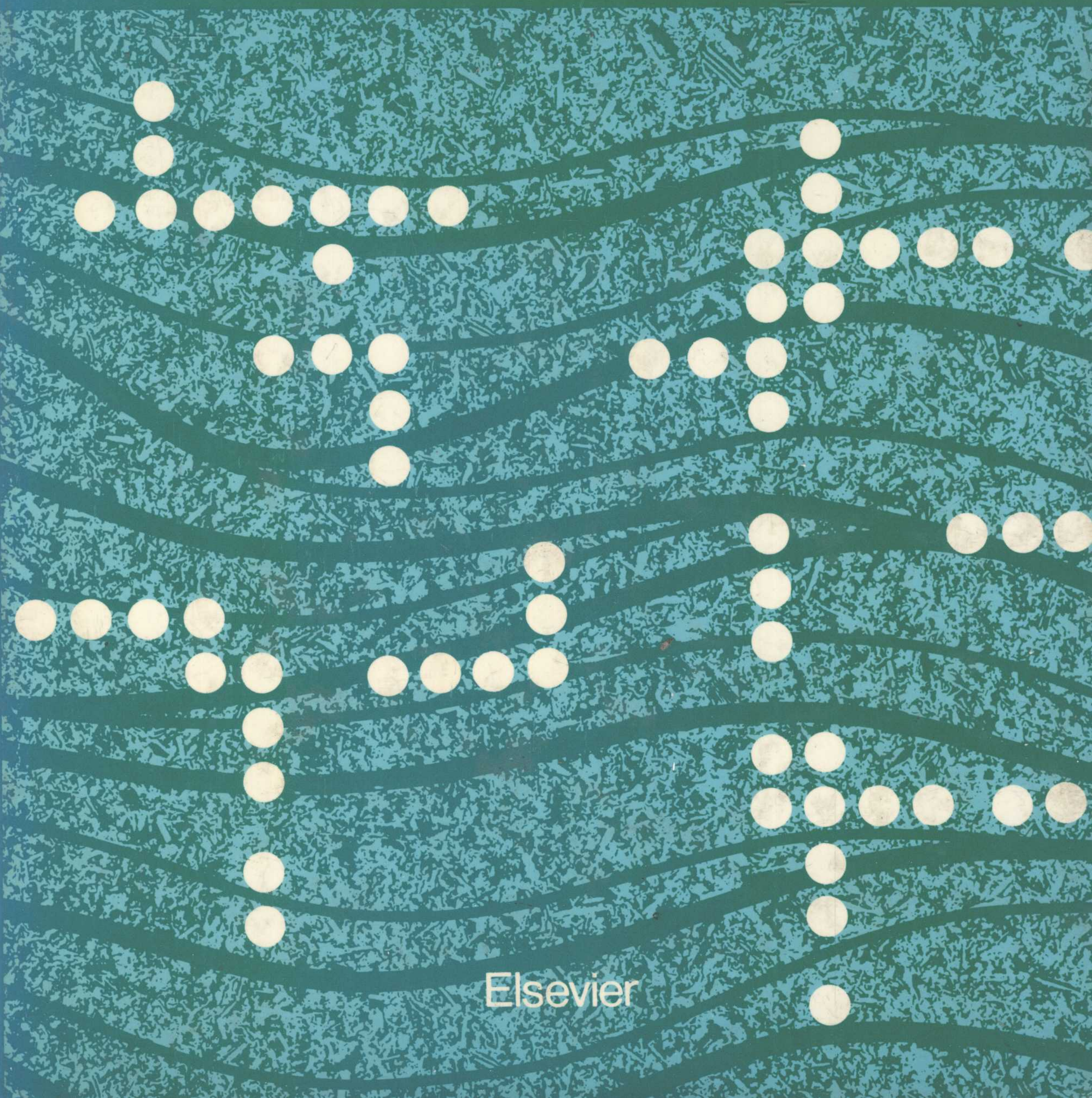
ENGINEERING GEOLOGY

An Environmental Approach

Perry H. Rahn



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Preface

The Association of Engineering Geologists defines engineering geology as "... the application of geologic data, techniques and principles to the study of naturally occurring rock and soil materials or subsurface fluids. The purpose is to assure that geologic factors affecting the planning, design, construction, operation, and maintenance of engineering structures and the development of groundwater resources are recognized, adequately interpreted, and presented for use in engineering practice." Some areas of practice of the engineering geologist include: 1) the investigation of foundations for all types of structures, such as dams, bridges, high-rise buildings, and residences; 2) the evaluation of geologic conditions along tunnel, pipeline, and highway routes; 3) the evaluation of earth materials for construction purposes; 4) the investigation and development of surface and ground-water resources; and 5) the evaluation of natural geologic hazards, such as floods, landslides, and earthquakes.

