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Sedimentation Engineering

Edited by Vito A. Vanoni

ASCE

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Vito A. Vanoni

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the ASCE Task Committee
for the Preparation of
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of the Hydraulics Division

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About the cover: River dunes in the Rio Paraná near Paso de la Patria, Argentina. Bed morphology measurements were made with a multibeam echo sounder in May 2004. Note the ubiquitous superimposition of smaller bedforms on the stoss side of the larger dunes. Image courtesy of Dan Parsons and Jim Best, University of Leeds, U.K.

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A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his everyday work, rather than the findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however; nor is it so elementary or so conclusive as to provide a "rule of thumb" for nonengineers.

Furthermore, material in this series, in distinction from a paper (which expressed only one person's observations or opinions), is the work of a committee or group selected to assemble and express information on a specific topic. As often as practicable the committee is under the general direction of one or more of the Technical Divisions and Councils, and the product evolved has been subjected to review by the Executive Committee of the Division or Council. As a step in the process of this review, proposed manuscripts are often brought before the members of the Technical Divisions and Councils for comment, which may serve as the basis for improvement. When published, each work shows the names of the committees by which it was compiled and indicates clearly the several processes through which it has passed in review, in order that its merit may be definitely understood.

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FOREWORD

ASCE Manual 54 *Sedimentation Engineering*, edited by the late Professor Vito A. Vanoni, provides both qualitative and quantitative guidance to theoreticians and practitioners with respect to sediment issues and processes associated with the development, use, and conservation of water and land resources. It describes the nature and scope of sedimentation problems, details methods of investigation, and presents practical approaches to solution and management.



Vito A. Vanoni (1904–1999)

As a major contribution to the profession, Professor Vanoni organized, partially wrote, and edited the definitive Manual 54. As chairman of the special Task Committee, established in 1954 with the charge of writing the manual, Vanoni worked for two decades and set a high standard. Many of the sections of the original manuscript for the book were first published in the *Journal of the Hydraulics Division ASCE* and received considerable discussion, which was taken into account in the final manuscript. Manual 54 received worldwide recognition and widespread use in academia and practice. In 1976, the book was awarded the ASCE Karl Emil Hilgard Hydraulic Prize for best publication.

Since the publication of Manual 54 in 1975, global awareness of sediment erosion, transport, and deposition processes and of their impact on the use and development of water and land resources has greatly increased. Manual 54 remains an important reference on many aspects of sedimentation engineering, but in other aspects it has been outdated by advances in knowledge and techniques and by the emergence of new problems and issues.

In 1991 a Task Committee was formed to update Manual 54. By 2000, however, the ASCE Sedimentation Committee decided that the original volume was to be preserved as a classic and that a new manual should be prepared to include more recent advances. This resulted in the preparation of ASCE Manual 110 *Sedimentation Engineering*: *Processes, Measurements, Modelling, and Practice*, which is intended to provide an updated review of sedimentation engineering as a complement to the original Manual 54. Both manuals document the evolution of the sedimentation field over a 50-year-period as well as the state of the art in sedimentation engineering.

ASCE/EWRI Sedimentation Committee is proud to be able to publish this second edition of the classic ASCE Manual 54 *Sedimentation Engineering* 30 years after its first printing. This edition includes a new index originally prepared by Vito Vanoni after the first edition had already been published. As a teacher and a practitioner himself, he would be delighted to know that future generations will be able to benefit from this monumental contribution to the engineering profession.

