Geomorphology in Environmental Management

AN INTRODUCTION

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PREFACE

Geomorphology is the study of landforms, and in particular of their nature, origin, processes of development, and material composition. This book is concerned with those aspects of geomorphology that relate to man's use of the natural environment. Such 'applied' aspects of the subject have attracted some attention from each generation of geomorphologists, but attitudes towards them are changing, and for good reasons.

In the first place, there has been a general resurgence of interest in those aspects of the natural sciences relevant to man. This arises largely from a growing anxiety within many societies over human exploitation of the natural environment, and from practical steps taken to tackle environmental problems. The passing of the National Environmental Policy Act by the U.S. Congress in 1969, and the creation in Britain of the Department of the Environment in 1971 are two reflections of public concern.

A second, more specific reason for changed attitudes to studies relating geomorphology to human use of the natural environment arises from changing fashions within geomorphology as a whole. In recent years, a long-established emphasis on landform evolution has been challenged by a growing interest in the analysis of relations between contemporary forms and processes and their spatial variations. Perhaps not entirely coincidentally, this trend has placed research emphasis on those areas of the subject of greatest relevance to man. At the same time, it is becoming clear that some aspects of 'pure' and 'traditional' research in geomorphology are potentially of real practical value.

Traditionally, geomorphology has found its university place within the departmental palisades of geology (and especially engineering geology) and geography, and it is from these disciplines that the geomorphological response to public and professional concern with man–environment relations has been most pronounced. Of the many recent examples of discussions in environmental management where geomorphological considerations have figured prominently, we might cite several conference proceedings published in the United States: *The Importance of the Earth Sciences to the Public Works and Building Official* (Association of Engineering Geologists, 1966), *Geologic Hazards and Public Problems* (Office of Emergency Preparedness, Santa Rosa, California, 1969), *Environmental Planning and Geology* (U.S. Department of Housing and Urban Development, 1969), and *Environmental Geomorphology* (State University of New York, Binghamton, Publications in Geomorphology, 1971). While the sphere of man–environment relations is the legitimate concern of many, it has been a focus of activity in geography for over

100 years, and it is a focus that is increasingly attracting attention. Recent contributions have included studies as diverse as Tuan's philosophical exploration of *Man and Nature* (Association of American Geographers, 1971), and Hare and Jackson's pragmatic *Environment: A Geographical Perspective* (Department of the Environment, Canada, 1972).

Despite their traditional links with geology and geography, geomorphologists have always sought and encouraged links with those natural sciences, such as pedology, climatology, hydrology, and ecology, that can provide evidence essential to the solution of geomorphological problems. Indeed, significant geomorphological research has been done by practitioners in these fields. But for geomorphological work to be used effectively in environmental management, more is required of the geomorphologist—he must also be aware of the social, economic, and technical contexts in which his information is relevant.

In this book we have tried to bring together geomorphological material that has been, or could be of value in environmental management. The studies we quote come from a variety of disciplines and research organizations. Our aim is to provide a useful introductory survey for those interested in exploring the practical applications of geomorphology and for those who require a geomorphological component in their study or practice of environmental management. To the geomorphologist we offer a fresh look at parts of the subject, often using material that has not previously appeared in systematic geomorphology texts. We hope that the display of techniques, problems, and environmental relationships may be of value to geologists, physical geographers, and other natural scientists with an interest in geomorphology. To them, our occasional forays into social science may serve as an introduction to the practical realities of environmental management. To social scientists, planners, and others who increasingly have to consider the natural environment, this book may serve to introduce those aspects of geomorphology central to some of their problems. We fully realize that these are ambitious aims, and that any introductory volume of this kind must have many shortcomings. Experience over several years of teaching geomorphology to geologists, geographers, planners, and economists leaves us in no doubt that our task is difficult but rewarding, and that there is still an enormous amount of work to be done.

In the Introduction we discuss briefly some of the broader aspects of geomorphology in environmental management, and the role that geomorphologists have played or could play in it. Subsequent chapters are of two major types. The majority are concerned with selected systematic aspects of geomorphology relevant to environmental management. The approach in these chapters (1–9) has been to analyse the appropriate geomorphological systems, and especially the processes at work within them, to indicate how the systems can be modified or manipulated by man, and to explore some of the social and economic implications related to the actions of man. In the remaining chapters (10–14), methods of survey and classification to which a knowledge of geomorphology is actually or potentially important are examined. Many of the techniques discussed have been developed by geomorphologists, often working as part of research teams in international or government-sponsored organizations, in consultancy, or in universities. A catholic selection of case studies is an important ingredient of the book as a whole.

