Irrigation and Drainage Engineering

21世纪高等学校精品规划双语系列教材

灌溉排水工程学

迟道才　编

中国水利水电出版社
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内容提要

本书是根据最新专业规范《灌溉排水工程学》的教学大纲而编写的英文版教材，用于该课程的双语教学。主要内容包括：农田水分状况和土壤水分运动，腾发量和作物需水量，灌溉技术，灌溉水源和引水工程，灌溉渠道系统，灌溉管道系统，排水要求及排水系统，政策与管理。为学习方便，本书附录给出了有关灌溉排水方面的主要专业词汇英汉对照。

本书不仅可用于本课程的双语教学需要，还可以用于相关专业的专业英语教材，也可供从事农业水利及其相关专业的工程技术人员、管理人员和教师学习使用。

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前言

面向21世纪的创新型人才培养，已使双语教学成为高等教育改革的重点。为了应对经济全球化和科技革命的挑战，培养“面向现代化、面向世界、面向未来”的新世纪科技人才，开展应用学科的双语教学任务紧迫。在国际环境中，交流能力十分重要，为学生提供更多交流能力训练是双语教学的主要目标之一。

水利是农业的命脉，旱灾和涝灾是农业面临的主要自然灾害。《灌溉排水工程学》是农业水利工程专业的核心专业课之一，主要讲授灌溉排水原理与技术。因此，开展《灌溉排水工程学》课程的双语教学，不仅有利于课程建设本身，更为重要的是有利于提高学生的英语应用能力，使学生能同时利用母语和外语在专业知识领域进行思维、学习和交际，有利于学生学习国外先进的专业知识，以培养学生掌握世界最新科技成果和对外学术交流的能力，培养国际竞争意识，形成国际化视野和开放型思维，对实现农业水利化和确保粮食安全具有十分重要的意义。

双语教学的成败在很大程度上取决于是否有一本合适的英文教材。目前国内还没有出版过《灌溉排水工程学》英文教材，国外没有合适的原版教材可以引进应用。鉴于此，编写组根据最新专业规范《灌溉排水工程学》的教学大纲，参考大量国外相关教材，编写了这本英文版《灌溉排水工程学》。主要内容包括：Farm Water and the Movement of Soil Water，Evapotranspiration and Water Requirement of Crop，Irrigation Technique，Sources of Irrigation Water and Diversion Works，Irrigation Canal System，Irrigation Pipeline System，Drainage Requirements and Systems，Policies and Management。

参加本书编写工作的有迟道才、鄂健、李禄、毕凤春、李智、韩培、刘彤、张瑞。全书由迟道才主编统稿，鄂健、李禄任副主编，并参加了统稿工作。

由于编者水平所限，加之第一次编写双语课程教材，错误和不足在所难免，恳请广大读者批评指正。

编　者

2009年11月

Preface

Bilingual teaching has been put to the front of higher education reform in catering to the need of educating innovative talents facing the 21st century. It is of pressing task to bring up scientific talents in the new century, the talents who can face the modernization, face the world and face the future, and to start bilingual teaching in applied science, taking the challenges of economic globalization and technology revolution. To some extent, communication ability even plays a bigger role than academic skills in international environment. Providing more communication capability training for the students is one of the main targets of bilingual teaching.

Water resource serves as the cornerstone of agriculture which is mostly challenged by two natural disasters, drought and flood. *Irrigation and Drainage Engineering* is one of the core courses of agricultural water resource and engineering subject, most pages involving irrigation, drainage principles and techniques. Thereby, the bilingual teaching of *Irrigation and Drainage Engineering* is not only in favor of the build—up of the course itself, more important, but of great significance in improving student capability of using English, conducting thinking, learning and communicating in academic area with both mother tongue and foreign language, keeping up with advanced professional knowledge abroad, building up the ability of mastering newly released scientific achievements and academic exchange, creating international competitive concept, thinking internationally and openly, realizing irrigated agriculture and ensuring food security as the final goal.

