GEOMORPHOLOGY AND ENGINEERING

Edited by
Donald R. Coates

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Donald R. Coates
State University of New York at Binghamton

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PREFACE

This book is the proceedings volume of the Seventh Annual Geomorphology Symposium held in the Department of Geological Sciences at the State University of New York at Binghamton on September 24–25, 1976. The organization of this meeting, "geomorphology and engineering," was set in motion more than three years ago in correspondence with Professor John Orsborn, then chairman, Department of Civil and Environmental Engineering at Washington State University, who suggested the idea for combining the two disciplines. With the exception of the first symposium on environmental geomorphology, the other five have dealt largely with landforms, surface processes, and techniques of analysis of primary interest to geomorphologists. Thus it is appropriate to provide data, examples, and methods that are applicable on the interdisciplinary level and to show the joint involvement of earth scientists with the engineering profession.

The potential subject matter that comprises the total interface of geomorphology and engineering is so vast that an attempt at complete coverage in a single volume would be impractical. Therefore, it is not intended or implied that this book is comprehensive or includes all important subject areas. Instead, the various chapters are suggestive and illustrative of the broad range of subject matter. Indeed, several of the other symposiums contain pertinent data on some of the fields, and the interested reader is referred to them. [For example, elements of coastal engineering are discussed in *Coastal Geomorphology* (1973) and highway engineering is covered in *Environmental Geomorphology* (1971) (both volumes edited by D. R. Coates and published by State University of New York, Binghamton, N.Y.]

Several criteria were considered when selecting a team of authors–speakers for the symposium. Since one purpose of the symposium is to expand communications between the geomorphology and engineering disciplines and to allow for interaction, there is an even split; half the articles are by geomorphologists and half by engineers and engineering geologists. The authors represent a broad spectrum of professional pursuits, including federal and state governmental agencies (U.S. Department of Agriculture's Forest Service and Soil Conservation Service, Corps of Engineers, U.S. Geological Survey, New York State Geological Survey), private business (Hershey) and private consulting firms, and a variety of universities and colleges. The authors come from broad geographic areas in North America, and they describe a range of field localities from Alaska to Canada, and from Washington, Oregon, California, and Colorado to the Mississippi River Basin. In the east, a variety of case histories are developed in such states as North Carolina, Maryland, Pennsylvania, and New York. The themes and topical areas that comprise the subject matter of the volume have been grouped into five parts for reader convenience and organizational style.

Part I: Methods and Mapping. Chapter 1, by Coates, sets the stage by describing the nature of the techniques, subject matter, and philosophies of the geomorphology and engineering disciplines. Chapter 2, by Olson, discusses the importance of mapping and understanding soils and how this relates to wise landuse decisions. Examples in New York and Central and South America are provided. In Chapter 3, Schmidt and Pierce describe the soil mapping techniques being used by the U.S. Geological Survey in the Denver region. Kreig and Reger, in Chapter 4, analyze the terrain classification system that was used to aid in routing the Trans-Alaska Pipeline and its network of support roads.

Part II: River Engineering. Although many other chapters contain elements of river planning and management, the papers in this section are exclusively devoted to an understanding of the dynamics and properties of the river. In Chapter 5, Noble reviews man-made structures of the Mississippi River, the great flood of 1973, and engineering implications. The companion Chapter 6, by Kolb, discusses the importance of the recognition and interpretation of alluvial landforms and soils for levee construction to reduce sand boils during high-water stages of the Mississippi River. Keller, in Chapter 7, analyzes the controversial engineering topic of channelization and suggests techniques that can be used to minimize environmental damage to streams. In Chapter 8, Orsborn provides quantitative methods that can be used by engineers for design purposes on rivers in ungaged watersheds.

Part III: Resource Engineering. Part III deals with the engineering and geomorphic relations involved when man plans and develops resources. Water is a recreational and scenic resource, and its impoundment creates new economies and the utilization of raw materials. Construction of Kinzua Dam and the rerouting of communication facilities are discussed by Philbrick in Chapter 9, wherein he shows the relation of geomorphology and engineering. Swanston and Swanson in Chapter 10 discuss the large array and chain reactions in erosion and sedimentation that result from improper roads and harvest methods for such living resources as timber in the Pacific Northwest. Chapter 11, by Fakundiny, shows the importance of landuse planning and resource assessment in the mining and transport of such nonrenewable resources as sand and gravel for the greater Rochester, New York, region.