Engineering geology is the oldest branch of geology. William Smith, one of the founders of geology, was a practicing engineering geologist who, during the early part of the nineteenth century, described the stratigraphy and construction problems along large canals in southern England. Although not rigorously defined, a geological engineer differs from an engineering geologist in background and emphasis. Typically, a geological engineer has an engineering background, including an undergraduate degree in engineering with geologic emphasis in upperclass studies; an engineer geologist is a geologist who has later received education and practice in engineering disciplines.

In the past two decades, it has become vogue to use the term environmental geology for many of the same subjects formerly covered by engineering geology. Both terms mean essentially the same thing, i.e., the study of applied geology: how man is affected by geological phenomena, and how man himself can trigger geologic processes. Engineering geology is quantitative (to the degree feasible) to allow for the assessment and prediction of the effects of various processes. Environmental geology is a much broader field, encompassing related sciences such as biology and meteorology. Environmental geology represents that part of ecology that relates earth science disciplines to man. Generally, environmental geology texts have less technical treatment of subjects than engineering geology. In the past ten years, numerous excellent environmental geology books have been published. The intended audience for these books is the nongeology student who is seeking an applied science course. While these books serve to expose a large audience to environmental geology or geologic hazards, for the most part they are not at a technical level sufficient for geologists who may pursue a career in this field.

Collections of papers in environmental or engineering geology share these shortcomings and have no continuous development of topics at a consistent level of difficulty.

This book is intended as a text for upperclass college students majoring in geological engineering. The book may also be useful to geology students who are interested in environmental geology or the application of geology to engineering. Geology students who do not have an engineering background (including prerequisite courses such as mechanics of materials) should be able to use this book if they independently pursue engineering subjects. Practicing engineering geologists may find this book a useful summary of engineering geology subject material and literature. However, the book is not a complete state of the art or synthesis of all of the diverse subjects encompassing engineering geology. Rather, material was selected so that it would be educational and interesting for the student who is first encountering the subject.

Every teacher has his own preferred approach, and may select different portions of this book for presentation in a different sequence. I have developed what I consider to be a logical sequence of subject matter, and to some degree subject material presented in one chapter depends upon material described in previous chapters. Some material is developed from one chapter to the next; for example, slope stability is discussed in Chapter 4 (Rock Mechanics) and further developed in Chapter 6 (Mass Wasting). Engineering geology includes applied aspects of hydrology. For this reason, two chapters on hydrology (Chapter 7, Ground Water, and Chapter 8, Fluvial Processes) are included in this book.

Emphasis is given in this book to geomorphological processes. A firm knowledge of processes which act on the surface of the earth is a requisite to understanding engineering geology. Today, unfortunately, geomorphology is rarely taught to undergraduates. The increasing awareness and need for engineering geologists in today's technical world may rekindle future interest in quantitative geomorphology.

An engineer must solve problems, using quantitative methods where applicable. Examples of problem-solving are given throughout this text, and problems are given at the end of the chapters. Solving problems is an excellent way to learn analytical techniques. The problems range from simple ones which mimic existing solutions, to complex problems involving more analysis and synthesis by the student, requiring in some cases consultation from outside references. SI (metric) units are the primary dimension mode in this book. English units are used where such units are quoted by others, or where knowledge of both units is deemed particularly useful.

This book contains a preponderance of examples (good and bad) from the United States in areas where I have lived and worked such as South Dakota. This is not because South Dakota has all the problems, but simply because I am more familiar with this area.

I would like to thank Arvid M. Johnson for making many helpful suggestions to this book. I appreciate the encouragement given by Richard J. Gowen and Alvis L. Lisenbee of South Dakota School of Mines and Technology. Sheryl Eddy and Lenora Hudson are to be thanked for their help in typing. David L. Royster, Michael P. Kennedy, and James G. Rosenbaum kindly sent photographs for inclusion in this book. John E. Eberlin, Kevin T. Brady, and other students in

my classes at South Dakota School of Mines and Technology have made a major contribution refining this book, and they deserve a special thanks. I would like to thank Allan Ross of Elsevier Science Publishing Co. for his editorial assistance.

One of the rewards that comes from writing is the increased correspondence and knowledge provided by the readers. I look forward to this correspondence.

Perry H. Rahn
Rapid City, South Dakota
December 1985

Contents

1

Population

The power of population is infinitely greater than the power in the earth to produce subsistence for man.

Thomas Malthus, 1766–1834

We come now to New York, which enjoys the double advantages of an excellent harbor and a large navigable river, which opens communication with the interior parts of the country; and here we find a flourishing city, containing forty thousand inhabitants, and increasing beyond every calculation.