The success of bilingual teaching, to a large extent, relies on if there is a good English textbook available. But unfortunately, there is no *Irrigation and Drainage Engineering* English version published up to now across the country, also no original one adaptable to be introduced. For that reason, based on the newly published teaching syllabus, *Irrigation and Drainage Engineering*, the editors compiled the English version, referring to many teaching material abroad. The main contents include: Farm Water and the Movement of Soil Water, Evapotranspiration and Water Requirement of Crop, Irrigation Technique, Sources of Irrigation Water and Diversion Works, Conveyance system, Irrigation Pipeline System, Drainage requirements and systems, Policies and Management.

This book is compiled by Chi Daochi, E Jian, Li Lu, Bi Fengchun, Li Zhi, Han Pei, Liu Tong and Zhang Rui. Chi Daocai is the editor - in - chief, E Jian and Li Lu are the vice editor - in - chiefs.

For knowledge limit and lacking of experience in compiling bilingual textbook, some weakness and errors are inevitable, advices and suggestions are warmly welcomed.

Editor
November, 2009

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Introduction

Centuries ago, irrigation enabled civilization to establish permanent sites of residence in arid and semiarid lands. Nomad activity no longer was needed to secure food for people and their animals. Today, irrigated agriculture continues to make civilization less dependent on the vagaries of climate for food and fiber needed to sustain life.

Irrigation is one of the oldest known agricultural technologies, but improvements in irrigated methods and practices are still being made. The future will require even greater improvements as competition for limited water supplies continues to increase.

Fukuda (1976) summarized irrigation history. He emphasized the development of the technical aspects of irrigation and drainage. The oldest civilizations developed along the Nile, Tigris, Euphrates, Indus and Yellow River and in Latin America. Cultivation along the Nile began about 6000 B. C.. Practices to keep canals free of sediment were in effect in Mesopotamia in 4000 B. C.. Shallow wells and flooding from the Indus River were used about 2500 B. C. and in Peru about 1000 B. C..

1. Development of Irrigated Land

The development of irrigated lands has paralleled increases in world population. The Food and Agriculture Organization (FAO) of the United Nations estimated in 1977 that the total global irrigated area was 223 million ha and this area would increase quickly with the world population. A comparison of cultivated land and the portion of that land irrigated by region and country is given in Table 1.

Table 1 **Irrigated Areas Data Table of Some Countries**

Continent and Country	Agricultural Land		
	Cultivated ha(1000's)	Cultivated Land Irrigated	
		ha (1000's)	percent of the Cultivated
India	16540	4305	26.0
America	18788.1	2376.8	12.6
USSR	22510	2121.5	9.4
Pakistan	2030	1650	81.3
Indonesia	1600	760	47.5
Iran	1410	575	40.8
Mexico	2315	518	22.4
Thailand	1900	430	22.6

Continued

Continent and Country	Agricultural Land		
	Cultivated ha(1000's)	Cultivated Land Irrigated	
		ha (1000's)	Percent of the Cultivated
Spain	1556	337	21.7
Rumania	945	321.6	34.0
Italy	909.8	312	34.3
Bengal	885.3	293.3	33.1
Japan	412.1	284.7	69.1
Afghanistan	791	276	34.9
Brazil	5040	270	5.4
Iraq	525	255	48.6
Turkey	2488	237	9.5
Egypt	233	233	100.0
Sudan	1283	190	14.8
Australia	5140	190	3.7
Viet Nam	569	184	32.3
Argentina	2500	168	6.7
Philippines	455	156	34.3
North Korea	170	154	83.5
South Korea	195	135.5	69.4
Morocco	871.3	127	14.6
Chile	427	126.5	29.6
Bulgaria	385.6	126.3	32.8
Peru	340	126	37.0
Greece	287.1	120	41.8
France	1798.9	117	6.5
South Africa	1238	112.8	9.1
Burma	956.7	100	10.4

Note FAO data as of 1991.

