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Ehsan Goodarzi
Mina Ziaei
Edward Zia Hosseinipour

Introduction to Optimization Analysis in Hydrosystem Engineering

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Ehsan Goodarzi
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, GA
USA

Edward Zia Hosseinipour
Ventura County Watershed Protection District
Ventura, CA
USA

Mina Ziaei
Department of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, GA
USA

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To my lovely wife, Mina

Preface

Population increase and socioeconomic rise of developing countries in many parts of the world has escalated the water demand for various uses including agriculture, municipal, recreational, and industrial demands. The increased demands in the past few decades have put severe stresses on the available water resources across the world particularly in arid and semi-arid regions. Hence, optimal management of water resources is a crucial issue and it is imperative to adopt realistic policies to ensure that water is used more efficiently in various sectors. In this book, we present the latest tools and methods to assist the students, researchers, engineers, and water managers to properly conceptualize and formulate the resource allocation problems, and deal appropriately with the complexity of constraints in water demand and available supplies. Although existing references supply total information relevant to the optimization analysis in water resources engineering, providing a book for undergraduate and graduate students and newcomers to this field is a requirement. In other words, what is needed is to present concepts more simply on the basics of optimization theories, get directly to the principal points, and apply simple examples in preparation for the use of more advanced texts.

In this book, the basics of linear and nonlinear optimization analysis for both single and multiobjective problems in conjunction with several examples with various levels of complexity in different fields of water resources engineering are presented. The main advantages of the current book rather than existing publications briefly are:

1. The authors' idea is to use simple examples and solve them step by step as the best way to introduce the materials in the book, and also to provide useful information to better understand the implementation of theoretical concepts. Hence, each chapter of the book contains some examples related to the basic principles of linear and nonlinear optimization analysis for both single and multiobjective problems (Chaps. 2–4).
2. As EXCEL, LINGO, and MATLAB are three of the well-known computer programs used today in optimization analysis, the process of solving optimization problems using those programs are presented in details as an alternative. This characteristic teaches the application of the noted computer programs in optimization analysis and makes analyzing, organizing, interpreting, and presenting results quick and easy (Chap. 5).

3. Real case studies are important resources for students to apply theoretical formulas, and computer programs to analyze real events. Hence, three real case studies as a valuable source for students, practitioners, and researchers are presented in the last chapters of book to show how the optimization concepts and theoretical formulas are used in analyzing real world problems (Chaps. 6–8). The case studies in brief are;
   - Reservoir Optimization and Simulation Modeling,
   - Reservoir Operation Management by Optimization and Stochastic Simulation, and
   - Water supply optimization in central Florida (simulation-optimization using integrated surface and groundwater modeling to allocate groundwater pumping that is protective of the natural ecosystem while meeting water supply demands of over two million people using a mix of surface water, groundwater, and desalinated water).
4. Finally, complete lists of most optimization studies on hydrosystem engineering (1963–2013) are presented in the Appendix of the book in table format. These tables include authors' names, dates of study, and a brief description of their work. With the help of these tables, readers can easily find all previous studies related to hydrosystem optimization analyses that may of particular interest to them.

To sum up, the main purpose of this book is to serve as a guide for conducting and incorporating optimization analyses in water resource planning processes. This book's main theme is to improve the understanding of the quantity and quality of information we have, and the importance of information we do not have, for the take only out purpose of improving decision making. The principal audiences of this book are undergraduate and graduate students of water engineering and all new researchers who are interested in academic research associate with optimization analysis as well as practitioners in the field of water resources management. Furthermore, this book can be used as reference for teaching in various fields of water engineering including: hydrology, hydraulic, water resources analysis, water quality analysis, etc. This book is also a useful reference for practicing engineers/professionals as well as students and individual researchers. They can apply optimization analysis as a useful tool to make best informed decisions when designing for unaccounted loads.

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Contents

Chapter 1
Importance of Optimization Analysis

Abstract This introductory chapter introduces the challenges that the water professionals will encounter in water management and allocation of water supply, factors that impact the water availability, water-energy-climate change relationships, water transfer and the role of various stakeholders, and finally policy decisions deriving the investments needs for planning and maintaining water supply systems.

