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	To convert English unit	Multiply by	To obtain Metric (SI) unit
Area	in <sup>2</sup> ft <sup>2</sup> acre	645.2 0.0929 0.4047	$mm^2$ $m^2$ hectare (ha) = $10^4$ m <sup>2</sup>
Density	slug/ft <sup>3</sup>	515.4	kg/m³
Energy (work or quantity of heat)	ft·lb ft·lb Btu = 778 ft·lb	$1.356 \\ 3.77 \times 10^{-7} \\ 1055$	joule $(J) = N \cdot m$ kwhr joule $(J) = N \cdot m$
Flowrate	cfs mgd = 1.55 cfs 1000 gpm = 2.23 cfs	0.0283 0.0438 0.0631	$m^3/sec = 10^3 l/sec$ $m^3/sec = 10^3 l/sec$ $m^3/sec = 10^3 l/sec$
Force	lb	4.448	newton (N)
Kinematic viscosity	ft²/sec	0.0929	$m^2/sec = 10^4 St$
Length	in. ft <i>mi</i>	25.4 0.3048 1.609	mm m km
Mass	slug lb (mass)	14.59 453.6	kg g (mass)
Power	$ft \cdot lb/sec$ $hp = 550 ft \cdot lb/sec$	1.356 745.7	$W = J/sec = N \cdot m/sec$ $W$
Pressure	psi psf	6895 47.88	$N/m^2 = Pa$ $N/m^2$
Specific heat	ft·lb/(slug)(°R)	0.1672	$N \cdot m/(kg)(K)$
Specific weight	lb/ft <sup>3</sup>	157.1	$N/m^3$
Velocity	fps mph	0.3048 1.609	m/sec km/hr
Viscosity	lb-sec/ft <sup>2</sup>	47.88	$N \cdot sec/m^2 = 10 P$
Volume Weight (see Force)	ft <sup>3</sup> U.S. gallon = $0.1337 \text{ ft}^3$	0.0283 3.785	$m^3$ $/ = 10^{-3} m^3$

# IMPORTANT QUANTITIES

	English unit	SI unit
Acceleration of gravity	32.2 ft/sec <sup>2</sup>	9.81 m/sec <sup>2</sup>
Density of water (39.4°F, 4°C)	$1.94 \text{ slug/ft}^3$ = 1.94 lb·ft <sup>2</sup> sec <sup>-4</sup>	$1000 \text{ kg/m}^3 = \text{g/cm}^3$ or $1.0 \text{ Mg/m}^3$
Specific weight of water (50°F, 15°C)	62.4 lb/ft <sup>3</sup>	$\sim 9810 \text{ N/m}^3$ or $9.81 \text{ kN/m}^3$
Standard sea-level atmosphere	14.7 psia 29.92 in. Hg 33.9 ft H <sub>2</sub> O	101.32 kN/m <sup>2</sup> , abs 760 mm Hg 10.33 m H <sub>2</sub> O 1013.2 millibars

	To convert metric (SI) unit	Multiply by	To obtain English unit
Area .	$cm^2$ $m^2$ hectare (ha) = $10^4$ m <sup>2</sup>	0.155 10.76 2.47	in <sup>2</sup> ft <sup>2</sup> acre
Density	$kg/m^3 = 10^{-3} g/cm^3$	0.00194	slug/ft <sup>3</sup>
Energy (work or quantity of heat)	joule $(J) = N \cdot m$ kwhr joule $(J) = N \cdot m$	$0.738$ $2.65 \times 10^{6}$ $0.000948$	ft·lb ft·lb Btu = 778 ft·lb
Flowrate	$m^3/sec = (10^3 l/sec)$ $1/sec = (10^{-3} m^3/sec)$	35.33 15.85	cfs gpm
Force	newton (N)	0.225	lb
Kinematic viscosity	$m^2/sec = (10^4 \text{ St})$	10.76	ft²/sec
Length	mm m km	0.0394 3.28 0.621	in. ft mile
Mass	kg 453.6 g (mass)	0.0685 1.0	slug lb (mass)
Power	$W = J/sec = N \cdot m/sec$ (watt)	0.7375 0.00134	$ft \cdot lb/sec$ $hp = 550 ft \cdot lb/sec$
Pressure	$\begin{array}{l} N/m^2 = Pa \\ N/m^2 \end{array}$	0.000145 0.02089	psi psf
Specific heat	$N \cdot m/(kg)(K)$	5.98	ft·lb/(slug)(°R)
Specific weight	$N/m^3$	0.006365	lb/ft <sup>3</sup>
Velocity	m/sec km/hr	3.28 0.621	fps mph
Viscosity	$N \cdot sec/m^2 = 10P$	0.02089	lb·sec/ft2
Volume	$m^3$ $\ell = (10^{-3} m^3)$	35.34 0.2642	ft³ U.S. gallon

# IMPORTANT QUANTITIES

	SI unit	English unit
Acceleration of gravity	9.81 m/sec <sup>2</sup>	32.2 ft/sec <sup>2</sup>
Density of water (39.4°F, 4°C)	$1000 \text{ kg/m}^3 = \text{g/cm}^3$ or $1.0 \text{ Mg/m}^3$	$1.94 \text{ slug/ft}^3$ = 1.94 lb·ft <sup>2</sup> sec <sup>-4</sup>
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Standard sea-level atmosphere	101.32 kN/m <sup>2</sup> , abs 760 mm Hg 10.33 m H <sub>2</sub> O 1013.2 millibars	14.7 psia 29.92 in. Hg 33.9 ft H <sub>2</sub> O