Isaac Weld, Jr., 1807

Unlike plagues of the dark ages or contemporary diseases we do not understand, the modern plague of overpopulation is soluble by means we have discovered and with resources we possess. What is lacking is not sufficient knowledge of the solution but universal consciousness of the gravity of the problem and education of the billions who are its victim.

Martin Luther King, Jr., 1929–1968

I feel like I'm really contributing something. Even after I'm dead, I'll go on.

Mother of 17 children, Rapid City, SD, 1980

1.1 Introduction

A main concern of the engineering geologist is to allow for the improvement in man's condition. It is important, therefore, to understand what man's condition is and to grasp the magnitude of population growth—not only to obtain a perspective on future urban pressures and related geotechnical problems, but also, as an educated person, to be cognizant of the population explosion, its impact on the environment, and the limits of growth.

Ancient civilizations have crumbled because they fouled their own environment. Several thousand years ago the irrigation-based civilization in the Tigris and Euphrates Valley in Mesopotamia collapsed as the soil became salinized. The Romans succumbed not only because of the invading Huns but because the Romans destroyed their own forests and contaminated their own water. Ancient Indian tribes in the New World such as the Maya in Mexico and Hohokam in Arizona perished from drought and irrigation malpractice.

Many people in today's world seem to be enjoying growth and material prosperity unmatched in historic times, and yet there are signs that the planet earth is in trouble. A special report to the President of the United States, compiled by 13 U.S. government agencies (Council on Environmental Quality, 1980), warned that only international cooperation could arrest degradation of the world environment, exhaustion of resources, and overpopulation. "If present trends continue," the report stated, "the world in 2000 will be more crowded, more polluted, less stable ecologically, and more vulnerable to disruption than the world we live in now. Serious stresses involving population, resources, and environment are clearly visible ahead. Despite greater material output, the world's people will be poorer in many ways than they are today."

Nobody can tell what the future will bring, and it is often difficult to separate facts from propaganda spread by either the doomsday environmentalists or the optimistic promoters of growth. This chapter presents some data on population. Chapters 13 and 14 deal with environmental questions related to the future availability of mineral, energy, water, and land resources.

1.2 World Population

Man is believed to have evolved about 2 million years ago. Ehrlich and Ehrlich (1970) estimate that the total population of earth 10,000 years ago (8,000 B.C.) was approximately 5 million people. By the time of Christ, the population was around 250 million, and it increased to 500 million (doubled) by the year 1650. It then doubled to 1 billion around 1850, doubled again to 2 billion by 1930, and doubled again to 4 billion by 1975. The 1983 world population was about 4.72 billion.

The growth of human population is exponential (Fig. 1.1). In other words, the world's population has not only increased continuously (with minor irregularities such as the fourteenth century plague), but the rate of increase has also grown. Viewed in terms of geologic time, the "explosion" of human population is truly an exceptional biologic event, probably without parallel in the entire history of the earth.

Figure 1.1 World population growth (from van der Tak et al., 1979).

