

### Irrigation Engineering

This textbook provides a comprehensive treatment of irrigation engineering for advanced undergraduates and graduate students. It does not require a background in calculus, hydrology, or hydraulics, offering a one-stop overview of the entire field of study. It includes everything a student of irrigation engineering needs to know: concepts of climate, soils, crops, water quality, hydrology, and hydraulics, as well as their application to design and environmental management. To demonstrate the practical applications of the theories discussed, there are over 500 worked examples and end-of-chapter exercises. The exercises allow readers to solve real-world problems and apply the information they've learned to a diverse range of scenarios. To further prepare students for their future careers, each chapter includes many illustrative diagrams and tables containing data to help design irrigation systems. For instructors' use when planning and teaching, a solutions manual can be found online alongside a suite of PowerPoint lecture slides.

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# Irrigation Engineering

Principles, Processes, Procedures, Design,  
and Management

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VPS: Wife, Anita, who is no more; son, Vinay;  
daughter, Arti; daughter-in-law, Sonali; son-in-law,  
Vamsi; and grandsons: Ronin, Kayden, and Davin

QS: Parents and husband, Yun



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## Preface

Food security is a major concern, especially in developing countries, and this concern is being heightened by increasing population and climatic vagaries and change causing higher uncertainty in the space–time distribution of rainfall, rising standards of living leading to greater demand for food and greater wastage, inadequate facilities for grain storage and transport, and improper soil and water management. Productive agriculture is therefore fundamental to sustained food security, which is not possible without irrigation. Irrigation is also needed for transforming non-agricultural land, such as wasteland, into agricultural land, and less productive lands into more productive lands.

Irrigation has many aspects, such as agricultural, environmental, engineering, design, operation, and management, which together constitute a vast discipline. Over the years, irrigation engineering has branched out into canal irrigation, tubewell irrigation, and agricultural irrigation. Canal irrigation primarily entails design, operation, and management of canal systems that include canals, gates and diversion systems, and delivery systems. This is a discipline in civil engineering, but agricultural engineers also deal with some aspects of canals – especially small canals. It goes without saying that climatic, soil, and crop characteristics are considered in the design and operation of these canal systems. Tubewell irrigation involves design, operation, and management of tubewells. Since tubewells are constructed in agricultural lands, they primarily fall within the discipline of agricultural engineering, although civil engineering is also concerned with the design and operation of tubewells. Agricultural or farm irrigation is a major discipline in agricultural engineering, although many civil engineering aspects are involved therein. Because of increasing concern for the environment, diminishing availability of water, and growing incorporation of socio-political, economic, legal, and administrative issues, irrigation engineering has taken on a much broader scope and no single book can cover all aspects in complete detail.

There are many excellent authored and edited books on agricultural irrigation engineering. However, many of these books are at an advanced level or at the graduate level, and much work is needed to extract material that will be suitable for a one-semester undergraduate course in agricultural irrigation engineering. Furthermore, there are several aspects that an undergraduate student learning irrigation engineering for the first time needs to understand but which are not covered. Thus, a book primarily designed for an undergraduate course in irrigation engineering seems to be lacking. This book aims at filling this gap. To help the student appreciate the importance of irrigation engineering, a large number of solved problems are included in each chapter and a number of end-of-chapter problems are provided that are solved in the solutions manual that accompanies this book.

Introducing agricultural irrigation, including definitions, needs, benefits, and limitations of irrigation; food security; development of irrigation worldwide and in the United States; impacts of global warming and climate change; environmental concern; and the future of irrigation in Chapter 1, the subject matter of the book is divided into seven parts. Part I discusses fundamentals spanning six chapters. Chapter 2 deals with those aspects of climate that are pertinent to agricultural irrigation, such as weather and climate, types of climate, causes of climate variability, meteorological variables, the Earth system, and the greenhouse effect. Sources and availability of water are described in Chapter 3. Both surface water and subsurface water sources, availability of water, water sharing, and allocation are included.