1.1 Introduction

The world's readily available fresh water resources are becoming increasingly scarce due to higher demands by municipal, industrial, recreational, and agricultural sectors mostly because of population increase and higher standards of living in many areas, but also in part due to changes in land use and global climate change as a result of rapid development. In fact, the nexus between water and energy use seems to be a real issue that needs the attention of decision makers at all levels of governments and international organizations. The water energy nexus and related stresses do not subscribe to jurisdictional and political boundaries recognized nationally or internationally, and hence requires multi-organizational/ stakeholders solutions. Effective management of natural and water resources is becoming one of the most important challenges of our era to resolve, for maintaining and/or improving the living standards we enjoy in the developed and developing counties. In addition, the relations between energy, water, food, and environmental issues must be considered carefully in the development of water management plans and ultimately towards the goal of Integrated Regional Water Management (IRWM) Plan which is closely tied to sound watershed planning. The realities of water management include a limit to the availability of water whether local or imported supplies. This places a greater emphasis on innovative local/ regional projects that are multi-faceted and multi-purpose considering a holistic approach and consensus from various stakeholders. The water professionals must

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focus on many aspects when performing initial studies as a building block for water management plan developments, those include:

1. Future water supply availability/reliability,
2. Direct and indirect municipal/irrigation water reuse,
3. Water quality through salinity management and desalting opportunities,
4. Water projects and tie-into climate change adaptation,
5. Future funding needs and revenue streams,
6. What are the pros and cons of various funding options? As well as other site specific consideration.

To overcome the stresses on natural resources and in particular the fresh water supply sources multi-purpose and multi-objective water/natural resources management is taking root across the world. These days we see professionals in various fields of environmental and water resources engineering as well as allied disciplines of economics and social sciences collaborate to develop water resources management solutions that meet the urban, agriculture, industrial, habitat, environmental, recreational, and ecosystems requirements with constraints and priorities that must be consensus based by the stakeholders.

Water is a valuable resource everywhere in the world even areas that have seemingly plenty of precipitation. For example, although southeastern USA and Great Lakes states in Midwest receive above average rainfall with respect to other regions of the world, these areas still have water management challenges because of extreme events, water quality issues and management of non-point source pollution. The world is facing water supply challenges that will test the technical and managerial skills of trained professionals and the expertise of water scientists to the fullest extent in the next two–three decades. The effects of climate change, extreme floods and the economic and structural damages by frequent floods, pollution from urban and agricultural run-off, require collaboration from multitude of engineering and scientific experts as well as other stakeholders. In short, often there are competing interests in managing and protecting this vital resource in every region of the world. One area of utmost importance is the key component of how stakeholders consider water issues and make appropriate policy decisions or rank different priorities during water shortage and other emergencies.

Water management requires input from a multidisciplinary team from hydrologists to ecologists and other experts. To assess the availability of water for various uses under different conditions experts often develop water management models for a proposed project. These models often look at all sources available considering economics, water quality, specific use, and socioeconomic issues. For example, specialists may be looking at the hydrogeology of the area (ground and surface water interaction) in high water table conditions like much of south and central Florida and how exploitation of a water source impacts the other and the surrounding ecosystem; the economic aspects of water use and the impact of water use on the environment is of great interests to social scientists and ecologists. For instance, the potential relation between the ecosystem value and economic benefits of water use has been studied by ecological economists over the last decades.

Climate scientists also are looking at the effects of climate change and variability on water availability and scarcity, while behavioral scientists are examining people's biases and beliefs and the effects on the policy and decision making process.

1.2 Challenges Facing Water Management and Policy Professionals

Water resources management presents a variety of challenges, and growing world population make certain demands on the existing water resources across the world. Industry and industrial waste management cause other impacts, while agricultural water use bring about a variety of challenges from meeting water demand during droughts to soil water logging, salinization to nutrient and pesticide migration to groundwater aquifers and surface waters. Economic development and vitality is quite simply dependent on water availability at a reasonable price.

