Water Resources Engineering Risk Assessment

Edited by
Jacques Ganoulis

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PREFACE

Safety and performance of engineering projects have been always of primary concern for water resources and environmental engineers. The estimation of the T-year flood and the control of pollutant concentrations in a sewage treatment plant are two typical examples. In the design stage, a predominant factor for the reliability of the engineering project is the control of various uncertainties of the inputs and also the sample and model uncertainties.

Risk and reliability analysis provide the theoretical framework of methods and tools to evaluate and quantify these uncertainties. It is the aim of this book, based mostly on the lectures presented in the NATO/ASI, Porto Carras, Greece, May 18-28 1991, to summarize the up-to-date developments on risk and reliability analysis as applied to water resources and environmental engineering.

From Tuscon to Porto Carras

In May 1985 a NATO ASI was held in Tuscon, Arizona, USA for the purpose of classifying various concepts of engineering reliability and risk in water resources . The present NATO ASI, held in Porto Carras, Greece, six years later (May 1991) may be considered as a continuation and an extension of the initial endeavor. The main purpose was to provide a unified approach on risk and reliability in both water quantity and water quality problems reflecting in the same time concepts and techniques that have emerged during this time period.

In the edited volume of the 1985 meeting in Tuscon (**Duckstein & Plate,** 1987) a general systems engineering framework is provided for the engineering risk and reliability in water resources. Reliability investigations are presented in two groups: reliability in hydraulic structures and reliability in water supply systems. In the same volume, the last chapter is devoted to decision making under uncertainty and under multiple objectives.

In the present volume the structural reliability and standard techniques for reservoir management under "non-crisis" conditions are de-emphasized. Alternatively more emphasis has been placed on the quantification and management of risks related to a broad spectrum of problems: from the hydrologic estimation of the exceedance probability (**Bobée et al.**), the stochastic estimation of pollution risk in rivers (**Plate**), coastal waters (**Ganoulis**) and groundwater (**Bagtzoglou et al.**) to new techniques, such as the "envelope" approach for dynamic risk analysis (**Haimes et al.**) and the fuzzy set approach (**Duckstein & Bogardi**).

These techniques appear to be applicable to both scientific and decision making aspects of water resources and environmental engineering.

Organisation

The present volume includes the following topics:

1. Engineering risk and reliability related to hydrologic extremes under uncertainty.
2. Risk of pollution in surface and ground water problems.
3. Modeling of decisions under various uncertainties using Bayesian and related techniques.
4. Embedding of risk into multiobjective decision models and conflict analysis schemes.

Furthermore the following aspects are emphasized:

a. Water quality problems receive now wider attention whether in rivers, groundwater, estuaries or coastal waters, both from methodological and case study points of view.
b. Further new risks that are posed or examined include those related to global climatic change and oil pollution (**Stakhiv, Dracup & Kendall, Seip**). Concerning global climatic change the introduction of paleofloods and tree-ring information into the data base seems to be an interesting development (**Enzel et al., Ely et al., Dracup & Kendall**).
c. The results of applying more than one technique to the same problem are extensively compared, for example:
   - systems analysis versus water resources engineering (**Parent et al.**)
   - use of different stochastic simulation techniques to account for uncertainties in the analysis of seashore protection measures (**Stakhiv et al.**)
   - model versus sample and other uncertainties (**Bernier**)
   - remote sensing versus numerical models (**Caussade**)

With the above considerations, the present volume is organized in four parts

(1) Uncertainty analysis of hydrologic inputs
(2) Quantification of risks in water quantity and quality problems
(3) Risk management in water resources and environmental engineering
(4) Case studies

The ***first part*** deals with various aspects of input uncertainty such as the randomness or natural uncertainties and the sample uncertainties. Here the probability of exceedance (**Bobée et al., Rasmussen**) and the reliability of estimating hydrologic extremes such as droughts (**Correia et al.**) and floods (**Enzel et al., Ely et al.**) are considered together with the uncertainties in collecting groundwater quantity and quality data (**DeBacker**) and the use of remote sensing for oceanographic and coastal applications (**Gastellu-Etchegorry**).