Marcelo H. Garcia
Chair, Sedimentation Committee (1999–2004)
Corresponding Editor
Manual 110 *Sedimentation Engineering*: *Processes, Measurements, Modelling, and Practice*

FOREWORD TO THE FIRST EDITION

This book is concerned mainly with sediment problems involved in the development, use, control and conservation of water and land resources. Its aim is to give an understanding of the nature and scope of sedimentation problems, of methods for their investigation, and of practical approaches to their solution. In essence, it is a textbook on sedimentation engineering. As such, it must necessarily treat sedimentation in broad perspective, considering the interrelated processes of erosion, sediment transportation by water and air, and sediment deposition where it creates problems of practical importance. On the other hand, limitations of space and of objective preclude consideration of certain important aspects of sedimentation that are adequately treated in other publications. This treatment is concerned, for example, only with the dynamic phases of sedimentation excluding mass movement and not with the historical aspects that are described in many geological reference works. It deals with sediment control methods for watersheds, streams, canals, and reservoirs, but not with all of the details of sediment removal in the process of water purification—a subject extensively treated in books on waterworks practice and sanitary engineering. Nor does it consider the important subject of littoral and ocean sedimentation. Some economic and legal aspects of sedimentation and a section on transportation of particulate matter in pipes are also included.

In preparing the text it was assumed that the reader has a knowledge of elementary fluid mechanics, calculus, and a general technical background. The material is presented in sufficient detail so the reader can follow developments from basic principles. For those readers faced with practical problems the text may not give enough information and it may be necessary to seek additional material in some of the references listed at the end of each chapter.

The text was prepared from reports published in the ASCE *Journal of the Hydraulics Division* and the discussions of these reports. Each of the published reports was prepared by a specialist in the field and reviewed by at least three experts. By this procedure the material in the book has been reviewed and checked by many specialists.

The book was prepared under the supervision of the Task Committee for the Preparation of the Manual on Sedimentation of the Sedimentation Committee of the Hydraulics Division of ASCE. The idea for the work was conceived by the late Carl B. Brown in 1949 when he was the first Chairman of the Sedimentation Committee and the work was carried on by the Committee until 1954. At that time the Task Committee on Preparation of the Manual on Sedimentation was formed with V. A. Vanoni as Chairman. Others who served on the Task Committee were D. C. Bondurant, C. S. Howard, T. Means, J. Smallshaw, J. E. McKee, L. M. Glymph, Jr., P. C. Benedict, G. R. Hall, Jr., C. R. Miller, and R. F. Piest. Several people assisted the Task Committee in reviewing material, attending meetings, and carrying out other work normally done by Committeemen. Among these, special mention is due T. Maddock, Jr., J. W. Roehl, H. P. Guy, and J. N. Holeman. During the period 1964–1975 when most of the book was completed the Committee consisted of P. C. Benedict, D. C. Bondurant, J. E. McKee, R. F. Piest and V. A. Vanoni.

The principal contributors to the book are listed as follows after the chapter and section number to which they contributed.

Chapter I—L. C. Gottschalk.

Chapter II—(A, B, D, E, G, and H) V. A. Vanoni; (C) A. G. Anderson*; (F) J. F. Kennedy; (I) N. P. Woodruff, W. S. Chepil, and A. W. Zingg; (J) H. W. Shen, S. Karaki, A. R. Chamberlain, and M. L. Albertson; (K) D. R. F. Harleman; and (L) S. C. Happ.

*Deceased July 1, 1975. Mr. Anderson received the 1965 J. C. Stevens Award for his discussion of Chapter II, Section C.

Chapter III—(A) P. C. Benedict; (B) J. M. Lara; (C) J. W. Roehl, J. N. Holeman, and V. H. Jones; (D) N. P. Woodruff, W. S. Chepil, and A. W. Zingg; and (E) H. P. Guy.

Chapter IV—R. F. Piest and C. R. Miller.

Chapter V—(A,B) J. W. Roehl and others in the United States Department of Agriculture; (C and E) D. C. Bondurant; and (D) J. A. Hufferd, R. L. Vance, and J. J. Watkins.

Chapter VI—T. Maddock, Jr.

Chapter VII—C. E. Busby.

Many others contributed to this work by reviewing and criticizing manuscripts, discussing ideas with authors, and contributing written discussions. One must also acknowledge the financial support contributed by the organizations who paid the salaries and other expenses of the contributors. And finally, the encouragement and support of the many people in ASCE must be acknowledged for without their patient support, this long-overdue work would not have been completed.