Our text has inevitably been limited to provide a volume of convenient dimensions. We have not attempted to be comprehensive. Rather, we have selected important themes and introduced them as fully as possible. Some of these themes are reviewed under several chapter headings. An example is the geomorphological contribution to solving problems in urban areas (Chaps. 2, 5, 6, 11, and 14). Our references are also selected. One of our discoveries during the preparation of this book was the extensive, valuable, but unpublished 'underground' literature which is not generally available; we have included some of this so as to give it wider attention, but we have also provided a substantial number of references to material available to students in most university or college libraries so that points raised in the text may easily be followed up.

We have greatly benefited from comments by acknowledged experts on particular topics. They have helped to eliminate errors of fact and to identify errors of emphasis and omission; we are, of course, alone responsible for any remaining inadequacies. We thank especially Dr. R. J. E. Brown (National Research Council of Canada), Dr. R. J. Chandler (Imperial College, London, England), Dr. K. J. Gregory (University of Exeter, England), G. E. Hollis (University College London, England), D. B. Honeyborne (Building Research Establishment, England), Dr. J. N. Hutchinson (Imperial College, London, England), B. E. Lofgren (U.S. Geological Survey, Sacramento, United States), Professor D. Lowenthal (University College London, England), Dr. M. Newson (Institute of Hydrology, England), Professor N. Woodruff (University of Kansas, Manhattan, United States), and Professor H. Th. Verstappen (I.T.C., Holland). Professor C. A. M. King has not only kindly written the chapter on coasts, but has also commented on much of the text. We would also like to thank Valerie Cawley (Cartographic Unit, Department of Geography, University College London) for her expert and sympathetic reconstitution of our primitive sketches into publishable diagrams, and Barbara Cooke and Rosemary Hudson, both of whom provided generous typing and secretarial assistance.

RONALD U. COOKE — 1 *July* 1973 — JOHN C. DOORNKAMP
University College London — *University of Nottingham*

CONVERSION TO METRIC

Throughout this book metric units have been used whenever possible. This has meant the conversion of some data originally obtained in non-metric units. In a few cases, however, conversion has not been possible and the data, results, or equations are given in the units in which they were originally derived. When conversion was possible the following equivalents were used:

DISTANCES

1 inch = 2·54 cm
1 foot = 30·48 cm or 0·30 m
1 yard = 91·44 cm or 0·91 m
1 rod = 5 m
1 mile = 1·61 km

AREAS

1 sq inch = 6·45 sq cm (cm^2)
1 sq foot = 0·09 sq m (m^2)
1 sq yard = 0·84 sq m (m^2)
1 sq mile = 2·59 sq km (km^2) or 259 hectares (ha)
1 acre = 0·40 ha

VOLUME

1 cu foot = 0·30 cu m (m^3)

WEIGHT

1 ton (U.S.) = 907·18 kg
1 lb = 453·59 g, or 0·45 kg

OTHERS

1 ton per acre = $2{\cdot}26795 \times 10^3$ kg per ha
1 cu ft per sec = 101·94 m^3 per hour

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INTRODUCTION: GEOMORPHOLOGY AND ENVIRONMENTAL PROBLEMS

WITHIN the contemporary concern for environmental management many problems relate to the interaction between man, land, and water. Geomorphology normally involves a study of the two latter, and frequently recognizes that today man is the most important geomorphological agent in some parts of the world. Wherever man uses land he has to accommodate its relief, materials, and water resources to his purposes. The study of these things falls within the domain of the hydrologist, engineering geologist, pedologist, and agriculturalist, and yet they maintain their identity under the title of geomorphology as well. It is with the form, materials, and processes of the earth's surface that geomorphology is concerned. It has its practitioners in many fields.

An awareness of the role of geomorphology in environmental management is growing rapidly after a very slow start. During the first half of this century the main stream of academic geomorphologists tended to overlook the work of Gilbert (1880) and others whose concern for the explanation of landform evolution through observable processes within the framework of geological materials laid down a potentially fruitful basis for geomorphological studies in environmental management. The geomorphological literature of the first half of this century does contain, however, a few applied studies. Glenn's (1911) paper illustrating accelerated erosion induced by man, Sherlock's substantial *Man as a Geological Agent* (1922), Bryan's (1925) extended analysis of erosion and sedimentation in the south-western United States, and the study of man-induced soil erosion by Jacks and Whyte (1939) are examples of these. In addition to these published works there are also a number of studies which were undertaken for private consultation. These include examinations of construction sites, evidence provided in legal disputes, and reports on the search for mineral resources. Most of them are not generally available.