The ***second part*** is devoted mainly to risk quantification i.e. the probability of the occurence of an adverse event. This part starts with a paper by **Parent** dealing with the stochastic dynamic hydrological systems. Using conceptual stochastic simulation and probabilistic modelling, risks of water pollution can be quantified in rivers (**Plate**), coastal waters (**Ganoulis**) and groundwater (**Bagtzoglou et al.**). The Bayes approach can be used not only in accounting sampling uncertainties but also modelling uncertainties (**Bernier**). The paper by **Duckstein & Bogardi** on the use of fuzzy sets and fuzzy arithmetic concludes this part and demonstrates that this relatively new technique is useful not only to quantify risks but also the expected losses corresponding to each action.

The ***thirt part*** of the present volume deals with risk management. Here the risks have been identified and, as much as possible, quantified. Various criteria have been defined to characterize risk, including performance indices related to effect of uncertainty. Some of these criteria may be probabilistic (mean and variance of a contamination mass in a polluted aquifer,**Woldt et al.**) or may be fuzzy (probability of ecological damage, **Stansbury et al.**). In any case, risk management provides the means to investigate the mitigation of the consequences of risks. For this purpose, trade-offs may be made at increasing by high levels between the various risk indications. For example, one risk may be traded off against another one at a certain level, and an overall risk index may be traded off against an overall cost at a higher level (**Woldt et al.**).A very important demonstration of how risk analysis can be useful to face new challenging problems such as the engineering implications from a potential sea level rise due to the climate change is given in the **Stakhiv et al.** paper.A multiobjective dynamic risk analysis is proposed by **Haimes et al.** to produce optimal flood warning threshold.Two papers on multicriterion reliability analysis are included in this part: the first by **Duckstein et al.** deals with a stochastic type estimation of risks in a hydrologic framework and the second by **Dahab & Lee** uses the fuzzy approach in the environmental engineering context.(short contribution). The operational control of denitrification in sewage treatment plants is the topic described in the short contribution of **Stamou**.

Some characteristic risk related case studies are presented in the ***fourth part***. **Parent et al.** show the application of system analysis and hydrological modeling for the real time operation of the NESTE water system in France. Drought analyses related to climate changes in the Colorado river basin are applied by **Dracup & Kendall**.The three papers which conclude this part deal with problem of coastal pollution : the first by **Caussade** for the suspended sediment transport in the Gambia estuary, the second by **Samsunlu et al.** for the sewage coastal pollution in Istanbul and the third by **Seip** for the oil pollution of the sea in Norway.

Risk and reliability is a relatively new subject in water resources and environmental engineering. As a contribution to understanding and using this powerful tool, the present volume is aimed to serve as a textbook. This is the main reason to start with an introductory paper by **Ganoulis, Duckstein & Bogardi**. In this text the general framework for risk analysis is presented from the traditional engineering (conceptual modeling) rather than from the systems engineering point of view. Methods and tools from stochastic modeling and fuzzy sets are also presented in this paper.

It is with great pleasure that I would like to acknowledge here the sponsors of this meeting: mainly the NATO Scientific Affairs Division,the Aristotle University of Thessaloniki,the City of Thessaloniki, and the National Power Corporation of Greece (DEI).Particular thanks are addressed to Dr. **Luis Vega Da Cunha**, Director of the NATO/ASI program for his efficient help and assistance. I want to gratefully recognize here the friendly help of the organizing committee: **Bernard Bobée, Lucien Duckstein** and **Francisco Nunes Correia**. In particular I wish to thank: colleagues and friends **Lucien Duckstein, Istvan Bogardi** and **Erich Plate** for their help during the meeting and reviewing part of the papers that appear in this book; staff and graduate students from the Aristotle University of Thessaloniki **Marios Vafiadis, Yiannis Mylopoulos, Petros Anagnostopoulos, Nikos Theodossiou and Themis Mavroidis**; technical assistants **Gina Mavidou** and **Olympia Sortikou**, who also has typed parts of the final manuscript; and last but not least the oustanding lecturers and participants in this ASI. We have all worked hard in Porto Carras. I am sure that the beauty of the site, the local conditions and the proximity of the Mount Athos may have increased our intellectual effort and inspiration to further our knowledge of risk and reliability in water resources engineering by another small step.

