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WORKSHOP : NON-STRUCTURAL ADAPTATIONS TO FLOOD MANAGEMENT

A PROCEDURE FOR EVALUATING THE VULNERABILITY OF HYDRAULIC CONSTRUCTIONS IN FLOOD PRONE AREAS

ENSO BASED CLIMATE FORECASTING FOR EARLY IMPOUNDMENT OF LARGE RESERVOIRS, CASE STUDY: KARKHEH DAM IN IRAN

ENSO BASE PRÉVISION CLIMATIQUE POUR MINIERS EARLY DE GRANDS RÉSERVOIRS, ÉTUDE DE CAS: KARKHEH DAM EN IRAN

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ABSTRACT

The El Niño Southern Oscillation, or ENSO, is a natural quasi-periodic redistribution of heat in the equatorial Pacific Ocean. For the first time in human history, the American scientists forecasted extreme floods in California and Florida six months in advance in the summer of 1997. In fact, the maximum annual precipitation in a period of 120 years was recorded in 1998. The mentioned forecasts were based on ENSO phenomena in the Pacific Ocean. Two years later, the synergy of ENSO based climate forecasts, seasonal flood characteristics and hydrological forecasts proved to be the key the early impoundment of Karkheh reservoir, the largest dam in Iran. The non-structural approaches adopted resulted in storing of 400 MCM in a very dry year which reduced the adverse effects of the drought. In this context it should be noted that a strong El Niño is forecasted for the next autumn and winter and climate forecasts can be used to enhance vigilance and reduce the casualties and damages in the countries with increased probability of floods such as Iran.

RÉSUMÉ

El Niño Southern Oscillation, ENSO, est une redistribution quasi-périodique naturelle de la chaleur dans l'océan Pacifique équatorial. Pour la première fois dans l'histoire humaine, les scientifiques américains ont pu prévoir six mois à l'avance des inondations extrêmes en Californie et en Floride pour l'été 1997. En fait, les précipitations annuelles maximales sur une période de 120 ans ont été enregistrées en 1998. Ces prévisions mentionnées étaient basées sur les phénomènes ENSO dans l'océan Pacifique. Deux ans plus tard, la synergie des prévisions climatiques basées sur ENSO, avec les caractéristiques des crues saisonnières et les prévisions hydrologiques se sont révélées être la clé de la mise en eau précoce du réservoir Karkheh, le plus grand barrage en Iran. Les approches non structurelles adoptées ont abouti à stocker 400 Mm3 dans une année très sèche, réduisant les effets négatifs de la sécheresse. Dans ce contexte, il convient de noter qu'un fort phénomène El Niño est prévu pour l'automne et l'hiver prochains, les prévisions climatiques peuvent être mobilisées pour améliorer la vigilance et réduire les pertes et les dommages dans les pays ayant une probabilité accrue d'inondations, tel que l'Iran

Keywords: Climate Forecasting- ENSO – Adaptive Management - Early Impoundment – Non-structural approaches

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1. Introduction

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 (Emami, 1998). 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 (Emami, 2012)(ICOLD,2001)(U.S. Army Corp. of Engineers, 2004):

- ❑ Adaptability (Changing Threat to Opportunity)
- ❑ Flexible Decision Making (to cope with uncertainties)
- ❑ Monitoring, forecasting 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

2. ENSO based climate forecasting

In its simplest explanation, E`l Niño, which occurs every 2 to 7 years, is an abnormal warming of the eastern Pacific waters that interferes with the normal trade wind patterns. The ripple effect from El Niño has been held responsible for everything from droughts in Asia to floods in California. In 1982, scientists began to believe that the El Niño phenomenon and its atmospheric counterpart—this Southern Oscillation—was perhaps the most important mechanism affecting weather patterns on time scales of a season out to a few years. The El Niño Southern Oscillation, or ENSO, is a natural quasi-periodic redistribution of heat in the equatorial Pacific Ocean. In broad terms, ENSO can be characterized as exhibiting one of three phases: warm, cold, and neutral (Figure 1). These phases, in turn, can be characterized by the distribution of sea surface temperatures in the Pacific. During the warm phase, the eastern equatorial Pacific is anomalously warm. The occurrence of this phase is commonly referred to as an El Niño event. During the cold phase, the eastern equatorial Pacific is anomalously cool. Finally, ENSO can exhibit a neutral phase during which the eastern equatorial Pacific is neither anomalously warm nor anomalously cold. Through its effects on atmospheric circulation, ENSO has a significant effect on regional climate on both sides of the Pacific. In many parts of the world, ENSO is the largest source of climate variability on the time scale of 1 to 10 years. In the United States, the clearest ENSO signal occurs in the southeast, where El Niño events are associated with cool, wet winters and warm, dry summers. El Niño events are also associated with reduced tropical storm activity in the Atlantic basin. Precipitation over the western United States is also affected. Since 1877, there have been around 31 El Niño events and 22 cold events. Thus, on average, an El Niño event occurs every 4 years. While the frequency of events fluctuates around this average, there is no evidence of a systematic change in the frequency over the historical period (Glantz, et al., 1991).

When an El Niño develops and unfolds, it changes the prevailing wind patterns over most of the earth. But it changes them in fairly complex ways. The result is that there are certain regions of the world where the effects of El Niño are fairly robust—what we would call robust—that is, you can count on them. The southeast portion of South America will be wetter than usual, in some cases very problematically wetter than usual. The northeast region of South America along the Atlantic coast will suffer drought. It is a very consistent signal. The southeast of the United States is pretty well regularly affected by El Niño. The close correlation of Florida flood events per year with ENSO is given in Figure 2. In the United States alone, the benefit versus cost for the forecasting capability proposed by NOAA is about 300 to 1.