Part IV: Urbanization Effects. Different aspects of man's impact on natural systems in urban areas are discussed. The effect that urbanization has on major floods, erosion, and sedimentation in stream channels in Maryland is analyzed by Fox in Chapter 12. Landslides provide geomorphic hazards in many urbanizing areas of California; in Chapter 13, Leighton provides several case histories and discusses how geomorphology proved effective in cost and hazard reduction. Urban areas produce enormous waste products that must be disposed of; Foose and Hess, in Chapter 14, provide a case history of a landfill site in Pennsylvania where imaginative methods were employed to eliminate contamination of the land–water ecosystem.

Part V: Geomorphic Synthesis. Legget, in Chapter 15, summarizes the role of geomorphology in engineering planning by using case studies drawn from Canada and Europe of landslides, floods, and subsurface features. The concluding Chapter 16, by Palmer, shows the broad range of environmental and management considerations that are necessary to assess the entire river corridor. By using such an approach, the maintenance and integrity of the river process can be preserved.

I wish to thank the Geomorphology Group and the Department of Geological Sciences for their support of the symposium. Special thanks are reserved for Dr. Jorge Rabassa of the Barloche Foundation of Argentina for his assistance in editorial review during the year he spent at Binghamton while on a Fulbright Scholarship.

DONALD R. COATES

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LIST OF CONTRIBUTORS

Donald R. Coates
Department of Geological Sciences, State University of New York at Binghamton

Robert H. Fakundiny
New York Geological Survey, Museum and Science Service

Richard M. Foose
Department of Geology, Amherst College

Helen L. Fox
Soil Conservation Service, U.S. Department of Agriculture, College Park, Maryland

Paul W. Hess
Hershey Foods Corporation, Hershey, Pennsylvania

Edward A. Keller
Department of Geological Sciences, University of California, Santa Barbara

Charles R. Kolb
3314 Highland Drive, Vicksburg, Mississippi

Raymond A. Kreig
D. J. Belcher & Associates, Inc., Ithaca, New York

Robert F. Legget
531 Echo Drive, Ottawa, Canada

F. Beach Leighton
Leighton and Associates, Irvine, California

Charles C. Noble
Charles T. Main, Inc., Boston, Massachusetts

Gerald W. Olson
Department of Agronomy, New York State College of Agriculture and Life Sciences

John F. Orsborn
Department of Civil and Environmental Engineering, Washington State University

Leonard Palmer
Earth Sciences Department, Portland State University

Shailer S. Philbrick
117 Texas Lane, Ithaca, New York

Kenneth L. Pierce
U.S. Geological Survey, Denver, Colorado

Richard D. Reger
Alaska Division of Geological and Geophysical Surveys, College, Alaska

Paul W. Schmidt
U.S. Geological Survey, Denver, Colorado

Frederick J. Swanson
Department of Geology, University of Oregon

Douglas N. Swanston
Forest Service, U.S. Department of Agriculture, Corvallis, Oregon

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METHODS AND MAPPING

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GEOMORPHIC ENGINEERING

Donald R. Coates

INTRODUCTION

Many dictionaries describe engineering as the business of planning, designing, constructing, and managing machinery, roads, bridges, highways, dams, tunnels, etc. Others have defined it as the art, or even the science, of using power and materials most effectively in ways that are valuable and necessary to man. Engineering has been divided into many subfields, which represent nearly all the activities of man. Some of the older and more traditional fields include civil, mining, structural, hydraulic, sanitary, electrical, chemical, mechanical, military, agricultural, and related engineering specialities. Some newer fields in which the appellation "engineering" is commonly used include traffic, communications, illuminating, hydroelectric, aeronautical, automotive, heating, ventilation, acoustical, electronics, marine, and nuclear. New terms and combinations are continually instituted. For example, the U.S. Army Corps of Engineers, which was traditionally oriented along civil engineering lines, has begun to use such new terms as "coastal engineering," as in their Coastal Engineering Research Center (CERC) near Washington, D.C., and many of their works in the Mississippi River Basin are described as being "river engineering." Thus, the geomorphic process is increasingly being recognized as a significant component of engineering interest.

Geomorphology is the science of the study of landforms and the processes that create them. That part of the discipline which comes into contact with the engineering profession is the area that Coates has called "environmental geomorphology." He has defined this area as follows:

> Environmental geomorphology is the practical use of geomorphology for the solution of problems where man wishes to transform landforms or to use and change surficial processes (Coates, 1971, p. 6).