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INTRODUCTION

RISK ANALYSIS OF WATER QUANTITY AND QUALITY PROBLEMS: THE ENGINEERING APPROACH

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ABSTRACT

A unified approach to risk analysis in water quantity and quality problems is presented. This is done by overviewing the definitions and methodologies for risk and reliability analysis in water resources and environmental engineering, including the concepts of fuzzy sets.The various steps to be undertaken for a comprehensive application of engineering risk analysis to a specific problem are first analyzed. These are (1) hazard identification, (2) risk quantification, (3) consequences of risk, (4) perception of the consequences and (5) risk management. Then, methods and tools used in uncertainty analysis, stochastic simulation and the fuzzy set approach are summarized.

1.- INTRODUCTION

The aim of this paper is twofold

(1) to present a unified approach for engineering risk and reliability analysis in water quantity and quality problems

(2) to review the existing methodologies for engineering risk and reliability analysis, especially the stochastic and the fuzzy set techniques.

The approach followed herein is more from the traditional engineering point of view dealing with conceptual modelling and simulation, than from the systems engineering point of view where the system is considered as a black-box (Duckstein et al., 1987). Water resources engineers follow the traditional way to face the physical problems they have, which consists mainly of the following stages

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- Definition of the problem
- Formulation of a model
- Solution

Usually the problem is defined by a set of physical parameters and also the input and output variables. In groundwater flow the physical parameters are, for example, the porosity and the aquifer transmissivity. In coastal pollution they could be the eddy viscosity, the Coriolis coefficient and the turbulent dispersion tensor. In real situations examples of inputs or independent variables are the precipitation rate, the aquifer recharge and the pollutant loads discharging into the sea. The output or dependent variables could be the dissolved oxygen concentration, the velocity of the flow and the free surface variation .

According to the specific objectives of the engineering design and the existing standards, some of the output variables have to take on values belonging to a given interval or set. For example, the value of the dissolved oxygen concentration must exceed 5 ppm or the piezometric height must be below to a given value. "Crisis" conditions and losses are expected when the above conditions are not fulfilled. Generally speaking the engineering risk is a quantitative measure for accounting the expected losses in situations when an "incident" or a "failure" has occured.

In water resources and environmental engineering the main problem for evaluating the risk and reliability is that the physical parameters and the inputs of the system, because of the natural variability in space and time, show random deviations. To this natural randomness, one must add various other uncertainties due to the scarcity of the information concerning the inputs, the value of parameters (measurement and sampling uncertainties) and also the imperfection of the models (modelling uncertainties). It follows that the outputs are not deterministic, but they also show random variations. For dealing with randomness and uncertainties, risk analysis provides a general theoretical framework. This is based on the uncertainty analysis, the assessment of risk and the decision under risk conditions.

From the above considerations the organisation of this paper is the following. First a definition of the engineering risk and the various steps to follow for risk analysis are summarized. Then the methods for uncertainty analysis are reviewed from two point of views: the stochastic modelling and the fuzzy set approach. Risk assessment and risk management are further analysed before the conclusions are given.

2.- DEFINITION OF THE ENGINEERING AND HEALTH RISKS

In analysing a physical problem there is a characteristic variable, usually considered as an output which describes a specific situation. This characteristic variable is usually called ***"load"*** or ***"exposure"*** λ.