An important caveat in relation to ENSO climate forecasting is as follows: In any variable pattern of weather, El Niño is only part of the story. It is becoming clear that El Niño—this fundamentally important phenomenon with its global manifestation—is one of a family of types of variability in the system (Lewis, et al., 2015).

3. Early Impoundment of Karkheh dam

3.1 Karkheh dam

The Karkheh Dam is the largest multi-purpose earthen embankment dam constructed in Iran. The dam is located on the Karkheh River in the Northwestern province of Khuzestan. It is 127 meters high and has a reservoir capacity of 5.9 billion cubic meters (Figure 1.). The Karkheh Dam was 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 an American consulting company. In 1990, the final studies were completed by Mahab Ghods Consulting 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.

Figure 1. A general View of Karkheh dam

3.2 Adaptive Flood Management for Early Impoundment

Based on the worldwide experiences of dam failures, the first filling of a reservoir is the most dangerous period in the life cycle of dams. In this context, a comprehensive study for the first filling of Karkheh dam was undertaken in the last 20 months of construction. In the context of this study, the strategies of adaptive flood management were applied in an integrated approach as follows:

- Seasonal flood characteristics of the river were studied and utilized to minimize the risk;
- A day to day monitoring of the Karkheh basin was undertaken;
- Forecasting models (climate forecasting models based on ENSO along with meteorological and hydrological forecasting models) were utilized.

The seasonal flood characteristics of the Karkheh River include large floods in autumn followed by small floods in winter due to low temperature and frost. In spring, snow melting and intense showers can produce very large floods. On the other hand, the accuracy of hydrological forecasting models would be substantially enhanced by the end of the winter. In the context of the studies for the early impoundment, teleconnection with ENSO played a key role (IWPDC, 2000).

3.3 Teleconnection

Teleconnection in atmospheric science refers to climate anomalies being related to each other at large distances (typically thousands of kilometers). Teleconnection studies for the inflow of the Karkheh River with ENSO is summarized in Table 1 and indicated a rather strong correlation as follows (IWPDC, 2000):

- During Strong El Niño events the average monthly flow of the river was more than long-term average in Nov. or Dec. or both.
- During Strong La Nina event the average monthly flow of the river was less than long-term average in both Nov. and Dec.
- During weak events the above mentioned correlations were observed for 80% (El Niño) and 70% (La Nina) of the events.

Artificial Neural Network Models (ANN) also verified the correlations indicated above.

ENSO	Number of Years	Montly Average in Oct. and Nov.
Strong EL Nino	7	In 7 years the average monthly flows were more than long term average in Oct. or Nov. or Both
Strong La Nina	6	In 6 years the average monthly flows were less than long term average in Oct. and Nov.
Weak EL nino	10	In 8 years the average monthly flows were more than long term average in Oct. or Nov. or Both
Weak La Nina	7	In 5 years the average monthly flows were less than long term average in Oct. and Nov.

Table 1. The teleconnection of ENSO and Karkheh Mean Monthly Flow

3-4 Impoundment of Karkheh reservoir in Early 2001

In the summer of 2000, a La Nina event was forecasted for the next autumn and winter. Consequently the models forecasted a dry autumn and these forecasts facilitated a safe impoundment as follows:

- In view of the greatly reduced probability of floods in the next autumn and winter, the 3 of the 4 culverts used for diversion of the river were closed and bottom out gates were installed.

- In midwinter 2001, when the composite climate-hydrological models forecasted below average inflow for the next spring, the impoundment of the reservoir started while the dam was still under construction and the embankment crest was below the spillway crest (impoundment with no spillway scenario!). 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 substantially mitigated the adverse impacts of the drought.

Conclusions

In view of worldwide experiences, it has become obvious that the approach to flood management is increasingly non-structural: structural solutions appear as indispensable complements to the increasing non-structural, integrated water resources management of which flood damage reduction is but an integral part. In the last 2 decades, the climate forecasting models have been effectively used for efficient management of floods and droughts. The early impoundment of Karkheh reservoir, the largest dam in Iran, in early 2001 is an illustrating case study. Finally it must be noted that a very strong El Niño is forecasted for the fall and winter of 2015 and this forecasts can be used to enhance vigilance and reduce the probable casualties and damages in the countries with increased probability of floods such as Iran.

REFERENCES

Emami K., "Adaptive Flood Management", ICID workshop on Adaptive Flood Management, Adelaide, Australia, 2012.

Emami, K, "Holistic design of adaptive hydraulic structures, doctoral dissertation". Sharif University of Technology. 1998

Glantz, M. H., Katz, R.W., and Nicholls, N. (eds.). Teleconnections linking worldwide climate anomalies: scientific basis and societal impact. Cambridge: Cambridge University Press, 1991.

ICOLD, "Non-structural risk reduction measures; Benefits and costs for Dams". ICOLD, 2001.

IWPDC, "Reports for early Impoundment of Karkheh Reservoirs", IWPDC, 2000.

Tong, Jiang; Zhang Qiang, Zhu Deming and Wu Yijin., " Yangtze floods and droughts (China) and teleconnections with ENSO activities (1470–2003)". Quaternary International 144 (2006). pp:29–37.

U.S. Army Corp of Engineers, "Adaptive Management for Water Resources Planning". U.S. Corp of Engineers, 2004.

Lewis S. C. and A. N. LeGrande, " Stability of ENSO and its tropical Pacific teleconnections" , Climate of the Past Discuss., 11, 1579–1613, 2015.