanyar reservoir

In a value engineering study undertaken in 2003 on the spillway of Vanyar dam in North-West of Iran, the Kurit expert system guidelines on selection initial reservoir elevation in routing of the design flood and season characteristics resulted in considerable reduction of spillway length. The length of side channel spillway, which was 110 m in the base case was reduced to 40 m when a lower initial reservoir elevation for routing of the design floods in spring for wet years was proposed in the creative phase of the value engineering studies. The water resources modeling of the system demonstrated that if the decision for reservoir drawdown were based on the forecasting model, the draw down would not reduce the regulated flow of the reservoir. The intelligent operation proposed not only decreased the spillway cost by 40% and solved the geological problems at some part of the spillway, but also considerably would reduce the outflows of different floods in Tabriz, which is located just 5 km downstream of the dam. Finally the damages of flood inundation on the reservoir rim would be reduced substantially. It is interesting to note that a comprehensive Flood Forecasting and Warning system (FFWS), Emergency Action Plan (EAP), Decision Supporting System (DSS) have been designed for this project and based on the results of forecasting models for spring volume of Ajichay River in the last three years, a drastic improvement of the models and learning has been observed.

The general configuration of Vanyar Decision Supporting System (DSS) is illustrated in figure 5. As shown in the figure, it is envisioned that the synergy of long-term and short term forecasting models would enable the dam managers to cope with untimely or unexpected flood scenarios in order to increase the safety of downstream, upstream and the dam in diverse circumstances.