In almost all countries, a significant portion of irrigation water is derived from groundwater using wells. Chapter 4 therefore discusses rudimentary aspects of groundwater and wells from the perspective of pumping water for irrigation. Since the quality of water used

for irrigation has a significant impact on crop yield, degradation of soil, groundwater, and operation and life of irrigation systems, Chapter 5 discusses water quality from an agricultural irrigation point of view. Physical and chemical characteristics of water, and biological characteristics if wastewater is used for irrigation, that are important for irrigation are presented in the chapter. Irrigation of crops significantly depends on the type of soil, which is fundamental to our biosphere and requires proper management. Chapter 6 discusses basic soil properties relevant to crops and irrigation. Different types of crops require different types of climate and soil, and different crops and their optimum production have different irrigation requirements with respect to frequency and timing of irrigation, and the amount of water used per irrigation. Chapter 7 discusses the types of crops and their water requirements.

Hydraulic principles that are relevant to agricultural irrigation constitute the subject matter of Part II, which comprises four chapters. Water is conveyed from the source to the farm either by channels or by pipelines. Channels used in irrigation systems can be either erodible or non-erodible, and flow in these channels is governed by the principles of hydraulics. Chapter 8 discusses the rudimentary aspects of hydraulics and the design of open channels. The hydraulics of a pipe when it runs full is different from the hydraulics of open channels in which the upper surface of the flow is exposed to the atmosphere. Pipes or closed conduits are used in sprinkler and drip irrigation systems to carry water from the source to the individual sprinkler or emitter. Chapter 9 reviews the principles of pipeline hydraulics. Pumps are used to lift groundwater to the ground surface, raise water from a lower elevation to a higher elevation, transport water, overcome friction, or generate pressure for the operation of sprinkler and trickle irrigation systems. For many agricultural irrigation systems, pumps are therefore an integral part. Chapter 10 discusses the rudimentary aspects of pumps and their operation and selection. For irrigation management and maintenance, it is necessary to determine the volume of water that is applied to the field and the rate at which water is applied. Measurement devices are therefore included in irrigation systems. Chapter 11 discusses different methods and devices that are commonly employed for determining flow rates and volume.

Part III presents the principles of hydrology in three chapters. The purpose of irrigation is to supply water to plants, and this supply of water is made possible through infiltration into the soil. The infiltrated water is extracted by plant roots. Thus, infiltration plays a fundamental role in the design, management, and operation of irrigation systems. Chapter 12 discusses elementary aspects of infiltration and methods for computing it. The infiltrated water, called soil water, occurs in the unsaturated zone and is the only source of water for most agricultural crops. Since nutrients, including fertilizers, are dissolved in soil water, it is the only source from which plants can extract them. Different aspects of this water are discussed in Chapter 13. In cropland, water evaporates from soil and is transpired by plants – that is, water is transported to the atmosphere by evaporation plus transpiration, which together form evapotranspiration. Determination of evapotranspiration is vital for determining crop water requirements. Chapter 14 discusses the process of evaporation and some of the methods that are used in irrigation engineering for computing evaporation, including empirical and energy-balance-based methods, which constitute the basis of quasi-theoretical and theoretical methods.

Principles of irrigation science are discussed in Part IV, which comprises three chapters. The water used by a crop is not the same as its potential evapotranspiration, which is then modified for a specific crop using a crop coefficient, which is what constitutes the crop water use or consumptive use. Chapter 15 discusses the methods for converting estimated evapotranspiration to crop water use. When irrigating crops, one of the key considerations is to do irrigation efficiently so that crop yield is maximized. However, irrigation efficiency is not uniquely defined. Chapter 16 discusses the concept of irrigation efficiency and related aspects. Surface irrigation is commonly practiced around the world, more so in developing countries. There are different methods of surface irrigation and the selection of a particular method depends on a number of factors, including climate, soil, crop, water availability, landscape, availability of labor, energy, costs and benefits, and traditions. Chapter 17 discusses the preliminaries of the entire irrigation system.