The FAO estimated irrigated agriculture represented only 13 percent of the global land, but the value of crop production is 34 percent of the world total. Various groups are considering the future development of irrigated lands. In 1977, 15 national ICID (the International Commission on Irrigation and Drainage) committees presented reports on irrigation developments. Future development of irrigated land will be more difficult than it was in the past. New projects will be more than it did in the past.

2. Competition for Water

Competition for limited water supplies will significantly affect future irrigation development and practices. The growing impact of society attitudes towards water supplies and management is having a greater impact on water users, planners, legislators and managers. There are many new emerging demands for water. Many citizens today seem more concerned about environmental protection than about agriculture and are opposed to expanding irrigation. Other foreseeable demands for water will necessitate development of new energy sources.

Direct competition for water use from irrigation and hydroelectric power has become a major issue in the Pacific Northwest. The demands on water supplies are steadily increasing and in many areas the groundwater supplies have received a great deal of attention during the past decade and will be receiving greater attention in the future. At the same time, there is a tremendous reluctance to construct additional storage facilities, mainly because of environmental concerns and current economic aspects. There is also greater opposition to interbasin transfer and increased pressures to limit water supplies so as to form a growth controller.

3. The Role of Irrigation in Food and Fiber Production

Water is essential for plant growth. Water is needed for seeds to germinate, seedlings to emerge, and for the many plant growth functions. Water prevents the dehydration of plants, and provides the transport mechanism for plant nutrients and the products of photosynthesis. When water for plant growth can be controlled by irrigation, average yields under comparable climatic conditions generally are higher than those obtained under rained conditions. The difference in yield between irrigated and non-irrigated lands is greatest during seasons that have periods of drought and above normal evaporative demands. Because yields on irrigated lands are higher and more consistent, irrigation plays a major role in stabilizing food and fiber production.

Irrigation also affects food and fiber production in other ways. For example, irrigation may prevent severe freeze or frost damage to orchards, citrus nurseries, strawberries, ferns, and subtropical fruits. If fruit trees are severely damaged, many years would be required to reestablish them. Irrigation may provide the soil moisture needed to prepare a seed bed after an extensive period of drought before a normal rainy season. Irrigation has enabled otherwise nonproductive lands to be reclaimed.

4. Future Challenges

Irrigation technology has advanced significantly during the past two decades, but many existing projects and on-farm irrigation systems have not been improved significantly for decades. The irrigation challenges facing engineers will be greatest in developing countries where improved water management practices have a large potential to increase food and fiber production. Developing countries in Africa, Latin America, the Near East and Asia will need 22 million ha of new irrigated land and 45 million ha will need improvements. The costs of making these improvements and developing new irrigated lands will be high, but FAO suggests that one way to decrease these costs is by developing national facilities and skills to reduce the dependence on imported expertise, equipment and materials. Yesterday's technological changes were hardly greater than the first great revolution technology wrought on human history 7000 years ago, when irrigation civilization established itself. Technology, the result of creative efforts of engineers and scientists, may be the major force in shaping civilization. Irrigation technology played a major role in bringing about social and political changes. We can expect new irrigation technology to play a similar future role.

O. W. Israelsen devoted his life to the development and improvement of irrigation principles and practices. He is best known throughout the world for his text book entitled "Irrigation Principles and Practices", which was first published in 1932. In his second edition (Istraelsen, 1950), he stated, "If the population of the world continues to increase at its present rate, where is the food for these people to come from? The men and women with knowledge of irrigation will be called upon to assist in the solution of the world problem."

Chapter 1 Farm Water and the Movement of Soil Water

Water is essential for the structural integrity of biological molecules and hence for the integrity of cells, tissues, and the organism as a whole. It also performs a vital role as a solvent transporting mineral nutrients and other foodstuffs in solution throughout the plant body. Furthermore, and in contrast to the situation in terrestrial animals, in all actively growing plants there is a liquid phase continuity from the water in the soil through the plant to the liquid—gas interface at evaporation sites in the leaves. The proliferation of roots in the soil provides an extensive absorbing surface across which passes virtually all the water and mineral nutrients used by plants.