Nevertheless, the study of contemporary processes by geomorphologists was relatively unimportant during these decades, with the significant exceptions of work on glaciers (e.g. Johnson, 1904; Gilbert, 1906; Thorarinsson, 1939; see Embleton, 1972), on shoreline processes (e.g. Beach Erosion Board, 1933; Lewis, 1931; Gaillard, 1904; Johnson, 1919), and on aeolian processes (Bagnold, 1941). By and large the analysis of present-day processes, especially fluvial processes, became the responsibility of hydrology and hydraulic engineering. Within these fields there now exist textbooks of immense relevance to geomorphologists (e.g. Linsley, Kohler, and Paulhus, 1949; Chow, 1964).

Despite sporadic attempts during the 1950s to develop further the field of process studies, the major advance came with the publication of *Fluvial Processes in Geomorphology* by Leopold, Wolman, and Miller (1964). This work is replete with information about present-day fluvial processes and by implication has much relevance to a number of environmental problems. More direct relevance was implied by the later publication of *Water, Earth and Man* (Chorley, 1969), and of *Environmental Geomorphology* (Coates, 1971). In fact much work in geomorphology since 1950 is of direct relevance to environmental problems; but it has not often been applied to them.

In a presidential address to the South African Geographical Society, Dixey (1962) stressed the need for more geomorphological studies to be orientated towards the needs of man. Yet, in a broad review of the subject seven years later, Dury (1969) still had to admit that geomorphology does not record numerous applied contributions, though he prophesied that many such contributions would come, and recognized that great scope for applied work exists in the investigation and prediction of geomorphological processes and their effects. It may seem surprising that Dury should still have to say this in 1969, when fifteen years earlier Thornbury (1954) devoted a convincing chapter to applied geomorphology in a widely-read textbook. Using specific examples to illustrate his view, Thornbury reasoned the case for applying geomorphology to hydrological studies, mineral exploration, engineering projects including dam-site and airfield-site selection, as well as to oil exploration and to military needs.

The necessity to understand geomorphological processes has now been amply demonstrated in situations that involve such things as flooding, landsliding, soil erosion by wind or water, coastal erosion and deposition, and the weathering of building stones. Geomorphologists are increasingly realizing the value of their work in the solution of applied problems; and they are making some singularly important contributions.

By 1950 there were also new developments in landform evaluation taking place, most notably those made by members of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia. These developments initially amounted to little more than the making of an inventory in which a landform classification provided the framework for storing knowledge about the physical landscape. This became known as the land-systems approach. At the same time, particularly in Poland, attention was being directed towards a more comprehensive scheme for mapping land-surface form, materials, and processes as a basis for planning. The technique of geomorphological mapping which arose out of this work demanded the identification and classification of all slopes, the recognition of processes both past and present, and the relationship of form and process to bedrock and regolith materials. Its clear purpose was to provide a comprehensive analysis of the physical properties of an area, usually with a view to assessing its natural resources or its physical limitations for development.

During the 1960s, therefore, research activity became redirected towards geomorphological studies with an emphasis on contemporary forms and processes (e.g. Ward, 1971); and at the same time, resource surveys in the developing countries and in otherwise uncharted terrain were based on mapping procedures in which geomorphology played a leading (and sometimes the dominant) role. There is little evidence at present of cross-fertilization taking place between these two trends, despite their common relevance to many practical problems. The way out of this situation may lie in recognizing that both land-systems mapping and geomorphological mapping are valuable in effectively describing present conditions and in revealing much of the nature and context of contemporary processes. For some management problems little more may be required than a catalogue of data upon which decisions can be based. In many problems, however, the dynamic element of temporal and spatial variations in processes may be critical for sensible management.

Douglas (1971) reinforces this view by two case studies. The first concerns the River Aare, Switzerland, where engineering works and agricultural activity resulted in river erosion and deposition problems. In order to alleviate flooding engineering works were carried out in the mid-nineteenth century which thereby reclaimed land for agriculture. However, without recharge from flood waters there was a drop in the water table causing the peat of the reclaimed land to dry out and its surface to subside. This brought about renewed flooding, and the need for a second phase of engineering work, which took much more account of the dynamic relationships of fluvial processes. The second case study is of a coastal resort area in Belgium where harbour construction and the erection of buildings on sand dunes led to severe beach erosion. The stability of the dune coastline had already been partly threatened by the fall in level, through artificial drainage, of fields on the landward side. Construction on the dunes broke down their dynamic equilibrium with the beach by restricting the supply of sand from the dunes to the beach. This increased the steepness of the beach and erosion accelerated. Douglas concluded that man's challenges to nature occur quite frequently, with an alteration of one aspect of the physical environment leading to a succession of readjustments. Both of these case studies show that management of the environment requires a thorough understanding of physical process--response systems, not least if these systems are to be considered in cost-benefit analyses.