It thus involves

> (1) study of geomorphic processes and terrain that affect man, including hazard phenomena such as floods and landslides; (2) analysis of problems where man plans to disturb or has already degraded the land–water ecosystem; (3) man's utilization of geomorphic agents or products as resources, such as water or sand and gravel; and (4) how the science of geomorphology can be used in environmental planning and management (Coates, 1972, p. 3).

It therefore follows that

> The goal for geomorphic environmental studies is to minimize topographic distortions and to understand the interrelated processes necessary in restoration, or maintenance, of the natural balance (Coates, 1971, p. 6).

In summary, environmental geomorphology treats man as a physical process in changing the terrain, in the same manner that other surficial forces transform the landscape, such as rivers, oceans, winds, gravity movements, etc. Since man lives, works, and plays on the surface of the earth, many of his activities are designed to modify the land–water ecosystem. This habitat is the province of the geomorphologist, who is trained in understanding what constitutes process and landform equilibrium.

The activities of man in civilized society can be broadly grouped into water resources, living resources, nonrenewable resources, and services.

Relation of Geology, Geomorphology, and Engineering

Because geology, the science of the earth, is so broad and complex, it has been subdivided into many fields. A variety of names has been used for those disciplines that have some overlap with engineering: engineering geology, economic geology, environmental geology, environmental geomorphology, urban geology, urban geomorphology, etc. It is the thesis of this chapter that because of the vast spread in competences—and yet the need exists for coordinated expertise—the area of *geomorphic engineering* is a significant and integral part of man's stewardship of the earth and needs recognition as such.

In describing the interaction of geologists and engineers, Legget (1962) points out

> . . . how closely the science and the art are related and how dependent civil engineering work generally must be upon geology. It is, indeed, no mere figure of speech to say that the science of geology stands in relation to the art of the civil engineer in just the same way as do physics, chemistry, and mathematics
>
> Thus arises the need for cooperation between the civil engineer and the geologist, the practical builder and the man of science. . . . This partnership is, in some ways, a union of opposites, for even the approach of the two to the same problem is psychologically different. The geologist analyzes conditions as he finds them; the engineer considers how he can change existing conditions so that they will suit his plans (pp. 2–3).

There was a time when engineering geology meant only the application of geology to such civil engineering works as roads, dams, tunnels, etc. Recent writings and trends, however, are now claiming that it embraces such subjects as soil and rock mechanics, power siting, and even landuse management. The growth of the discipline is indicated

> . . . by the increasing number of citations per year under the heading "engineering geology" in the Geological Society of America's Bibliography & index of geology: 1969 (588), 1970 (586), 1971 (1,065), 1972 (2,063), 1973 (2,500 estimated) (Lee, 1974, p. 19).

The areas of rapid increase

> . . . could be pinpointed in several areas, including land-use and zoning controls, resource management, nuclear-reactor siting, underground construction, subsidence due to mining and fluid extraction, construction in seismic areas, and a wide variety of costly slope-stability problems.

And in 1975, Lee (1975) announced that

> Energy materials exploration and development were the dominant issues involving engineering geologists in 1974. Various extraction procedures will change the surface and subsurface environment. These changes will be significant; some may be tolerable, and others intolerable and dangerous (p. 28).

In his review article on what constituted important elements in engineering geology for 1975, Throckmorton (1976) devotes most of his analysis to landuse planning and when speaking of the third world nations states that

> We have a golden opportunity [U.S.A.] to help prevent the mistakes made when the United States was making similar spectacular strides in the use of land and the development of natural resources (p. 18).

Another approach to understanding how engineering geologists perceive their discipline is to review the types of studies that constitute the 10 case-history volumes that the Engineering Geology Division has prepared for publication by the Geological Society of America. Four of the volumes are organized around a central theme; these include legal aspects, rock mechanics, rapid excavation, and *Geologic Mapping for Environmental Purposes,* the most recent (Ferguson, 1974). The other six volumes each contain a variety of topics and include the geology of tunnels, bridges, dams, highway embankments, artificial recharge, aggregate, subsidence, landslides, till, rubble sources, radioactive wastes, relief wells, rock removal, sensitive sediments, swelling of rock, reservoir loading and waterflooding in relation to earthquakes, tsunamis, nuclear explosions, disposal wells, etc.