CHAPTER I

Nature of Sedimentation Problems

A. INTRODUCTION

1. General

Sedimentation embodies the processes of erosion, entrainment, transportation, deposition, and the compaction of sediment. These are natural processes that have been active throughout geological times and have shaped the present landscape of our world. The principal external dynamic agents of sedimentation are water, wind, gravity, and ice. Although each may be important locally, only the hydrospheric forces of rainfall, runoff, streamflow, and wind forces are considered herein. Thus, erosion will be defined as the detachment and removal of rock particles by the action of water and wind. Fluvial sediment is a collective term meaning an accumulation of rock and mineral particles transported or deposited by flowing water. Aeolian sediment is that moved or deposited by wind.

The processes of erosion, entrainment, transportation, and deposition of fluvial sediment are complex. The detachment of particles in the erosion process occurs through the kinetic energy of raindrop impact, or by the forces generated by flowing water. Once a particle has been detached, it must be entrained before it can be transported away. Both entrainment and transport depend on the shape, size, and weight of the particle and the forces exerted on the particle by the flow. When these forces are diminished to the extent that the transport rate is reduced or transport is no longer possible, deposition occurs.

Water erosion may be quite obvious and even spectacular as seen in the Grand Canyon or Bryce Canyon in the western United States. It may also be relatively imperceptible, e.g., the sheet erosion that occurs on vast areas of cleared or poorly vegetated land in the United States and elsewhere in the world. The muddy waters of streams provide evidence, even to the uninformed, that erosion is occurring upstream and that sediment is being transported. Mud on sidewalks and streets, sand splays on fertile bottom lands, and the great deltas of the Nile and Mississippi Rivers are all examples of deposition of eroded and transported materials.

The deposition of sediment may produce new land or enhance existing land used for various purposes; it also may create serious problems. In fact, the processes of sedimentation can create severe problems. Erosion, besides producing harmful sediment, may cause serious on-site damage to agricultural land by reducing the fertility and productivity of soils. In more advanced stages, it may even modify farm fields to the extent that cultivation is no longer profitable or even physically possible. Sediment in transport effects the quality of water and its suitability for human consumption or use in various enterprises. Some industries cannot tolerate even the smallest amounts of sediment in water used for certain manufacturing processes, and the public pays a large price for removing sediment from water used in everyday life.

Problems created by the deposition of sediment are many and varied. Harmful materials deposited on farm lands at the foot of slopes or on fertile flood plains may reduce the fertility of soils, impair surface drainage, and even completely bury valuable crops. Sediment deposited in stream channels reduces the flood-carrying capacity, resulting in more frequent overflows and greater floodwater damage to adjacent properties. The deposition of sediment in irrigation and drainage canals, in navigation channels and floodways, in reservoirs and harbors, on streets and highways, and in buildings not only creates a nuisance but also inflicts a high public cost in maintenance removal or in reduced services (Bennett, 1939) (Brune, 1958).[1]

Sedimentation is of vital concern in the conservation, development, and utilization of our soil and water resources. Without these resources man cannot exist, and when they are of poor quality or of insufficient quantity, man's lot is a sad one, indeed. With a rapidly expanding population and an ever-increasing demand for food and products derived from soil and water, exploitation and apathy must rapidly be replaced by wise planning and circumspection if future generations are to maintain standards of living prevalent

[1] References are given in Chapter I, Section G.

today (in 1972). History records many instances of civilizations that declined because people could not cope with problems of sedimentation (Lowdermilk, 1935). In the United States, early settlements along the shores of the Chesapeake Bay fell into decay because they were unable to surmount the problems of sediment deposition in harbors (Gottschalk, 1945).