The concept of land management taking place with an informed awareness of the nature of geomorphological systems is not entirely new. The exponents of geomorphological mapping, even in the 1950s, often implied the importance of linking the mapping of form to an understanding of process. Indeed, by 1957, Dylik, who was involved in geomorphological mapping, was able to talk about the importance of dynamic geomorphology to the economy of a country:

The earth surface whose diversification constitutes the object of geomorphological studies, is the meeting point of lithosphere, hydrosphere and atmosphere. Furthermore it is closely related to the biosphere.... Land-form surfaces and their elements are ... also surfaces of human activities, surfaces of actual or future economic exploitation. Economic activities, although sometimes adapting themselves to the existing land forms of the area, are anyhow always compelled to take them into account (Dylik, 1957, p. 6).

Dylik added that since the land surface is continually undergoing change it is evident that for economic ends a knowledge of processes and the possibility of anticipating the direction of future relief development are much more important than a mere description of the present-day relief pattern. Similar positions were adopted by Klimaszewski, Tricart, and others (see Chap. 14).

The complete understanding of a process can never come, however, from studying that process in isolation. A geomorphological process functions within a physical system. This will embrace not only landform and earth materials but also processes involving the exchange of energy and the movement of materials, and it will include the operations of man (Chorley and Kennedy, 1971). Man, as the two case studies referred to above have shown, has to be seen not only as someone who is affected by geomorphological events, but also as someone who can change, control, and generally manipulate the environment so as to influence the effect of geomorphological processes. The fact that man does not always understand the consequences of his manipulations is amply demonstrated by recurring man-induced catastrophies (Brown, 1970). To avoid such events a knowledge is required of the whole system within which the processes are operating. In Clayton's words: 'The environment is extremely complex, and anyone tempted to interfere with it, even in an attempt to reverse man-induced deteriorations, should wait until he has enough knowledge to predict the full results of his activity' (Clayton, 1971, 84). This is not an easy task. Much progress towards this end may be made, however, by continually examining the context within which the process is operating. A knowledge of physical principles and dynamic interrelationships makes possible an understanding of the processes themselves. Land-systems mapping helps to define the situation of a site problem. Geomorphological mapping isolates the relevant components of the geomorphological system.

A second fundamental consideration is that the physical systems of an area can never be fully understood in isolation from the social, cultural, and economic attitudes and conditions of the people of that area: 'The interaction between man and environment involves aspects of both the physical and social sciences, and an approach based on one alone is unsatisfactory' (Clayton, 1971, 84). Taken in the context of an exploding world population and an ever-increasing pressure on land, geomorphology is obliged to include more and more events which occur on a human time scale. At the same time pioneer work in man's perception of the physical environment (Craik, 1970) indicates that the relevance of geomorphology has to be seen in the context of man's response to what he *thinks* the environment is like rather than what it is *actually* like.

Many geomorphological systems embrace influences that extend beyond those traditionally claimed as part of geomorphology. By the same token geomorphologists may be seen by some to be laying claim to matters that they have long ignored; but subject boundaries may provide artificial barriers to progress. It is surely better to devote attention and energy to serious problems and not to be over-concerned with the name of the discipline, or with the antecedents of its practitioners. Thus the geomorphologist is likely to develop contacts with a variety of environmental managers and technicians, especially engineers, farmers, foresters, planners, and politicians, and he will probably find himself adding to his staple reading material studies in economics, engineering, geography, planning, law, and even psychology. In short, disciplinary boundaries have little meaning to the applied geomorphologist, except in so far as he must recognize them in order that he may cross them with caution.

The terms 'environmental management', 'resource management', and 'conservation' are fashionable today. The effective control in such activity rests with an enormous number of individuals, many of whom are not trained environmental scientists. The problem is to bring the scientist and the environmental decision-maker together. Frye (1967) recognized, for instance, that too many geologists (and by implication he included geomorphologists) are talking to each other rather than to the public or professional managers. In the management of the environment the public is extensively involved. In this context the public includes publicly appointed policy-making personnel. It also includes the farmer, the tourist, the building contractor, the forester, and indeed everyone who makes significant use of the land.

Many private firms and government agencies exist which deal with some part or another of the the earth's geomorphological systems. At the international level UNESCO, in its concern for the welfare of mankind, has acknowledged the important role of applied geomorphology (see, for example, the UNESCO publication *Nature and Resources*). It has also given much practical support to the International Hydrological Decade (IHD), in which geomorphologists have made a number of significant contributions; and, to name but one other example, to the postgraduate course in Applied Geomorphology at the University of Sheffield, England. On the national level