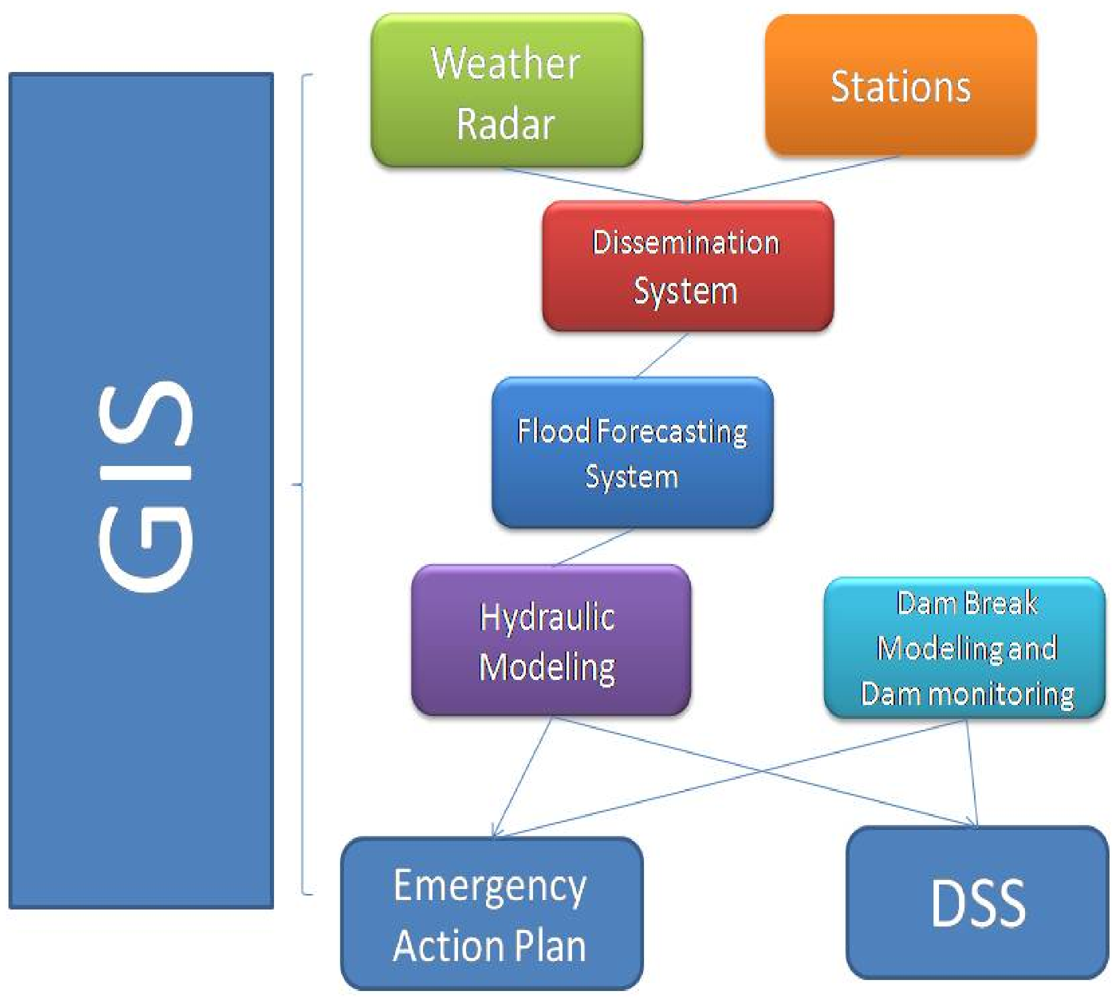

Figure 4.A general view of the comprehensive Ajichay Non-structural system (Monitoring, Forecasting, EAP and DSS