Part V, consisting of five chapters, deals with methods of irrigation. Depending on the type, crops are irrigated by different methods. Basin irrigation is a common method for

surface irrigation, especially in developing countries. A basin is an agricultural field with zero to little slope, which is diked from all sides. The usual method of water application is flooding. Chapter 18 briefly discusses the basin method of irrigation and its design. A simple but popular method is also border irrigation, which constitutes the subject matter of Chapter 19. Furrow irrigation is another popular method of irrigation, which is presented in Chapter 20. The availability of water for agricultural irrigation is diminishing for a variety of reasons. In order to use water in agriculture more efficiently, sprinkler irrigation and trickle irrigation are becoming popular all over the world. Chapter 21 discusses different aspects of sprinkler irrigation, and Chapter 22 covers trickle irrigation.

Irrigation design is the subject matter of Part VI, comprising four chapters. Irrigation system design begins with planning, which depends on the size of the system. Small systems may be owned by individual farmers, and farmers plan these systems on their own, with limited outside help. On the other hand, large systems are owned by government or groups of farmers and their planning is quite technical. Chapter 23 discusses the rudimentary aspects of irrigation planning. In irrigation, land surface characteristics play a significant role. Indeed, the type of irrigation system to be employed is determined by the land surface, which ideally should be such that the irrigation water moves as uniformly as possible, but the natural landscape is not always so. Therefore, the natural landscape or topography is altered by land leveling, which is discussed in Chapter 24. When irrigation is done, especially using border, furrow, or flooding methods, more water is applied than is actually used by plants. The excess water from the soil surface, as well as the soil profile or root zone, needs to be removed without eroding the soil and damaging crops. The orderly removal of this excess water is called drainage, which provides a suitable environment for the maximization of plant growth, keeping in mind financial constraints. Chapter 25 presents rudiments of agricultural drainage. Design of a farm irrigation system entails both technical and non-technical considerations. It is an integration of principles borrowed from agriculture, meteorology, hydrology, hydraulics, irrigation, and drainage engineering, as well as economic, environmental, and management sciences. Chapter 26 provides a snapshot of steps involved in designing a farm irrigation system.

The final part is on irrigation management, comprising five chapters. Considering the type of crop, soil, climate, method of irrigation, and agricultural practices, scheduling of irrigation is done. There are different methods for irrigation scheduling which are presented in Chapter 27.

Although irrigated agriculture is vital for food security, irrigation should be practiced such that it causes minimum environmental damage. Chapter 28 discusses important environmental considerations that should be kept in mind in planning, designing, operating, and managing irrigation systems. Irrigation systems are usually designed with the long-term objective that they are economically sustainable, although that is not always the case in many developing countries. Chapter 29 visits fundamental concepts of analyzing benefits and costs, which in the long term define the benefit–cost ratio. For large irrigation systems there is usually an organizational structure tasked with managing water, structures and equipment, and people. It engages in decision-making, resource mobilization, communication, and conflict resolution. Chapter 30 provides a snapshot of elements of irrigation management. The concluding Chapter 31 deals with irrigated agriculture for food security and the impact of climate change. Defining food and nutritional security, it discusses the factors affecting the security and the impacts of climate change.

Although the book is primarily designed for undergraduate or early graduate students in agricultural or irrigation engineering, it will also be useful for students in civil engineering, agriculture, horticulture, and water resources management. Faculty members engaged in teaching irrigation engineering and those engaged in farm management will also find the book useful.

## Acknowledgments

This book grew out of a senior undergraduate course, “Irrigation and Drainage Engineering,” being taught in the Department of Biological & Agricultural Engineering at Texas A&M University. Dr. Kyungtae Lee helped solve a number of problems in the book and prepare a number of figures. His help is deeply appreciated.

Like any other book, the authors have drawn from the works of a large number of irrigation engineers from the United States and abroad. Without their contributions, irrigation engineering would not be what it is today. The authors have tried to acknowledge these works as specifically as possible, and any omission on their part will be entirely inadvertent and they would like to express their apologies in advance. In the wake of growing population, rising demand for food, and increasing food wastage during the entire supply chain and consumption, irrigation is vital to ensure food security. The contributions of irrigation engineers to food security that we take for granted these days can hardly be over-emphasized. The authors are grateful that these engineers chose to pursue irrigation engineering.