1. 1 Soil Water Properties and Classification

1. 1. 1 Classes of Soil Water Availability

Soil water is of interest largely because of its influence on plant growth and crop production. The importance of soil water storage and availability in crop production has long been recognized and many research have been done to characterize the soil properties responsible for water absorption and retention.

First, we will concentrate on the description of categories of soil - water of general interest in a physical sense. The following definitions will refer to Fig. 1 - 1.

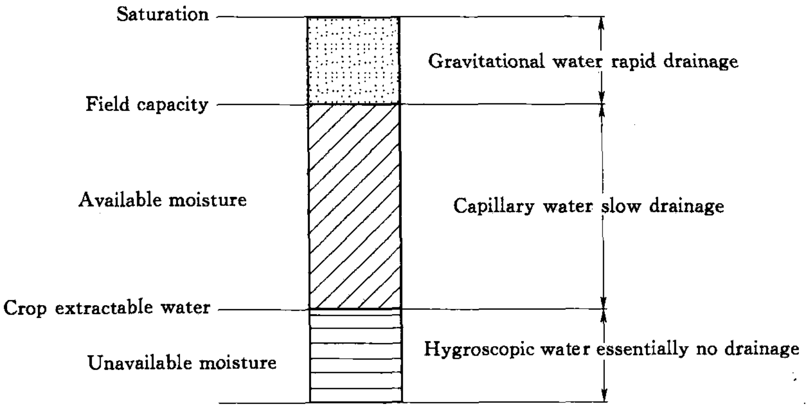

Fig. 1 - 1 Class of soil water availability to plants and characteristics of drainage

(1) Gravitational water is defined as that water which is rapidly drained from the soil profile by the force of gravity. The term rapid is relative and in soil - water studies normally refers to time periods of 24 to 48 hours.

(2) Capillary water is the water remaining after rapid drainage by gravity. This water may be removed by forces greater than gravity such as those exerted by plant roots.

(3) Hygroscopic water is water which adheres to soil particles which cannot generally be removed by forces found in nature. Hygroscopic water can be removed by oven drying a soil sample, but cannot be removed by plant roots.

1.1.2 Soil Water "Constants"

Field capacity and permanent wilting point once were considered to be soil water constants. They are now recognized as very imprecise but qualitatively useful terms.

(1) Field Capacity. Field capacity is defined as the soil - moisture content attained in an originally thoroughly wet field—that is, at or near saturation, after the rate of drainage by gravity has markedly decreased. After infiltration ceases, water within the wetted portion of the profile will redistribute under the influence of potential gradients. Downward movement is relatively rapid at first but decreases rapidly with time. Field capacity now is used only as a very rough term that refers in general to the water content of a soil a few days after it has been wetted. For most soils this is a near optimum condition for growing plants. However, soil water may continue to drain for many days after irrigation.

The field capacity concept is more applicable to coarse—than to fine—textured soils because in coarse soils most of the pores empty soon after irrigation and the capillary conductivity becomes very small at relatively high potentials. In fine - textured soils, with a narrower range of soil pore sizes, the hydraulic conductivity will not change so rapidly with time and the drainage can continue for weeks or months. Soil characteristics that have greatest influence on field capacity are soil texture and layers within the profile that impede water flow. Fine soils retain more water than coarse soils as well as drain longer at significant rates. Any layer interface will inhibit water movement across the interface and thus restrict redistribution and increase field capacity. Other factors that may influence field capacity are organic matter content, depth of wetting, wetting history, and plant water use.