Water resources are among the most important factors which could be affected by climate changes and recent global warming. In addition, increasing water use in turn can increase the negative impacts of climate changes on ecosystems and local hydro-climate. With most developments the environment typically gets short-changed, that is why we need to look at ecosystem sustainability as part of the equation. Engineers need to work closely with economists, information technologists, and ecologists for information on the economic value of ecosystem services and the impacts of water use on ecosystems. Resource management professionals want to figure out how we can support both ecosystem protection and economic development with the limited amount of available water. This requires managing the water supplies using schemes that can take into account various objectives and constraints with given priorities, this is called "optimization". The water management system that uses optimization is amenable to an adaptive management approach, based on various scenarios, which the study team can analyze and provide the results to the stakeholders for informed decision making. For example in a given area the scenarios may assume significant sea level rise and its impact on groundwater availability and quality degradation, rainfall and temperature changes over land, and a range of population and economic growth rates, and economic trade off among various uses.

Various stakeholders as well as scientists/engineers participate in the study helping the team in the course of developing appropriate plans for water management to find out public support on data and latest technological tools. The water resources professionals job is not only to solve the problem of water scarcity in every region, say for example in south Florida or southern California, rather to use a regional example as a case study to see how multiple stakeholders can cope with complex issues and move towards more sustainable water use on a consensus based approach that optimizes the use of available supplies simply because there are very limited additional sources often at much higher costs. Another area that requires input from water professionals as well as social scientist, economists and well informed stakeholders is considering reclaimed water as an available resource that can be used for various uses including municipal supply.

1.3 Local, Regional, and International Competition for Water and Ensuing Conflicts

In 2010 United Nations (U.N.) General Assembly declared 2013 as the International Year of Water Cooperation (IYWC). The U.N. is aware about the competition over the existing finite fresh water resources in the world. Current and past water conflicts and disputes have included confrontations between countries in the Middle East (Israel and Jordan, Israel and Lebanon, Turkey and Iraq, Palestine and Israel, etc.), in Southwest Asia (India and Pakistan, India and Bangladesh), in Africa (Egypt, Sudan and Ethiopia), and in South America (Bolivia, Peru and Chile), among many other places. Even within countries there are sometimes conflicts among different regions over water allocations of trans-boundary water resources and inter-basin transfers; for example in the USA, states of Alabama, Georgia and Florida have been fighting for decades over *Apalachicola-Chattahoochee-Flint River System* (ACF) and tributaries' inflow that end up in the Gulf of Mexico; and Colorado River transfer to California, Nevada and Arizona has been a source of hot debates for the past few decades; in central west Iran, water transfer from Zayandehrud in Isfahan to Yazd and from Karoon Basin to Zayandehrud Basin have caused local protests and in some cases physical conflicts. Another recent example is the damming of tributaries of Lake Urmia in northwest Iran which has caused the lake to shrink significantly posing irreversible ecological damage in the region and a lively national debate on dam building and irrigation water use (Fig. 1.1).

In the case of ACF, water allocation and establishment of Minimum Flows and Levels (MFLs) required for aquatic and ecologic health of downstream habitats especially during low flows and droughts was a source of conflict that took decades of negotiations and law suits and eventually an act of US Congress to develop an agreement among tri-states which was hard to accept by the parties, but their best options was to agree to share the limited resource rather than devoting time and money to endless conflict resolution (Fig. 1.2).

Conflicts like these have shown that the water professional/managers need not only to be well versed in the science and engineering aspect, but also need knowledge of applicable laws, regulations, negotiation skills and applied optimization principles in order to formulate feasible options that can be looked at as win–win for all parties involved. So, the upcoming conflicts will be extremely dependent on the human ability to deal with the water demand challenges; if we are able to increase water use efficiency and productivity such that we can free up

Fig. 1.1 Lake Urmia, the third largest salt water lake on earth at **a** 2003, and **b** 2010 (Payvand 2011)