Thus, it is becoming increasingly clear that engineering geologists now conceive of their role as greatly enlarged and more multifaceted. It has been expanded to embrace everything from the original kinship with civil engineering to analysis and decision making in nuclear siting, landuse policy, and even economic geology. Because the discipline is currently threatened with the danger of running in all directions, of being spread very thin, and may have reached a critical mass (such as in New York City, which has such a vast array of problems as to be nearly unmanageable), it is time to review goals, purposes, and content to see whether alternative strategies may more effectively use the talents of the engineering geologist.

In recent years, the engineering profession has reviewed its mission, and increasing numbers of universities are broadening their base into the environmental sciences. For example, by 1975 at least 43 major universities had instituted graduate degree programs in departments, divisions, or schools of "environmental engineering" (Hufschmidt, 1975, p. 46). Typical names that are now employed include Civil and Environmental Engineering, Environmental Systems Engineering, and Environmental Sciences and Engineering. Again, it becomes apparent that, with such an all-encompassing eclecticism, service to science and society will be enhanced by a redefinition of some of the elements that constitute this growing morass.

Scope of Geomorphic Engineering

The education and training of a geomorphic engineer needs perceptive and balanced treatment. Basic philosophical differences may occur in the extreme views of geomorphologists and engineers. The geological background of the geomorphologist has trained him to think in vast time dimensions (except for hazard and such catastrophic events as floods, hurricanes, landslides, earthquakes, and volcanic activity), whereas the engineer is generally summoned to solve rather immediate or short-range problems that are measured in days, months, or a few tens of years. Another difference concerns the scale of operations. Engineers are taught to solve individual problems at specific localities. Although many exceptions occur, construction activities generally are not regionally designed. The immediate problem may be solved as far as the local contractor, or even city, is concerned, but the construction may prove damaging to contiguous areas. The location of groins may save the individual property that it was designed for, but the natural feedback mechanism of the coastal regime may cause severe erosion in downdrift properties. Thus, the total land–water ecosystem must be understood, evaluated, considered, and managed, instead of using a piecemeal approach. Such analysis would heed the truth behind the saying, "The operation was a success but the patient died." Geomorphology and engineering are united under the EIS clauses (Environmental Impact Statement) of the National Environmental Policy Act of 1969 (NEPA). Here it is mandated that major industrial and governmental construction activities must consider alternative actions and sites and must predict the environmental changes of the construction. Thus, the complete evaluation of all terrain forms and processes is necessary for legal compliance with the NEPA.

Books on environmental awareness and the need for more earth science input in the decision-making process, such as those by Flawn (1970) and Coates (1971), are of rather recent vintage in the geological literature. Actually, the call for action and need for interdisciplinary terms in the management of terrain systems received much of its impetus from landscape architects, such as Whyte (1968) and McHarg (1969), and many elements they describe constitute some of the content of *geomorphic engineering.*

Geomorphic engineering combines the talents of the geomorphology and engineering disciplines. It differs from environmental geomorphology, wherein man is studied as one of the typical surface processes that change the landscape, and instead brings knowledge of physical systems to bear on problems that may require construction for their solution. The geomorphic engineer is interested in maintaining (and working toward the accomplishment of) the maximum integrity and balance of the total land–water ecosystem as it relates to landforms, surface materials, and processes. This approach also differs from that of the engineering geologist, who supplies the data base for construction in terms of strength, distribution, and structure of rock types to be encountered in foundations and excavations. A useful model that embodies the type of unity that should be inherent in geomorphic engineering work is that provided by such groups as CERC. This *coastal engineering* subdiscipline combines process and sediment-oriented specialists with design and planning personnel. Thus, a strong geomorphic component is brought into full orchestration with those who deal with the problems related to decision making on and management of beaches, coastlines, and harbors. In similar fashion, *river engineering* (see Part II and Chapter 16) would include those scientists with special skills in morphology of river systems, channels, and hydrogeology. *Resource engineering* includes not only the extraction and planning that accompanies mineral mining, but total management of the system in site development, delivery systems, and rehabilitation procedures.

There is a continuous spectrum of viewpoints of man and his relation to the environment. Preservationists would represent one end of the series, whereby man's inheritance of the planet mandates him to leave everything alone without disturbance. Complete adherence to such a policy would revert civilization back and beyond the horse and buggy stage. The other end of the spectrum would be represented by the money dedicated entrepreneur-type capitalist (in Marxian dogma) who is only interested in the quickest and most profits to himself. While working in Arizona for three years with the U.S. Geological Survey (1951–1954), I unfortunately encountered more than a few such land barons and absentee landlords, who instructed their tenants and workers to grow as much cotton as rapidly as possible, without regard for the amount of water required in such operations or for that loss of soil nutrients or salt buildup. Therefore, it is hoped that a certain morality might be associated with geomorphic engineering decisions, such as practiced by the Amish in their land and soil husbandry philosophy. They know their farms will be handed down to their children and to other generations, so they build a bit of immortality into their unusual care and management of the earth and its products. Thus, the geomorphic engineer should take every study and precaution to assure that (1) the structures that are built are necessary and will accomplish their intended purposes, (2) construction is located at the optimum site that will cause minimum environmental disturbance, and (3) planning and management have accounted for environmental feedback on contiguous lands and waters.