(2) Wilting Point. The permanent wilting point or percentage is the soil water content below which plants growing in that soil remain wilted even when transpiration is nearly eliminated. It represents a condition where the rate of water supply to the plant roots is very low. The water content corresponding to the wilting point applies to the average water content of the bulk soil and not to the soil adjacent to the root surfaces. The soil next to the root surfaces will usually be drier than the bulk soil, because water cannot move toward the root surfaces fast enough to supply plant demands and a water content gradient develops near the root.

Like field capacity, permanent wilting is not a soil constant or a unique soil property. There is no single soil water content at which plants cease to withdraw water. Even though wilted, plants will absorb water, but not at rates sufficient to regain turgor. Plants growing under low atmospheric demand can dry soil to lower water contents than if the demand is high, because more time is allowed for water to move through the soil to the roots. Also, when atmospheric demands are high, plants may temporarily wilt even though soil water contents are considered adequate. Sugar beet wilting in midday during the summer is an example. The wilting is simply the result of water not moving to and through the root surfaces as fast as the plant demands it.

In the wilting range, almost all soil pores are empty of water and the water content is determined largely by the specific surface area and the thickness of water films on these surfaces. The thickness of these films is related to potential, and Richards and Weaver (1944) found the water content in soil subjected to a pressure potential of −15 bars was closely correlated with the permanent wilting percentage, as determined with sunflowers for a wide range of soils. Because of its simplicity and the availability of reliable equipment, the 15-bar percentage is now commonly used to estimate the permanent wilting percentage. Sunflowers are the standard test plant used for determining permanent wilting percentage.

(3) Available Water. The amount of water released by a soil between field capacity and permanent wilting is called the available water. The term implies that the available water can be used by plants, but this is misleading. If the soil water content approaches the wilting range, especially during periods of high atmospheric demands for water or flowering and pollination, yield or quality of most crops will be greatly decreased. Some crops, however, can extract soil water to potentials considerably below −15 bars. Wheat is a notable example, as are many drought-or salt-tolerant species. Plants may remove water from a wet soil before it drains to field capacity.

In as much as the difference between field capacity and available water can be no more meaningful than either of the terms, available water itself is only an estimate of the amount of water a crop can use from a soil. It was once generally accepted that soil water was equally available to plants from field capacity to wilting point. This was disputed by Richards and Wadleigh (1952), and it is now recognized that more energy must be exerted to extract water as the soil dries, in accord with the potential theory of water movement. As with field capacity, available water is a useful concept, providing that one recognizes its limitations and that it varies with soil depth, climatic factors that influence evapotranspiration, and the soil profile characteristics.

1.1.3 Soil Water Properties Defined

It is often necessary to be able to determine the amount of water in a soil. Gardner

(1965) and Rawlins (1976) have discussed the various methods and associated errors for measuring soil wetness. Various soil - water properties may be defined in a number of different ways, the following listing indicates the definitions for soil - water properties which will be used throughout this book. The formulas refer to the elemental soil volume in Fig. 1 - 2. The mass of air, M_a, is assumed negligible. The mass of water and solids are indicated as M_w and M_s, respectively. The total mass is shown as M_t.

Water content on mass basis, θ_m

$$\theta_m=\frac{\text{mass water}}{\text{mass dry soil}}=\frac{M_w}{M_s} \tag{1-1}$$

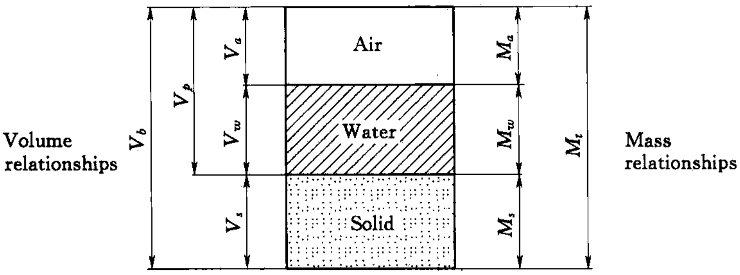

Fig. 1 - 2 Schematic diagram of soil block as a three - phase system

Volumetric water content, θ_v

$$\theta_v=\frac{\text{volume water}}{\text{bulk volume soil}}=\frac{V_w}{V_b}=\frac{V_w}{V_s+V_p}=\frac{V_w}{V_s+V_a+V_w} \tag{1-2}$$