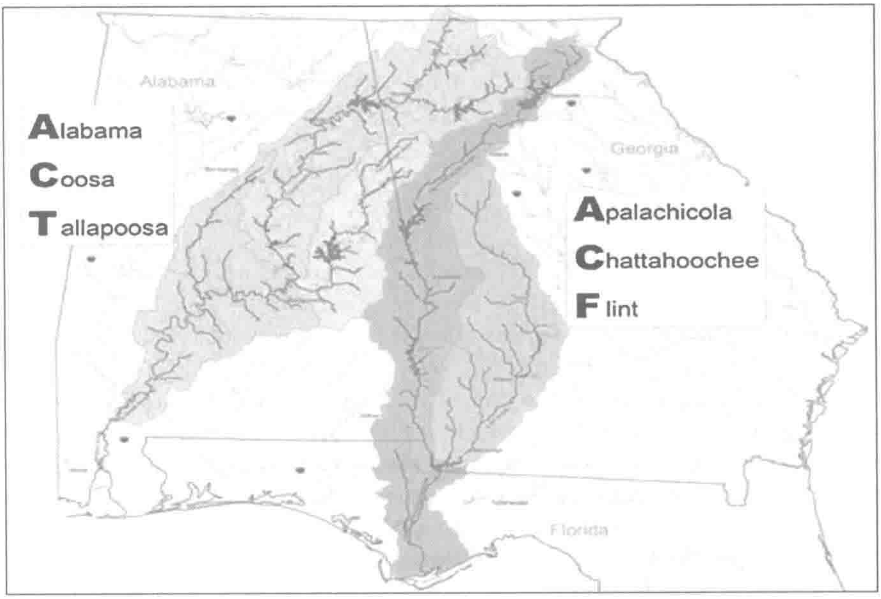

Fig. 1.2 Map of the ACF river basin watershed in the southeast USA showing the Apalachicola river and its two main tributaries, the Chattahoochee river and Flint river (Atlanta Regional Commission 2010)

water resources for protecting our environment, thereby ensuring the sustainability of the supply, and allowing for new users and uses, it will be easier to cooperate. If we cannot manage the available water demands, water management will become difficult like a zero-sum exercise, and so there would be permanent challenges on the available water resources.

According to the recent figures, nearly 800 million people in the world live without safe water, that is, roughly 15 % of the world population. Some 2.5 billion others live without access to sanitation, about 40 % of the world's population (United Nation Water 2013). These figures portray a grim scenario for political and social stability in many areas of the world for the foreseeable future: ethnic conflicts, regional tensions, political instability and mass migrations would prevail without immediate actions by governments and international organizations.

In the not too distant future, many countries will certainly face water related problems including shortages, water quality issues, epidemics due to contaminated water, or floods, and these problem increase the risk of instability and regional tensions (Global Water Security: Intelligence Community Assessment 2012). In this report these issues are connected to a world where the population is growing fast and the demand for freshwater is growing even faster. Therefore, close coordination and cooperation between various sectors in governments, NGOs, international organizations is of fundamental importance if we are to successfully share and manage our most precious resource (fresh water), for which we need reliable and defensible information to make sound and consensus based decisions.

To address these issues there is a need to cooperate with players outside the water sector, to foster collaboration between the various decision-making entities, between the private, public and civic sectors as well as between actors who work in water research, public policy and public relations. That is, only through sound and forward-looking consensus based partnerships a water wise world may be achieved. Because of population growth and pressures on water and natural resources within and among nations, sound and fair resource management is a clear imperative; water professionals will have no time to waste to come up with a solution to natural resources management in general, and water resources in particular.

One area of great need is the optimal management and operation of existing reservoirs and water allocation which are critical issues in sustainable water resource management due to increasing water demand by various sectors. Multiplicity of stockholders with different objectives and especially water utilities make reservoir operation and other sources of available water a complicated problem with a variety of constraints, and at times conflicting objectives to be met. In such cases, the conflict resolution models can be efficiently used to determine the optimal water allocation scheme considering the utility and relative authority of different stakeholders. Water resources planning and management is a combined process of sharing water that very often involves specific difficulties and complex decisions on resolving conflicts among decision makers, water users and stakeholders. Because of limitations on the quantity and quality of water resources, the optimal operation of reservoirs in a watershed is very important for providing a secure water supply from a system's point of view, Karamouz et al. (2003) discuss this issue in details.