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Density	slug/ft <sup>3</sup>	515.4	$kg/m^3$
Energy (work or quantity of heat)	ft·lb ft·lb Btu = 778 ft·lb	$   \begin{array}{r}     1.356 \\     3.77 \times 10^{-7} \\     1055   \end{array} $	joule (J) = N·m kwhr joule (J) = N·m
Flowrate	cfs mgd = 1.55 cfs 1000 gpm = 2.23 cfs	0.0283 0.0438 0.0631	$m^3/sec = 10^3 l/sec$ $m^3/sec = 10^3 l/sec$ $m^3/sec = 10^3 l/sec$
Force	lb	4.448	newton (N)
Kinematic viscosity	ft <sup>2</sup> /sec	0.0929	$m^2/sec = 10^4 \text{ St}$
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Power	ft·lb/sec hp = 550 ft·lb/sec	1.356 745.7	$W = J/sec = N \cdot m/sec$ $W$
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Velocity	fps mph	0.3048 1.609	m/sec km/hr
Viscosity	lb·sec/ft <sup>2</sup>	47.88	$N \cdot sec/m^2 = 10 P$
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	$kg/m^3 = 10^{-3} g/cm^3$	0.00194	slug/ft <sup>3</sup>
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	$m^3/sec = (10^3 l/sec)$ $1/sec = (10^{-3} m^3/sec)$	35.33 15.85	cfs gpm
Force	newton (N)	0.225	lb
Kinematic viscosity	$m^2/sec = (10^4 \text{ St})$	10.76	ft²/sec
1	mm m km	0.0394 3.28 0.621	in. ft mile
Mass	(g 163 6 a (mass)	0.0685 1.0	slug lb (mass)
e.		5 34 0145 089	ft·lb/sec hp = 550 ft·lb/sec psi psf ft·lb/(slug)(°R)
		365	lb/ft <sup>3</sup> fps mph
** ***		39	lb·sec/ft <sup>2</sup> ft <sup>3</sup> U.S. gallon
			English unit
			32.2 ft/sec <sup>2</sup>
	or 1.0 <b>Mg</b> /n	$n^3$	$1.94 \text{ slug/ft}^3$ = 1.94 lb·ft²sec <sup>-4</sup>
Specific weight of water (50°F, 15°C)	~9810 N/m or 9.81 kN/		62.4 lb/ft <sup>3</sup>
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#### McGraw-Hill Series in Water Resources and Environmental Engineering

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### To Eugene Lodewick Grant

Pioneer in engineering economy Teacher, colleague, and friend

#### **PREFACE**

With world population growing rapidly, the water resources of the world are becoming one of its most important assets. Water is essential for human consumption and sanitation, for the production of many industrial goods, and for the production of food and fiber. Water is an important means of transport in many parts of the world and a significant factor in recreation. Crops are being grown as a source of fuel such as methanol, and this will place an increasing demand for irrigation water. Even a valuable resource can be a hazard and excessive water—floods—cause substantial damage and loss of life throughout the world. Water is unequally distributed about the earth, and its availability at any place varies greatly with time. Finally, in its use of this resource, humanity pollutes much of the available fresh water and degrades it so that it is unfit for many or all uses.

Skilled planning and careful management are essential to achieve the level of efficiency in water use which will be required in the future. These efforts, however, must be substantially broader in scope than the common concept of engineering would visualize. Investments in water-resources development are influenced by economic, social, and political considerations as well as the basic engineering facts. In revising and updating their book "Elements of Hydraulic Engineering," the authors elected to increase the emphasis on planning and to adopt the title "Water-Resources Engineering" as more descriptive of its intended scope. Planning in the true sense of the word is a complex operation, which is perhaps nowhere more complex than in the planning of water resources for many competing uses while subject to both economic and physical constraints. Engineers cannot, however, shirk the planning task if they wish to maintain their position in the profession which "directs the forces of nature for the benefit of mankind."

Water-resources engineering draws on the background of the student in engineering science, design, the humanities, and social sciences. A course in water-resources engineering by its nature must be a terminal course. It seems important, therefore, to present the material in a unified course treating the subject in its broadest scope and emphasizing the "why" instead of the "how." The authors hope that students will be stimulated by the broad perspective of water-resources engineering as a unified field and that the instructor will find the text both interesting and effective.

The first five chapters present the subject of hydrology, basic to all water-management efforts. Chapter 6 discusses the legal aspects of water use which often provide important constraints on the planning effort. Chapters 7 through 12 discuss the physical works—dams, canals, pipelines, etc.—which are utilized in almost all types of water-resources projects. Chapter 13 reviews the important principles of engineering economy basic to water management. Chapters 14 through 20 then discuss the principal water uses in more detail, with particular attention to the aspects of each use which differ from the other uses. The final chapter summarizes the planning procedure for single- and multipurpose projects.

The authors wish to express special appreciation to Professor Eugene L. Grant for his review of Chapter 13, which he originally prepared, and for his many other helpful suggestions. We appreciate also the work of Professor George Tchobanoglous in rewriting Chapters 15 and 19. The list of colleagues and friends who have contributed thoughts or facts for the three editions has grown very long and it would be difficult to recompile with accuracy. We extend our thanks to all who have contributed including the unknown reviewers who provided comments to the publishers.

Ray K. Linsley Joseph B. Franzini

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