One place that requires the interaction of many disciplines is the design of "open space." Here priorities must be assessed, natural processes maintained as much as possible, and multiple landuse employed whenever feasible. Thus, geomorphology, engineering, economic geology, and landscape architecture must join forces for stewardship of the cityscape.

WATER RESOURCES

We shall now turn our attention to a brief description and analysis of those subfields where the expertise of the geomorphic engineer is an important ingredient in their use and management. Water can be considered as the basic building block in civilization.

> You could write the story of man's growth in terms of his epic concerns with water. . . . The habits of men and the forms of their social organizations have been influenced more by their close association with water than with the land by which they earned their bread (Frank, 1955, pp. 1–2).

> According to our present information, it would seem that, prior to the commercial and industrial revolution, the majority of all human beings lived within the orbit of hydraulic civilization (Wittfogel, 1956, p. 161).

Wittfogel's thesis subscribes to the old adage that "necessity is the mother of invention." He traced the development of civilization in many of the early great empires to man's requirements for water in the agrarian economy. To transport, handle, monitor, and use water, science and engineering had to combine with a strong governmental structure based on firm legal foundations for the total management of the irrigation water system.

> Irrigation demands a treatment of soil and water that is not customary in rainfall farming. The typical irrigation peasant has (1) to dig and re-dig ditches and

furrows; (2) to terrace the land if it is uneven; (3) to raise the moisture if the level of the water supply is below the surface of the fields; and (4) to regulate the flow of the water from the source to the goal, directing its ultimate application to the crop (Wittfogel, 1956, p. 157).

The use of water as a resource involves many geomorphic considerations, both in surface water and groundwater planning and management, and the knowledge of the engineer in constructing, for example, dams to impound water for storage in reservoirs, canals to transport water from surplus to deficit areas, and wells to transfer water from below ground to the surface. Each of these areas has its own special problems and constraints that need a geomorphic engineering viewpoint.

The reciprocal linkage between terrain and construction knowledge is well illustrated by the irrigation works of the hydraulic engineers who designed the canal networks in India during the nineteenth century. In irrigation agriculture it is vital to design channel shape and gradient with utmost precision; if improperly engineered, erosion will occur where gradients are too steep, and siltation where slopes are too shallow. Thus, it was no accident that some of the equations for water transport in open systems were developed using the empirical methods of the trained field observer. Using other techniques in natural stream systems, Leopold and Maddock (1953) developed the laws of hydraulic geometry, which have wide applicability to stream design characteristics when channelization is required (see Chapter 7).

Use of water in irrigation can have a double-barreled reaction: siltation *and* salinization. Jacobsen and Adams (1958) describe some of the effects of salt encrustation of soils and the resulting loss of fertility and crop productivity.

> ... that growing salinity played an important part in the breakup of Sumerian civilization seems beyond question (p. 1252).

They discuss how, in the Diyala region of Iraq, silt in the fields raised their level 1 m (3 ft) in 500 yr, and other authors have indicated that the cleaning of canals consumed the time and energy of more than half the labor force.

Not only do surface waters introduce salinity problems in some areas, but so can groundwater usage. The excessive withdrawal and depletion of groundwater reservoirs can lead to still another problem: subsidence. The Imperial Valley of California suffers from the twin problems of salinization and subsidence. Millions of dollars are spent yearly to retile and relevel the fields. To avoid waterlogging and salt encrustation, underdrain tiles, which previously were often spaced at intervals of 200 ft and more, are now being spaced at intervals as short as 50 ft. The subsiding areas need yearly maintenance and resetting of canals, ditches, and pipes.

LIVING RESOURCES

Engineers have played a vital role in the development of the agricultural croplands that produce the living resources so necessary for man's subsistence. Although such resources are renewable, in many parts of the world good cropland is at a premium. In such situations, it is the engineer who must undertake those terrain adjustments wherein landforms are modified and new agricultural lands are created. Land-reclamation sites

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