Soil bulk density, ρ_b

$$\rho_b=\frac{\text{mass dry soil}}{\text{bulk volume soil}}=\frac{M_s}{V_b}=\frac{M_s}{V_s+V_a+V_w} \tag{1-3}$$

Soil porosity, N

$$N=\frac{\text{total pore volume}}{\text{bulk volume soil}}=\frac{V_p}{V_b}=\frac{V_a+V_w}{V_b}=\frac{V_a+V_w}{V_s+V_a+V_w} \tag{1-4}$$

Saturated water content (volume basis), θ_{vs}

$$\theta_{vs}=\frac{\text{volume of water when saturated}}{\text{bulk volume soil}}=\frac{V_p}{V_b} \tag{1-5}$$

Saturated water content (mass basis), θ_{ms}

$$\theta_{ms}=\frac{\text{mass of water when saturated}}{\text{mass dry soil}}=\frac{\rho_w V_p}{M_s} \tag{1-6}$$

where

ρ_w—density of water.

Different parameters may be derived using the values defined under soil - water properties. As an example, the bulk density may be derived as a function of the soil porosity and density of the soil particles. Eq. (1 - 4) for soil porosity may be rewritten as

$$N=\frac{V_P}{V_b}=\frac{V_b-V_s}{V_b} \tag{1-7}$$

Defining density as mass divided by volume, Eq. (1 - 7) may be rewritten as

$$N = \frac{M_s/\rho_b - M_s/\rho_s}{M_s/\rho_b} = 1 - \frac{\rho_b}{\rho_s}. \tag{1-8}$$

where

ρ_s—particle density.

Eq. (1 - 8) may be rewritten to describe bulk density as a function of porosity and particle density

$$\rho_b = (1 - N)\rho_s \tag{1-9}$$

A common value for ρ_s in agricultural soils is approximately 2. 65 g/cm^3, the particle density of silica sand, granite, and quartz rock, which are common parent materials. A common value of ρ_b in agricultural soils is in the range of 1. 3 g/cm^3, indicating that porosities of agricultural soils are typically in the neighborhood of 0. 5 or 50 percent air plus water.

Another relationship which may be derived is that between water content on a mass basis, which is relatively easy to measure, and water content on a volume basis, which is more useful in irrigation system design. Rewriting Eq. (1 - 2) as

$$\theta_v = \frac{V_w}{V_b} = \frac{M_w/\rho_w}{M_s/\rho_b} \tag{1-10}$$

Substituting the water content on a mass basis from Eq. (1 - 1) into Eq. (1 - 10)

$$\theta_v = \theta_m \left[\frac{\rho_b}{\rho_w}\right] \tag{1-11}$$

The quantity in brackets in Eq. (1 - 11), ρ_b/ρ_w, is termed the apparent specific gravity of the soil.

The volumetric water content is more useful than the water content on a mass basis because it represents the equivalent depth of water per unit depth of soil. Prior to the use of the neutron moisture probe, which is calibrated to indicate θ, most field studies considered ρ_b, once determined during a study, to remain constant at a given depth throughout the season or study. This assumption is reasonable below the plow depth, but can result in substantial measurement error in the total soil water in the plowed layer. The error is not great for determining changes in soil - water content over 5 - to 15 - day periods. However, ρ_b should be adjusted for changes in water content in swelling and cracking soils.

1. 1. 4 Soil Water Potential

About the turn of the century, soil water was arbitrarily classified into different forms such as gravitational water, capillary water, hygroscopic water; these early groupings have been replaced by a fundamental concept referred to as soil water potential. Soil water does not vary in form, within the range of our interest, but it does vary in the energy with which it is retained in the soil.

The work required to move an incremental volume of water from some reference state