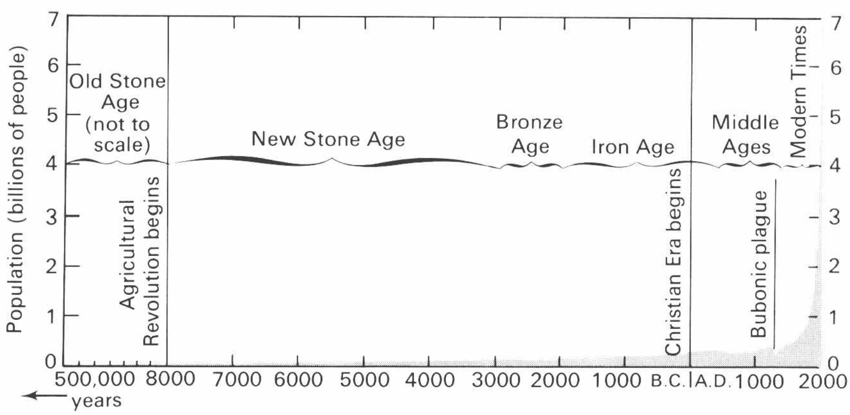

Table 1.1 Population Data and Projections for Selected Countries

	1975 (million)	2000	Percent increase by 2000	Average annual percent increase	Percent of world population in 2000
World	4090	6351	55	1.8	100
More developed regions	1131	1323	17	0.6	21
Less developed regions	2959	5028	70	2.1	79
Major regions					
Africa	399	814	104	2.9	13
Asia and Oceania	2274	3630	60	1.9	57
Latin America	325	637	96	2.7	10
U.S.S.R. and Eastern Europe	384	460	20	0.7	7
North America, Western Europe, Japan, Australia, and New Zealand	708	809	14	0.5	13
Selected countries and regions					
People's Republic of China	935	1329	42	1.4	21
India	618	1021	65	2.0	16
Indonesia	135	226	68	2.1	4
Bangladesh	79	159	100	2.8	2
Pakistan	71	149	111	3.0	2
Philippines	43	73	71	2.1	1
Thailand	42	75	77	2.3	1
South Korea	37	57	55	1.7	1
Egypt	37	65	77	2.3	1
Nigeria	63	135	114	3.0	2
Brazil	109	226	108	2.9	4
Mexico	60	131	119	3.1	2
United States	214	248	16	0.6	4
U.S.S.R.	254	309	21	0.8	5
Japan	112	133	19	0.7	2
Eastern Europe	130	152	17	0.6	2
Western Europe	344	378	10	0.4	6

From Council on Environmental Quality, 1980.

The population in some countries is increasing faster than others. Table 1.1 shows that the people of the world, as a whole, are presently increasing at an annual rate of about 1.8%; but people in Central American countries are increasing at 3.2%/yr, whereas northern Europe is increasing at only 0.5%/yr. Sociological reasons for the larger growth rates generally involve religious factors (birth control taboos) as well as economic factors (more children help support the parents).

Figure 1.2 shows the distribution of people according to age in Mexico, the United States, and Sweden. The contrast is remarkable and illustrates the severity of population growth in a country such as Mexico or India (Population Reference Bureau, 1970). It is particularly disconcerting to realize that the countries with rapid growth rates are also the poorer countries (the "developing countries"), where food and other resources are inadequate or barely adequate. Population and environmental problems in many countries in Africa and Latin America are

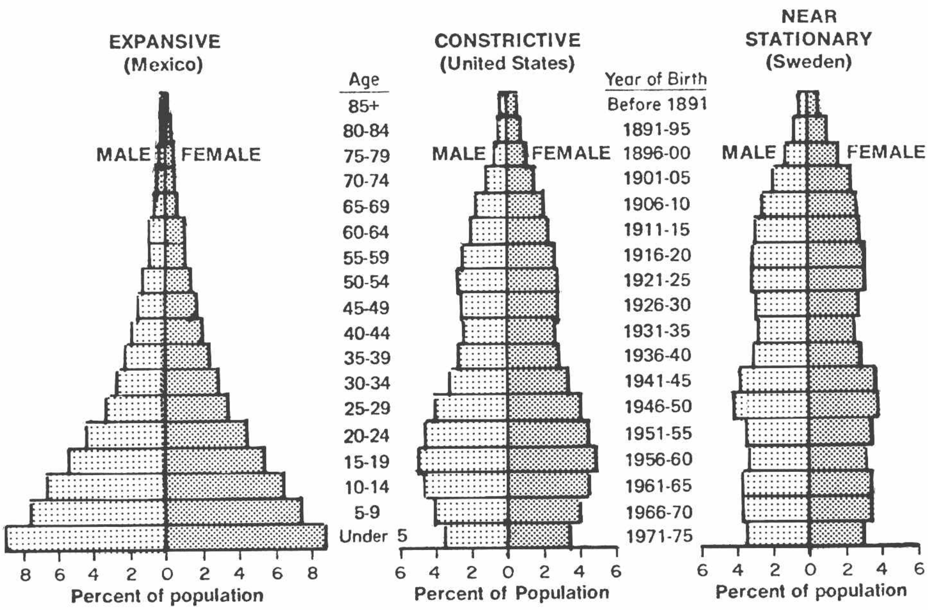

Figure 1.2 Age structure population pyramids (year 1976) for Mexico, United States, and Sweden (from Haupt and Kane, 1982).

critical, yet the education of the people and amelioration of problems of these countries is difficult to achieve where the majority of people are not only uneducated but are under 15 years of age.

1.3 Exponential Functions

One of the most useful equations in engineering is the relationship of the future value of some parameter. If its growth rate is constant, this equation can be simply derived as follows. The increase in number of items present (dN) is proportional to the original number of items (N) times some increment of time (dt). Then:

$$dN = \lambda N dt,$$

where λ is a constant. Arranging terms, we have:

$$\frac{dN}{N} = \lambda dt.$$

Integrating both sides, we obtain:

$$\int \frac{dN}{N} = \int \lambda dt,$$

$$\ln N = \lambda t + c.$$

If the number of items present at $t = 0$ is N_0, then:

$$\ln (N_0) = \lambda(0) + c,$$

$$c = \ln N_0.$$