Considerable knowledge relative to the nature and influences of the forces involved in sedimentation has been accumulated during the past few decades. Some of the more important elements are summarized in the subsequent chapters. Out of this knowledge has emerged the realization that man, through his activities and endeavors, can locally influence the so-called "natural sedimentation processes" and that the results may be beneficial or harmful to his own well being. Out of this knowledge has also come a better understanding of the fundamentals involved in the creation or alleviation of sedimentation problems. This information is basic to the proper planning, design, installation, and maintenance of works of improvement for the development, use, and conservation of our soil and water resources to assure that they will function as designed and will not create new problems or accentuate existing ones.

B. PROBLEMS OF EROSION

2. Geologic Erosion

Geologic erosion is defined as erosion of the surface of the earth under natural or undisturbed conditions. The vast extent and great thicknesses of sedimentary rocks found on the earth's surface provide evidence of the tremendous amount of geologic erosion and deposition that has occurred throughout geologic times. Whereas the most recent deposits of the Mississippi River delta are measured in terms of feet, during Paleocene and Eocene epochs alone, sediment measuring nearly 4 miles in thickness was deposited in the ancient estuary of the Mississippi River (Termier, 1963). Erosion is not a process of recent origin nor is it restricted to the ancient past. Geologic erosion exists today (in 1972) as it did in the past (Leopold, et al., 1964).

Geologic erosion varies in different places on the earth's surface because of differences in character of rocks and climatic and vegetative conditions. In some areas, e.g., in parts of the western United States where there are extensive deposits of geologically young and poorly indurated rocks, and where vegetation is sparse and rainfall torrential, the rate of geologic erosion is high. Thus, the Missouri and Colorado Rivers and many of their principal tributaries are heavily laden with sediment and have been for a long time before man occupied the area. Conversely, streams such as those in New England are relatively clear because they drain areas where the surface formations consist of ancient well-indurated, and erosion-resistant rocks that are covered with a more luxuriant canopy of vegetation.

The control of geologic erosion, by and large, is often difficult to achieve because the natural conditions that have prevailed over centuries of time cannot be changed significantly to effect any great reductions in erosion. Under certain local conditions, however, improvements can be made to reduce erosion. For example, long, gently-sloping flats that have sparse vegetation can often be chiseled and scarified or contour furrowed to increase water intake. The resulting improvement in soil moisture conditions will increase the density of existing vegetation or permit the introduction of better species for protection against erosion. On high and steep mountain slopes, e.g., those along the Wasatch front in Utah, the San Gabriel Mountains in California, and elsewhere, the Forest Service of the United States Department of Agriculture has installed contour trenches to reduce rapid runoff and improve vegetative conditions that have proved most effective in reducing erosion and sediment movement (Noble, 1965).

Where geologic erosion is confined primarily to channel erosion, stabilizing structures can often be built to halt such erosion. These include mostly grade-control structures, e.g., check dams and sills and water-level control structures that drown out the head cuts of natural arroyos or barancas. The difficulty in controlling geologic erosion comes mostly from the standpoint of economic feasibility. This is because the land on which serious geologic erosion often occurs is usually of low value for agricultural purposes. The justification for structural measures, therefore, depends mainly on the reduction of severe sediment damages immediately downstream from the source.

3. Accelerated Erosion

Accelerated erosion is defined as the increased rate of erosion over the normal or geologic erosion brought about by man's activity. That man can exercise any great influence on the natural process of erosion seems inconceivable, yet locally it is possible. The erodibility of natural materials can be altered by disturbing the soil structure through plowing or other tillage activities. The protective vegetative canopy can be changed by grubbing, cutting, or burning existing vegetation and by introducing new species. Recent developments indicate that man may be able to change rainfall conditions by cloud seeding. The runoff conditions from land surfaces and the hydraulic characteristics of flow in channels can be changed by structural works of improvement or by altering the natural characteristics of stream channels, e.g., channel cross sections, alinements, or gradients. All of these activities can have a profound influence on erosion. Under some circumstances, it is not uncommon to increase erosion rates by more than 100 fold over the normal or geological rate.

4. Agricultural Activities

In the short life-span of man's occupancy of the earth's surface, many changes have been brought about that have