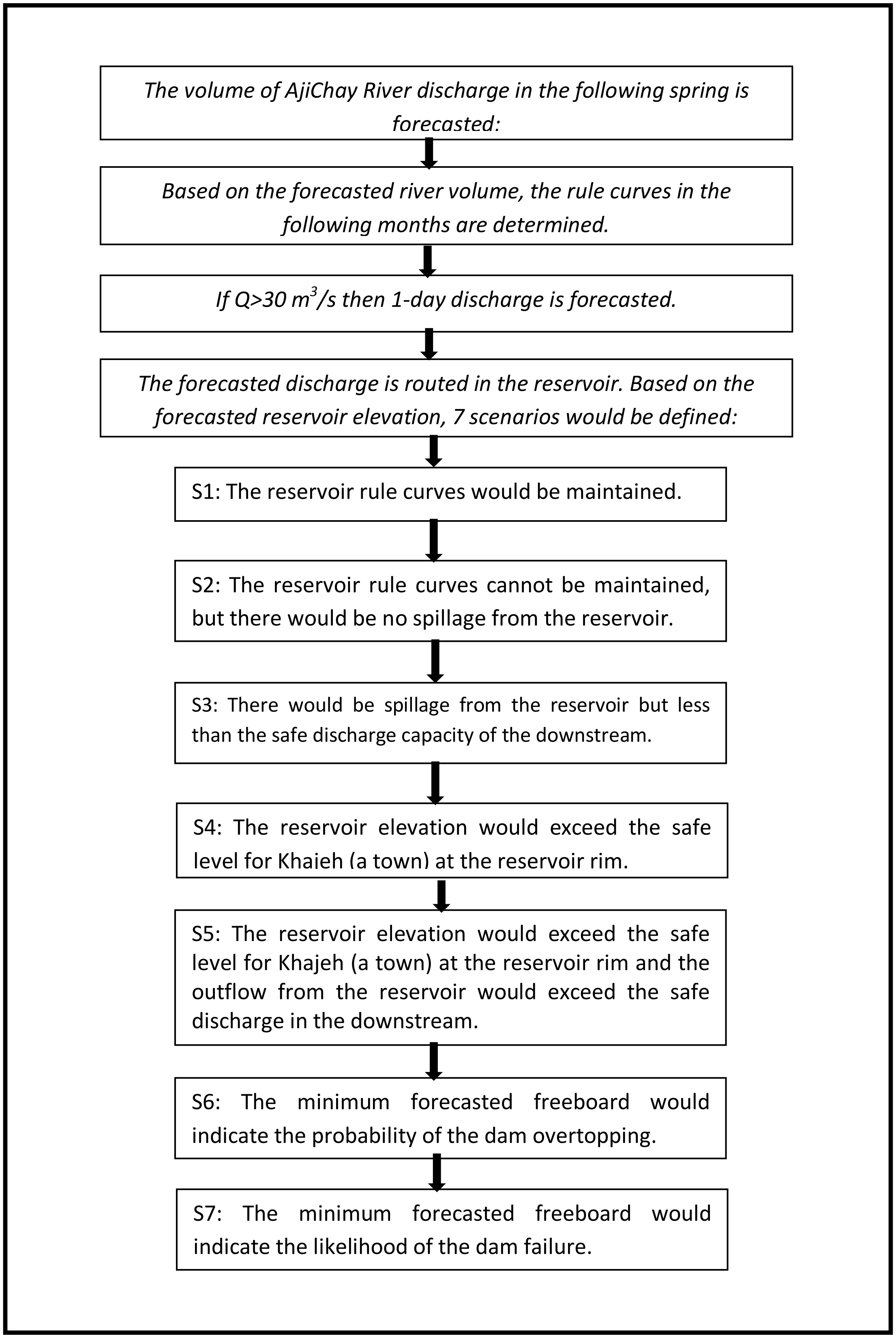

Figure 5. The general configuration of Vanyar DSS

Case Study Number 2: Early Impoundment of Karkheh dam

The Karkheh Dam is a large multi-purpose earthen embankment dam built in Iran on the Karkheh River in 2001. The dam is on the Karkheh River in the Northwestern province of Khuzestan, the closest city being Andimeshk to the east. It is 127 meters high and has a reservoir capacity of 5.9 billion cubic meters. The Karkheh Dam is designed to irrigate 320,000 hectares of land, produce 520 MW of hydro-electricity and prevent downstream floods. In 1956, studies began on the Karkheh Dam by the American company Development and Resources Corporation, which was headed by David E. Lilienthal, the former Chairman of the TVA. In 1990, the final studies were completed by Mahab Ghods Consulting Space Engineers. The construction of the Karkheh Dam started in 1992 and the dam was completed in 2001. During construction, 120 contractual and over eight consultative companies worked on the dam.

Based on the worldwide experiences of dam failures, the first filling of a dam is the most dangerous period in the life cycle of dams. In this context, a comprehensive study for first filling was undertaken in the last 20 months of construction. In the context of this study, the strategies of AFM were applied in an integrated approach. A day to day monitoring of the Karkheh basin was undertaken and climate forecasting models based on ENSO (El Nine Southern Oscillations) were utilized along with hydrological forecasting models. When the models predicted below average inflow in next spring in Feb. 2000, the impoundment of the reservoir started while the dam was still under construction and the embankment crest was below the spillway crest. The following spring was one of the driest seasons in the history of the river but a volume of 400 MCM of water stored in the reservoir in the previous winter saved the day !

Figure 6. A general View of Karkheh dam

Summaries and Conclusions

The most import challenge of the flood engineers in the 21st century is to design and construct safe and low cost hydraulic structures in the shortest time possible with uncertain design parameters. Solution of this problem will above all require adopting a holistic and adaptive approach. The main strategies of the holistic design are to :

- Ensure a flexible and adaptive design in view of hydrosystems changes and the inherent uncertainties of water engineering.
- Establish the interdependence of structural and non-structural approaches in design. In this context management of hydraulic structures should designed too.
- Adapt to the stochastic nature of river flow by integration of seasonal characteristics and river forecasting.
- Learning while doing.
- Recognize the uncertainties of risks of project and design hydraulic structures to adapt to extreme events far larger than design parameters and remain inherently safe (structural ductility and resilience).
- Base the design on comprehensive management and flexibility.
- Enhance safety by 'designing' emergency and crisis management preceding the events and in real time for the structure and downstream population centers.

In the past decade the holistic design has been used for several water projects including dam construction, flood management and value engineering studies. In all the cases the holistic design has resulted in enhanced safety and reduced cost and construction time.

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